

USER MANUAL TRSYS01

High-accuracy building thermal resistance measuring system with two measurement locations



Warning statements



Putting a voltage of over 15 VDC to TRSYS01 may result in permanent damage to the system.



Thermocouple pairs TC in TRSYS01 are matched. They should be used as installed. Using these thermocouples in different combinations or with extension of thermocouple cables will lead to loss of accuracy.



TRSYS01 has an internal battery in the MCU that powers the clock and the SRAM when external power is not supplied. This battery needs periodic replacement.

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List of symbols

Quantities

Heat flux
 Voltage output
 Sensitivity
 Temperature
 Temperature difference
 Time constant
 Thermal resistance per unit area
 Λ -Value, thermal conductance
 Thermal resistance per unit area,
 Including ambient air boundary layer resistances
 U-Value, thermal transmittance
 Time
 Thermal conductivity
 Thermal resistivity
 Ambient air / wind speed
 Volumic heat capacity
 Resistance
 Heat transfer coefficient
 Convection heat transfer coefficient
 Radiation heat transfer coefficient

Symbol	Unit
Φ	W/m ²
U	V
S	V/(W/m ²)
T	°C
ΔT	°C, K
τ	s
$R_{\text{thermal,A}}$	K/(W/m ²)
Λ	W/(m ² ·K)
$R_{\text{thermal,A, B}}$	K/(W/m ²)
U	W/(m ² ·K)
t	s
λ	W/(m·K)
r	m·K/W
V	m/s
C_{volumic}	J/(m ³ ·K)
R	Ω
h	W/(m ² ·K)
h_c	W/(m ² ·K)
h_r	W/(m ² ·K)

Subscripts

Property of thermopile sensor
 Property of ambient air
 Property at indoor location
 Property at outdoor location
 Property of the surrounding environment

sensor
 ambient
 indoor
 outdoor
 environment

Introduction

TRSYS01 is a high-accuracy system for on-site measurement of thermal resistance, R-value, and thermal transmittance, U-value, of building envelopes. TRSYS01 is mostly used for measurements according to standard practices of ISO 9869 and ASTM C1155 / C1046. The system is equipped with high-accuracy electronics, two heat flux sensors of model HFP01 as well as two pairs of matched thermocouples. The two measurement locations provide redundancy, leading to a high level of confidence in the measurement result. The high accuracy of the heat flux sensors and temperature difference measurements ensures that TRSYS01 continues measuring when other systems no longer perform; in particular at very low temperature differences across the wall.

HFP01 is a sensor for heat flux measurement in the soil as well as through walls and building envelopes. For HFP01 specifications, see the [HFP01](#) manual.



Figure 0.1 TRSYS01: the complete measuring system includes 2 HFP01 heat flux sensors and 2 matched thermocouple pairs, TC, (in total 4 temperature sensors) and the MCU01 measurement and control unit

On-site measurements of thermal resistance, R, are often applied in studies of buildings. Alternatives are to measure its inverse value, the thermal conductance which is called the Λ -value, or the thermal transmittance which includes ambient air boundary layer thermal resistance, the U-value.

The measurements of R are based on simultaneous time averaged measurement of heat flux Φ and differential temperature, ΔT , (using two temperature sensors, each on a different side of the wall).

$$R = \Delta T / \Phi$$

The ISO and ASTM standards give detailed directions concerning the measurement method, sensor installation and data analysis.

The TRSYS01 system employs dedicated sensors and electronics. Their high accuracy and sensitivity ensure that TRSYS01 will still measure under circumstances where competing systems no longer perform reliable measurements; i.e. down to very low heat fluxes and low temperature differences across the wall. The matched thermocouple pairs in TRSYS01, model TC, measure temperature differences with an uncertainty of better than 0.1 °C over the entire rated temperature range. TRSYS01 includes 2 x HFP01 heat flux plates. HFP01 is the world's most popular sensor for heat flux measurement in studies of buildings.

The system generates a measurement file, including time, heat flux, temperature and temperature difference for the two measurement locations. The measurement is stored in the MCU and later downloaded to a PC. The user is responsible for data analysis, calculating the R-value or U value of the building envelope according to the ISO or ASTM standards.

Equipped with heavy-duty components, TRSYS01 has proven to be very robust and stable. It survives repeated installation necessary in this application where measuring systems are typically used at multiple locations.

The measurements and the analyses that have to be performed are not straightforward; although the measurements are standardised, this always involves a significant element of expertise and a subjective data interpretation. Hukseflux helps to gain the necessary experience by offering operator training.

Training vastly improves the level of service to the end user, the efficiency of working with the equipment and reduces the uncertainty of the end result. Please [contact](#) us for more information on training courses in thermal measurement at Hukseflux.

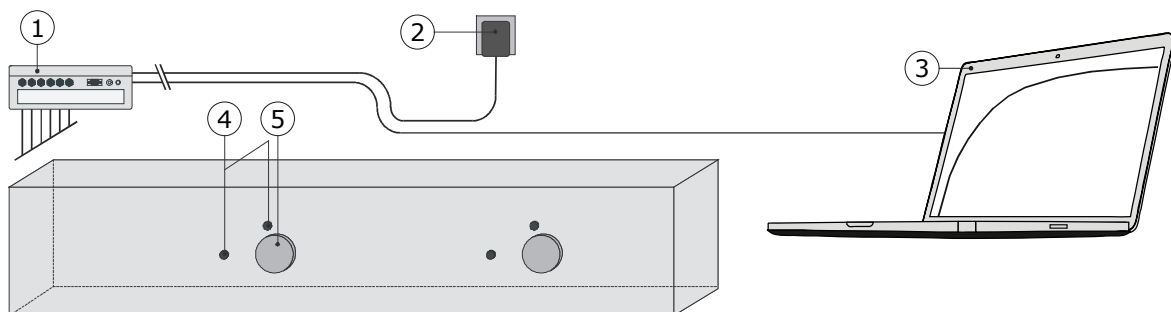


Figure 0.2 TRSYS01 consists of MCU Measurement and Control Unit (1), a 12 VDC adapter to power the MCU (2), two pairs of matched thermocouples model TC (4), and two model HFP01 heat flux plates (5). MCU01 measures and stores measurement data. Readout is performed by connecting temporarily to a PC (3) (not included). User interface software for the PC (Loggernet) is included.

Calibration of TRSYS01 components is traceable to international standards. HFP01 and MCU01 are traceable to the international standards for voltage, current and length, the thermocouples to ITS-90. TRSYS01 undergoes a functional test at the factory. This conformity assessment includes temperature difference measurement accuracy.



Figure 0.3 TRSYS01 in its carrying case on the left and one HFP01 sensor on the right. 2 HFP01 heat flux sensors and 2 matched thermocouple pairs, TC, (in total 4 temperature sensors) are included in TRSYS01.

1 Ordering and checking at delivery

1.1 Ordering TRSYS01

The standard configuration of TRSYS01 is with 2 x heat flux sensor, one with 10 and one with 20 m cable, and 2 x matched thermocouple pairs, TC, one pair with 10 m cable and one pair with 20 m cable.

Common options are:

- rechargeable battery pack for autonomous use (TRSYS01F)
- SR05-A1-TMBL pyranometer (TRSYS03)
- more measurements locations (on request)

1.2 Included items

Arriving at the customer, the delivery should include:

- carrying case
- TRSYS01
 - 1 x HFP01-10
 - 2 x TC-10
 - 1 x HFP01-20
 - 2 x TC-20
 - 1 x MCU01
- adapter 12 VDC
- USB cable
- RS-232 cable (9-pin)
- Loggernet software on CD-ROM
- TRSYS01 software on USB flash drive
- SC USB driver software on USB flash drive
- 1 x product certificate TRSYS01
- 1 x product certificate HFP01-10
- 1 x product certificate HFP01-20

2 Instrument principle and theory

2.1 MCU01 Measurement system

MCU01 is a measuring system with a clock and memory. It is specified to measure the voltage output of heat flux sensors as well as thermocouples. It has an on-board temperature sensor that acts as a cold junction measurement for the thermocouples. This is called the panel temperature.

2.2 Heat flux sensor HFP01

For the measurement principle and theory of the HFP01 heat flux sensor, see the [HFP01 manual](#).

2.3 TC-10 and TC-20 matched thermocouple pairs

While the absolute accuracy of thermocouples is low, matched thermocouple pairs very accurately measure temperature differences. Proper selection / pairing leads to uncertainties better than 0.1 °C over the full rated measurement range.

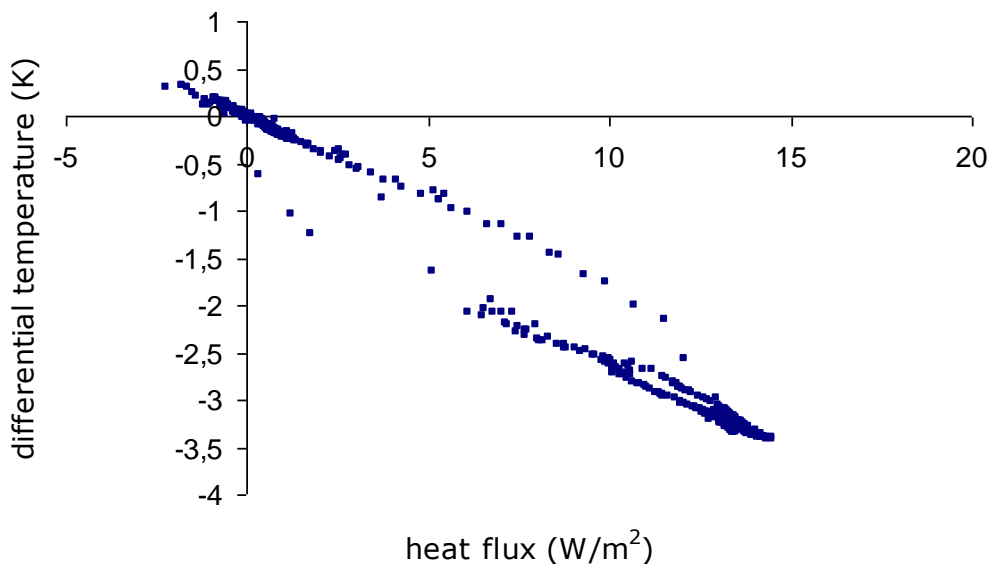


Figure 2.3.1 typical graph showing stored data of TRSYS01 over a measurement interval of 2 days

3 Specifications of TRSYS01

TRSYS01 is a system used for on-site measurement of thermal resistance, R , thermal conductance, the Λ -value, and thermal transmittance, the U -value, of building envelopes. TRSYS01 is used for measurements according to standard practices of ISO 9869 and ASTM C1155 / C1046. The system is equipped with MCU01 electronics, two heat flux sensors of model HFP01 as well as two pairs of matched thermocouples of model TC. The sensors are used to measure at two locations. The system includes Loggernet user interface software. A PC is not included. Data review and calculation of the thermal resistance from heat flux and temperature difference is the responsibility of the user.

Table 3.1 Specifications of TRSYS01 (continued on next page)

TRSYS01 SPECIFICATIONS	
Description	High-accuracy building thermal resistance measuring system with two measurement locations
Measurand	heat flux (2 x)
Measurand in SI units	heat flux density in W/m^2
Measurand	temperature (2 x)
Measurand in SI units	temperature in $^{\circ}C$
Measurand	temperature difference (2 x)
Measurand in SI units	temperature difference in $^{\circ}C$
Number of measurement locations	2
Cable length per location	location 1: 10 m location 2: 20 m
Required data analysis to determine thermal resistance, R , thermal conductance, the Λ -value, and thermal transmittance, the U -value	to be performed by the user according to ISO and ASTM recommended practices
Measurement duration range	> 3 days
Included sensors location 1	heat flux: 1 x HFP01-10 with 10 m cable temperature and temperature difference: 1 x TC-10 matched thermocouple pair with 10 m cable Marking TC11 and TC12
Included sensors location 2	heat flux: 1 x HFP01-20 with 20 m cable temperature and temperature difference: 1 x TC-20 matched thermocouple pair with 20 m cable Marking TC21 and TC22
Measurement function / required programming for heat flux measurement for temperature difference measurement	$\Phi 1 = U1/S1$ and $\Phi 2 = U2/S2$ $\Delta T1 = TC11-TC12$ and $\Delta T2 = TC21-TC22$
Rated operating temperature range	HFP01 and TC: -30 to $+70$ $^{\circ}C$ MCU01: -20 to $+50$ $^{\circ}C$
Standards governing use of the instrument	ISO 9869 Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance. ASTM C 1155-95 Standard Practice for Determining Thermal Resistance of Building Envelope Components from the In Situ Data. ASTM 1046-95 Standard Practice for In Situ Measurement of Heat Flux and Temperature on Building Envelope Components
Cable markers heat flux sensor	2 x sticker, 1 x at sensor and 1 x cable end, wrapped around the heat flux sensor cable. Both stickers show sensitivity and serial number.

Table 3.1 Specifications of TRSYS01 (started on previous page, continued on next page)

Cable markers temperature sensors	location 1: TC11 and TC12 location 2: TC21 and TC22
IP protection class	HFP01 and TC: IP67 MCU01: IP65 Adapter 12 VDC: IP60
Rated operating relative humidity range	0 to 100 %
Net weight total TRSYS01 including carrying case	approx. 8 kg
Gross weight	approx. 11 kg
Carrying case	box of 480 x 390 x 190
MCU01	
Measurand	analogue voltage and conversion to heat flux using the sensitivities of the heat flux sensors
Measurand	analogue voltage and conversion to temperature using the panel temperature and general thermocouple type K characteristics
Measurand	analogue voltage and conversion to temperature difference using general thermocouple type K characteristics and temperature
Measurand	panel temperature to serve as a cold junction reference temperature for the thermocouple measurements
Measurand	date and time
Sample rate	1 Hz
Stored measurement definition	10 min: averages of heat flux, temperature and temperature differences, panel temperature, heat flux sensor 1 sensitivity, heat flux sensor 2 sensitivity 24 hour: averages of heat flux, temperature and temperature differences, minimum battery voltage, panel temperature, heat flux sensor 1 sensitivity, heat flux sensor 2 sensitivity
Storage capacity	> 30 days
Temperature difference measurement resolution	< 0.02 °C
Heat flux measurement resolution	< 0.02 W/m ²
MCU rated power supply	9.6 to 16 VDC
Connection to PC	via USB or RS-232
User interface on PC	Loggernet software (supplied on CD-ROM)
System requirements for use with PC	Windows XP and later, CD-ROM drive, USB port, and USB or RS-232 (COM) port
Program running on MCU	TRSYS program (supplied on USB flash drive)
Power switch / LED	red LED [ON] when power is supplied to MCU
Optional batteries	2 x Cyclon Monoblock 6 V
Internal system battery	powering the clock and the SRAM when no external power is connected. Type: 3.6 VDC, 1.2 Ahr, 1/2 AA size cell.
ADAPTER 12 VDC	
Adapter rated power supply	110 - 220 VAC, 50 / 60 Hz

Table 3.1 Specifications of TRSYS01 (started on previous pages)

HFP01 HEAT FLUX SENSOR	
Specifications	see HFP01 manual
Included sensors	see TRSYS01 specifications
Guard width to thickness ratio	5 (as required by ISO 9869 D.3.1)
TC MATCHED THERMOCOUPLE PAIR	
Included sensors	see TRSYS specifications
Temperature sensor type	KX according to IEC 584.3: 1989
INSTALLATION AND USE	
Performing a representative measurement	see the chapter on standards and recommended practices for use and the chapter on installation of HFP01 and TC.
Installation	see the chapter on standards and recommended practices for use and the chapter on installation of HFP01 and TC.
Sensor mounting	for mounting sensors on walls, we recommend use of double-sided "removable" carpet laying tape such as TESA 4939, which has free removability up to 14 days from the most common surfaces (needs to be tested individually before usage).
Cable extension	HFP01 cables may be extended: see the HFP01 manual. TC cables may not be extended
CALIBRATION AND FUNCTIONAL TEST	
Production report	included
Performance verification	via functional test
Calibration traceability	HFP01, TC and MCU are traceable to SI units
Calibration uncertainty heat flux sensors HFP01	$\pm 3\%$ ($k = 2$)
Acceptance interval temperature difference measurement	$< \pm 0.1^\circ\text{C}$ (required by ISO 9869, paragraph 5.2)
Recommended recalibration interval	2 yr
On-site performance verification	is possible by comparison of the two HFP01 sensors and the two thermocouple pairs. Usually sensors and thermocouples are mounted side by side on the same object alternatively heat flux sensors may be mounted on top of one another. Temperature sensors may be compared by mounting them in stirred water.
MEASUREMENT ACCURACY	
Uncertainty of the measurement	statements about the overall measurement uncertainty can only be made on an individual basis. see the chapter on uncertainty evaluation. ISO 9869 chapter 9 shows examples of uncertainty evaluation, arriving at typical uncertainties of the order of $\pm 20\%$ of on-site measurements of thermal resistances (between 14 and 28 %).
VERSIONS / OPTIONS	
TRSYS01F	rechargeable battery pack for autonomous use
TRSYS03	with SR05-A1-TMBL pyranometer
More measurement locations	on request
Operator training	recommended. on request. contact hukseflux

4 General directions for performing a thermal resistance measurement

TRSYS01 should be used in accordance with the recommended practices of ISO and ASTM.

TRSYS01 measures heat flux and temperature in buildings, estimating the building's energy budget and thermal transmission of walls. The total measurement system consists of multiple heat flux- and temperature sensors, sometimes combined with measurements of solar radiation, wind speed and wind direction.

The required data analysis to determine thermal resistance, R , thermal conductance, the Λ -value, and thermal transmittance, the U -value must be performed by the user according to ISO and ASTM recommended practices.



Figure 4.1 HFP01 heat flux sensor and TC mounted on a wall

4.1 Applicable standards

Table 4.1.1 contains a listing of applicable standards. We recommend users to purchase the latest version of the standard.

Table 4.1.1 *Standards with recommendations for instrument use in building physics*

STANDARDS FOR INSTRUMENT USE FOR BUILDING ENVELOPE THERMAL RESISTANCE MEASUREMENT	
ISO STANDARD	EQUIVALENT ASTM STANDARD
ISO 9869 Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance	ASTM C 1155-95 Standard Practice for Determining Thermal Resistance of Building Envelope Components from the In Situ Data ASTM 1046-95 Standard Practice for In Situ Measurement of Heat Flux and Temperature on Building Envelope Components

4.2 ISO 9869: thermal conductance (Λ -value) and transmittance (U-value)

ISO 9869 may be applied both in “hot-box” steady state laboratory methods and in long-term averaging in field measurements. In this standard the heat flux sensor name is heat flowmeter (HFM).

ISO 9869 makes a distinction between:

- thermal resistance R from surface to surface by conduction, calculated from heat flux and surface temperature difference T_{surface} (or the inverse value: Λ -Value or thermal conductance)
- thermal resistance R_{T} from environment to environment by convection plus conduction, calculated from heat flux and ambient air temperature difference T_{ambient} (or the inverse value: U-value, or thermal transmittance)

At Hukseflux we typically measure the wall thermal conductance using surface temperatures on the wall:

$$\Lambda\text{-value} = 1/R_{\text{thermal A}} = \Phi / (T_{\text{surface, indoor}} - T_{\text{surface, outdoor}}) \quad (\text{Formula 4.2.1})$$

The thermal resistance $R_{\text{thermal A}}$ of an old insulated wall is of the order of 2.5 K/(W/m²), a modern insulated wall may attain 6.7 K/(W/m²).

When measuring the thermal transmittance:

$$U\text{-value} = 1/R_{\text{thermal A, B}} \quad (\text{Formula 4.2.2})$$

The U-value includes $R_{\text{ambient, indoor}}$ and $R_{\text{ambient, outdoor}}$ thermal boundary layer plus radiative transport resistance.

$$R_{\text{thermal A, B}} = R_{\text{thermal A}} + R_{\text{ambient, indoor}} + R_{\text{ambient, outdoor}} \quad (\text{Formula 4.2.3})$$

Formula 4.2.4 shows a typical assumption for non-ventilated walls for 2 surfaces:

$$R_{\text{ambient, indoor}} + R_{\text{ambient, outdoor}} = 0.25 \text{ K}/(\text{W}/\text{m}^2) \quad (\text{Formula 4.2.4})$$

The convective transport of heat from the wall to the ambient air, Φ , is a function of the heat transfer coefficient, h_c , and the temperature difference between ambient air and sensor.

$$\Phi = h_c (T_{\text{ambient}} - T_{\text{object}}) = 1/R_{\text{ambient}} \quad (\text{Formula 4.2.5})$$

In buildings under indoor conditions we expect wind speeds of < 1 m/s. Working environments will typically have wind speeds < 0.5 m/s. Outdoors, wind speeds may reach 15 m/s under normal conditions, and up to 60 m/s in case of heavy storm.

An approximation of the heat transfer coefficient at a single surface at moderate ambient air speeds, V , and taking $5 \text{ W}/(\text{m}^2 \cdot \text{K})$ for the radiative transfer coefficient, is given by:

$$h = h_r + h_c = 5 + 4 V \quad (\text{Formula 4.2.6})$$

According to ISO 9869, A.3.1, a common value for the heat transfer coefficient by convection, h_c , for a single surface is $3.0 \text{ W}/(\text{m}^2 \cdot \text{K})$; in the equation above this would represent a wind speed of 0.75 m/s. The total heat transfer coefficient h for one surface then is $8 \text{ W}/(\text{m}^2 \cdot \text{K})$. For two surfaces it the $R_{\text{ambient, indoor}} + R_{\text{ambient, outdoor}}$ then becomes 0.25 of formula 4.2.4.

The radiative heat transfer coefficient of $5 \text{ W}/(\text{m}^2 \cdot \text{K})$ follows from the Stefan–Boltzmann law, linearised around 20 °C.

Measuring the thermal resistance of a building element, the duration of the test according to ISO 9869 should at least be 96 h (ISO 9869 paragraph 7.2.3). The user should verify the representativeness of the area with a thermal camera. The installation should not be in the vicinity of potential sources of error such as thermal bridges, cracks, heating or cooling devices and fans. Sensors should not be exposed to rain, snow, and direct solar radiation.

Installation is described in ISO 9869 paragraph 6.1.2. The standard recommends use of thermal paste and a passive guard ring with a width to thickness ratio of >5 . Hukseflux discourages the use of thermal paste because it tends to dry out. Silicone glue and double sided tape are more reliable. HFP01 is equipped with a guard ring.

In some cases only night time data may be included in the analysis. At the end of a test the obtained R – value should not deviate by more than $\pm 5 \%$ from the value obtained 24 h before.

Chapters 7 and 8 of the ISO standard describe corrections for storage effects (changes in average wall temperature), added thermal resistance by the heat flux sensor, which we call the resistance error, and errors caused by the finite dimensions of the sensor. We use the term deflection error, while ISO uses the term operational error.

ISO 9869 chapter 9 shows examples of uncertainty evaluation, arriving at typical uncertainties of the order of $\pm 20\%$ of on-site measurements of thermal resistances (between 14 and 28 %).

Sensors for measurement of temperature difference should be calibrated to an accuracy of $\pm 0.1\text{ }^{\circ}\text{C}$, reference paragraph 9.3.

Annex D.3.2 states that “the width of the guard ring should be at least 5 times the thickness of the heat flux meter”.

4.3 ASTM C 1155 and ASTM 1046: thermal resistance R

ASTM C 1155 and ASTM 1046 focus on the measurement of thermal resistance R (from surface to surface) only. This is the $R_{\text{thermal A}}$ of formula 4.2.1.

ASTM 1155 defines a Heat Flow Sensor or Heat Flux Transducer (HFT). Paragraph 5.8 specifies that during the test the indoor temperature changes less than $3\text{ }^{\circ}\text{C}$, and specifies that the density of the construction material is $< 440\text{ kg/m}^3$. Areas with a high lateral heat flux should be avoided. Time constants should be estimated according to ASTM 1046. The duration of the test is at least 24 h, and a convergence test may be used to determine total required timespan.

ASTM 1046 offers good practices for installation and site selection.

4.4 Measurements on glass windows

TRSYS01 and HFP01 may be mounted on glass windows; please note the following:

- We recommend using night-time data only. During daytime, the window material typically transmits solar radiation, while the HFP01 absorbs this radiation. During daytime the measurement is not representative of the heat flux through the window
- The user may correct for the resistance error

5 Arrival of a new TRSYS01

5.1 Preparation before arrival

As a preparation, preferably the operator should read the chapters 1 to 4. We recommend that users follow operator training at Hukseflux.

Table 5.1.1 *List of items that the operator should have available*

ITEM	REMARKS
Standards	purchase the relevant standards see http://www.iso.org and http://www.astm.org
PC	running Windows XP or later, with a CD-ROM drive, one free USB port, and one USB port or RS-232 (COM) port
Power	110-240 VAC
Mounting	tape or glue for mounting HFP01 and TC

5.2 Checking upon arrival

When the instrument arrives, it is recommended to check if the delivery is complete. The list of delivered items can be found in the chapter on Ordering and Checking at Delivery. For the most common overall system check, see the next chapter.

6 Software, system check and data retrieval

The user should be familiar with the warning statements indicated on page 2 of this manual.

6.1 Installation in summary

Table 6.1.1 gives a summary of the installation procedure and quick system test. The remainder of this chapter explains this in detail.

Table 6.1.1 *Summary of procedures for installation and a quick system test*

PROCEDURE	
1	install the USB driver
2	install the Loggernet user interface software
3	connect the MCU to 12 VDC using the Adapter 12 VDC
4	connect the MCU to the PC, using the USB cable, switch on the MCU power
5	make contact with the MCU through Loggernet get the heat flux, temperature and temperature difference data on screen
6	test the response of the sensors by touching them with your hand
7	verify that the right sensitivities are entered in the TRSYS program

6.2 Software installation

Table 6.2.1 *Procedures to install software on the PC*

PROCEDURE	
1	make a backup of all received files
2	install the USB driver, delivered on USB flash drive
3	install the LoggerNet software starting the windows explorer and double clicking the application "Autorun". The latest versions of LoggerNet are delivered on CD-ROM. The installation procedure is straightforward. The directory in which the software is installed is usually called LoggerNet.
4	the TRSYS01 software is delivered on a USB flash drive. File extensions are: .CR1. upon delivery the TRSYS01 software is already installed and "running on power-up".

6.3 PC connection and user interface

Table 6.3.1 summarizes the procedure of connecting MCU and creating an user interface. Step 3 and 4 are explained in detail in this section.

Table 6.3.1 *Procedures to connect MCU to a create a user interface. Step 3 and 4 are explained in this section.*

PROCEDURE	
1	connect the MCU to 12 VDC using the Adapter 12 VDC
2	connect the MCU to the PC, using the USB cable. Switch on the MCU power. The red LED should burn, confirming that the system has 12 VDC power
3	make contact with the MCU through Loggernet
4	get the heat flux, temperature and temperature difference data on screen

6.3.1 Make contact with the MCU through Loggernet

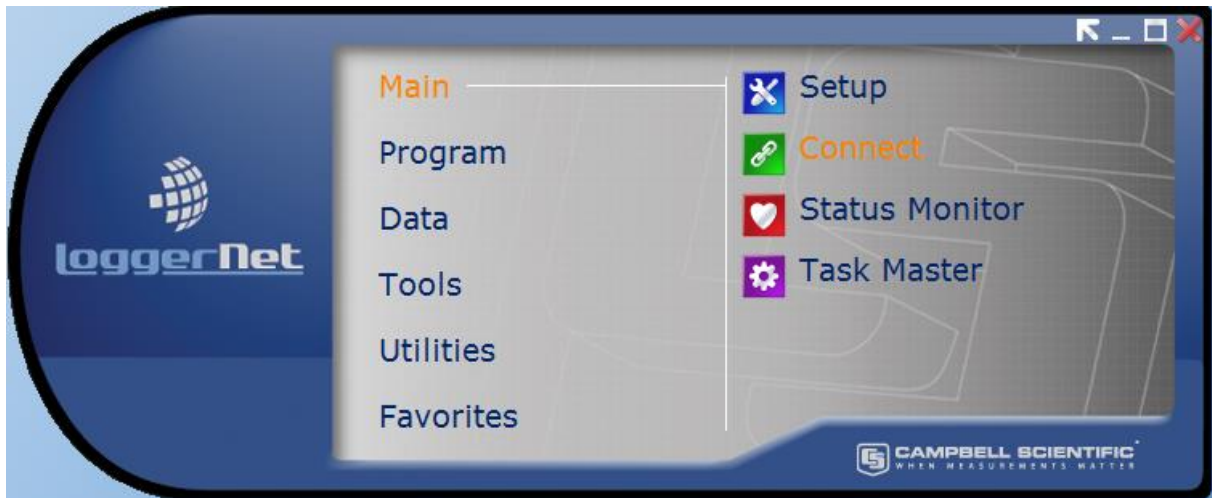


Figure 6.3.1.1 The heading menu of Loggernet. The MCU can be connected through 'Setup'. During operation only 'Connect' is used.

Open 'Setup' to install/connect the MCU.

Keep in mind that at any time during Setup, you may ask for assistance by clicking on the Help button.

Table 6.3.1.1 provides instructions on how to install the datalogger.

Table 6.3.1.1 Guidelines on how to install a the MCU

PROCEDURE	
1	select 'Add'
2	select CR1000, and give it the appropriate name: 'TRSYS01'
3	select 'Direct Connect'
4	select what COM port (typically COM port 1) you plugged the cable in. Set delay at 0.
5	set Baud Rate to 125200
6	set Dataloggers' clock if the datalogger time does not match the server time
7	check if TRSYS01 v1305.cr1 is running. If the program is not running, browse to where the TRSYS01 v1305.CR1 program is situated (delivered on USB flash drive) and click OK
8	select HF_10min in Tables. Make sure option Table collected during Data Collection in turned ON. Data file option should be: Append to File. Output file should be: C:\CampbellSci\LoggerNet\CR1000_HF_10min.dat. Or select an other folder / file name if required.
9	select HF_24h in Tables. Make sure option Table collected during Data Collection in turned ON. Data file option should be: Append to File. Output file should be: C:\CampbellSci\LoggerNet\CR1000_HF_24h.dat. Or select an other folder / file name if required.
10	it is recommended to select 'Scheduled Collection Enabled'

6.3.2 The heat flux, temperature and temperature difference data on screen

Use the heading menu of Loggernet to open 'Connect'.

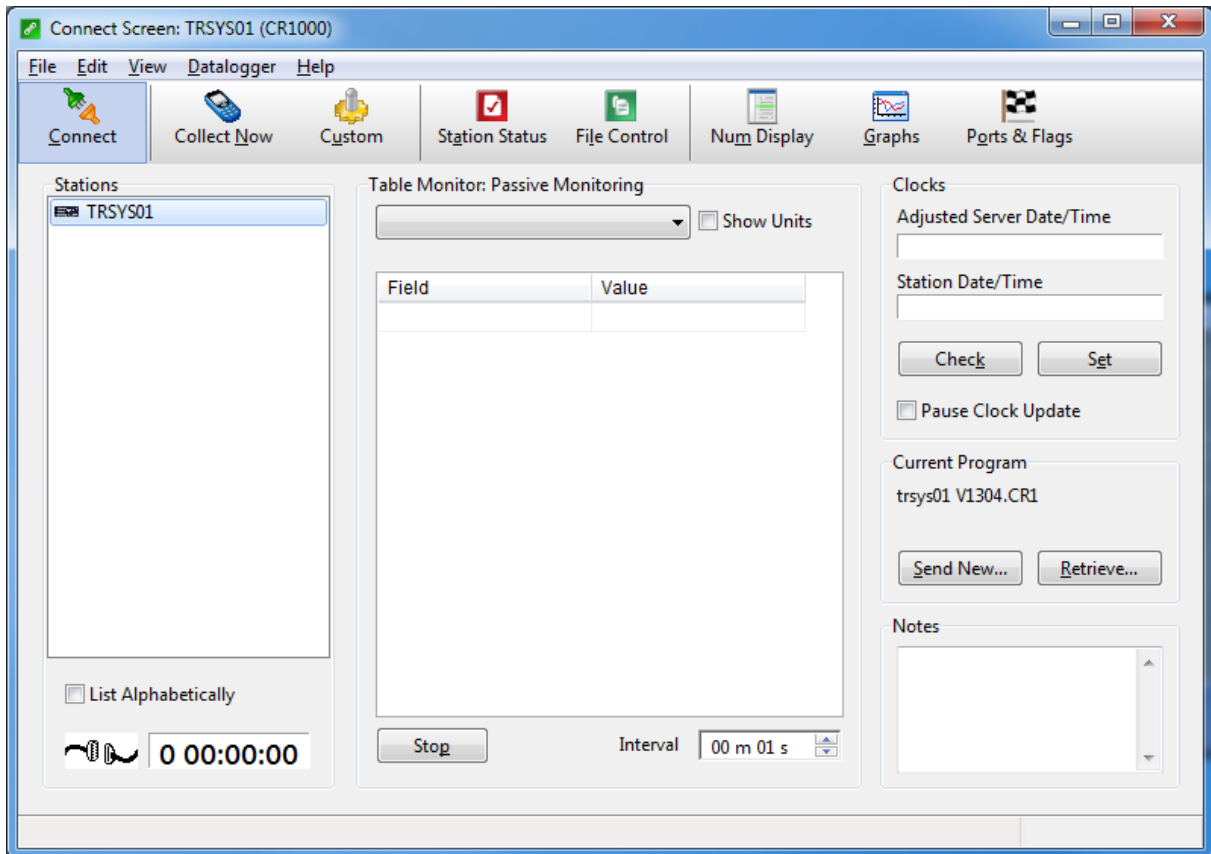


Figure 6.3.2.1 The screen in Connect. During Normal operation the Numeric and Graphs buttons are used for on-screen data display.

The numeric display can be used to view various parameters numerically. Parameters can be added through the 'Add' menu.

It is recommended to view 'T11', 'DT1', 'HF1', 'T21', 'DT2' and 'HF1'. The parameters are described in appendix 10.1.

T11 is the absolute temperature of the T11 joint of thermocouple 1 in °C, DT1 is the temperature difference between T11 and T12 in °C and HF1 is the heat flux of sensor 1 in W/m². T21 is the absolute temperature of the T21 joint of thermocouple 2 in °C, DT2 is the temperature difference between T21 and T22 in °C and HF2 is the heat flux of sensor 2 in W/m².

E_HF1 and E_HF2 are the sensitivities of the heat flux sensors in $\times 10^{-6}$ V/(W/m²).

Definitions of the other parameters used in the program are given in Appendix 10.1.

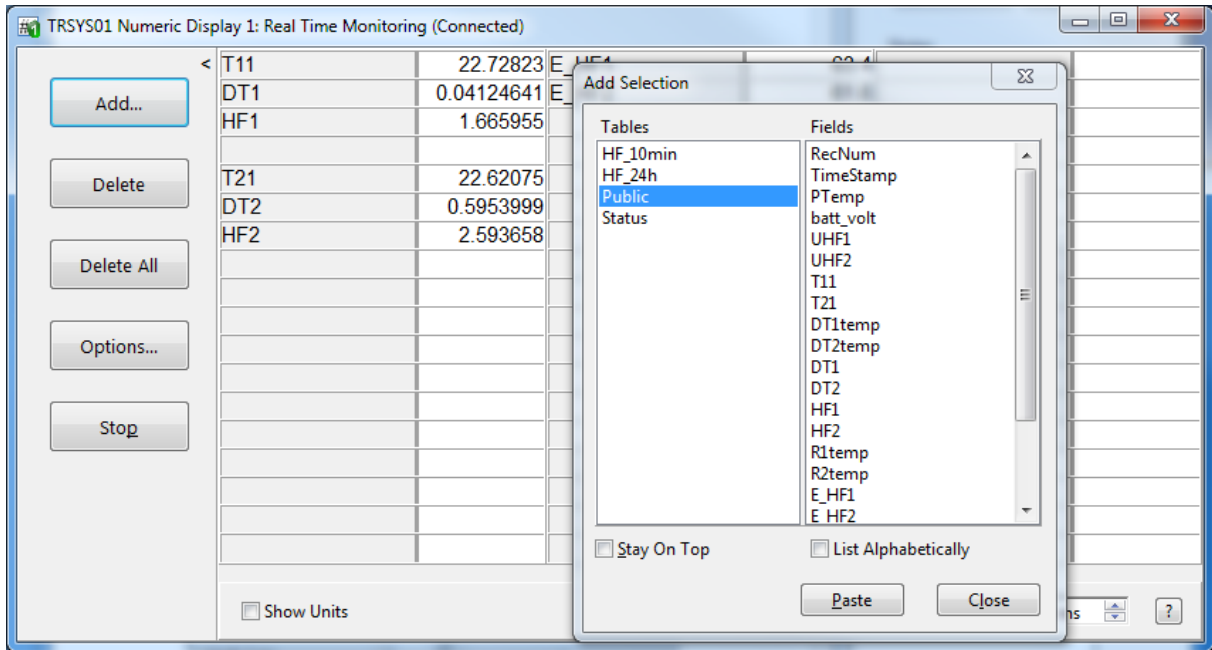


Figure 6.3.2.2 The Numeric Display can be used to view the value of parameters numerically. Parameters can be added by pressing 'Add', select 'Public' and drag the parameters to be viewed to the table. It is recommended to view 'T11', 'DT1', 'HF1' 'T21', 'DT2', 'HF1' 'E_HF1' and 'E_HF2'.

The graph display can be used to view various parameters graphically. Parameters can be added through the '+' menu.

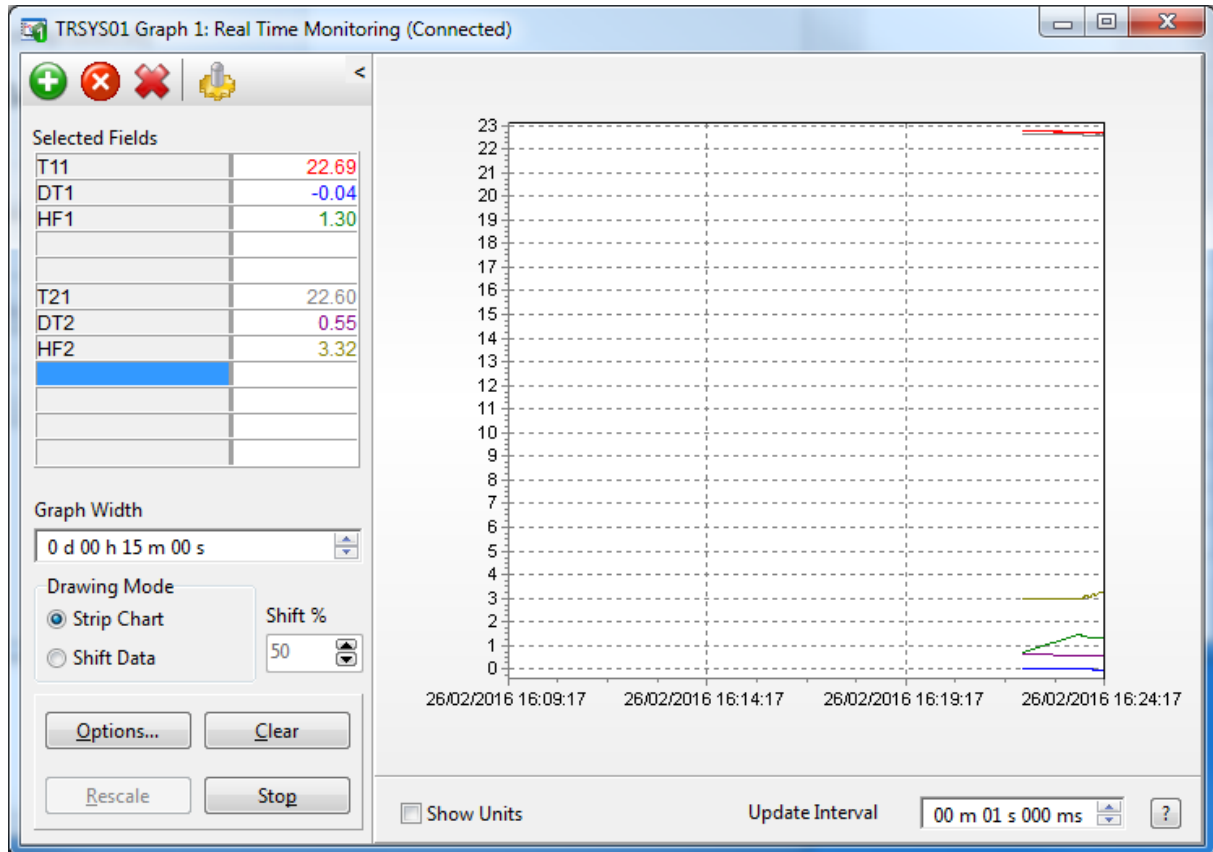


Figure 6.3.2.3 The Graph Display can be used to view the value of parameters graphically. Parameters can be added by pressing '+', select 'Public' and drag the parameters to be viewed to the table. It is recommended to view 'T11', 'DT1', 'HF1' 'T21', 'DT2' and 'HF1'. By right clicking on the parameter color and axis can be changed.

6.4 Functionality check

To check the functionality of TRSYS01 first check whether the right sensitivities are entered in the TRSYS program. After that test the response of the sensors by touching them with your hand (see table 6.4.1).

Heat flux sensors are individually calibrated and have individual sensitivities. The sensitivity value of the sensor can typically be found on a cable marker attached to the sensor.

In Numeric Display the E_HF1 and E_HF2 can be viewed. Check if the values correspond to the values on the calibration certificate.

The values can be changed by double clicking on it and entering the new/correct value, press Enter to confirm the new value.

E_HF1 and E_HF2 are stored in the 10-minute and 24-hour averages.

Table 6.4.1 *Testing the functionality of the system*

PROCEDURE	
touch a heat flux sensor with your hand. Look at the numeric screen	See if the heat flux sensor signal reacts.
touch the other side of the same sensor	See if the polarity of the signal changes (+ should go to -)
repeat the test for the other heat flux sensor	
touch temperature sensor 11 with your hand. look at the numeric screen	Check if T11 and DT1 react. Verify that T11 is realistic.
touch sensor 12 with your hand	Check that T11 does not react and that DT1 reacts in the opposite direction.
repeat the tests with temperature sensors T21 and T22	

6.5 Data retrieval and handling

The measurement data are stored in the CR1000 of MCU01. These data can be retrieved for further analysis.

Table 6.5.1 *Retrieval of measurement data*

PROCEDURE	
1	detailed measurement data can be retrieved using Collect Now in the Connect Screen.
2	when retrieving data, immediately make a backup. For example by saving the data on memory card or hard disk.
3	details regarding data analysis can be found in the ISO and ASTM standards.

The data averaged every 10 minutes is saved in the file
 C:\CampbellSci\LoggerNet\CR1000_HF_10min.dat

The data averaged every 24 hours is saved in the file
 C:\CampbellSci\LoggerNet\CR1000_HF_24h.dat

The files are comma separated ASCII. They can easily be imported in Excel if you use the following procedure:

Table 6.5.2 *Procedure for getting the ASCII-data in an Excel file*

PROCEDURE	
1	open Excel
2	choose Open file and select the desired data file
3	choose Separated in Step 1 and select Next
4	select Comma at Separation Signs and uncheck Tabs then select Next
5	if you have the comma assigned as the decimal separator, select Advanced and choose `.` (dot) as decimal and `,'` (comma) as thousands separator. Select OK
6	select Finish

7 Installation of sensors: HFP01 and TC

7.1 Site selection and installation

Table 7.1.1 Recommendations for installation of heat flux sensors and temperature sensors in building physics (continued on the next page)

Location	<p>Preferably mount heat flux sensors indoors and not outdoors</p> <p>Preferably use a large wall section which is relatively homogeneous in the northern hemisphere, north-facing walls are preferred</p> <p>Do not exposure sensors to sun, rain, etc. Do not expose indoor sensors to drafts and lateral heat fluxes Do not mount sensors in the vicinity of thermal bridges, cracks, heating or cooling devices and fans</p> <p>Close window blinds and curtains Switch off artificial light sources</p> <p>For detailed analysis of a single building element users may consider to install one heat flux sensor indoors, and the other outdoors. Measuring on two sides permits a detailed analysis of the thermal response time.</p> <p>For mounting sensors on glass windows: see paragraph 4.3.1.</p>
Orientation	<p>The two heat flux sensor sides are equivalent. The two temperature sensors of the matched thermocouple pair TC are equivalent.</p> <p>Recommended orientation is with the red face of the heat flux sensors facing indoors, and the blue face connected to the indoor wall. This generates a positive output signal when the heat flux direction is from indoors to outdoors.</p> <p>The thermocouples of the TC pair of location [1] are numbered [11] and [12]. In case the temperature of [11] is higher than [12] the difference has a positive sign.</p> <p>Reversing the heat flux sensor orientation or the positions of the two sensors of the TC pair will result in a change of sign of the heat flux- or temperature difference output. If necessary, this may be compensated in the post processing for example by giving the sensitivity a negative sign.</p>
Performing a representative measurement	<p>We recommend using > 2 sensors per measurement location / wall. This redundancy also improves the assessment of the measurement accuracy</p>
Creating a temperature difference	<p>For the measurement of thermal resistance of walls it is best to have a constant high level heat flux; strongly cooled or strongly heated rooms are ideal. We recommend activating heaters or air conditioning to create optimal conditions.</p>

Table 7.1.1 Recommendations for installation of heat flux sensors and temperature sensors in building physics (started on the previous page)

Mechanical mounting	<p>Avoid any air gaps between sensors and wall. Air thermal conductivity is in the 0.02 W/(m·K) range, while a common glue has a thermal conductivity around 0.2 W/(m·K). A 0.1×10^{-3} m air gap increases the effective thermal resistance of the sensor by 60 %.</p> <p>We recommend use of double-sided “removable” carpet laying tape such as TESA 4939, which has free removability up to 14 days from the most common surfaces (needs to be tested individually before usage).</p> <p>For thermocouple mounting the same tape may be used as for the heat flux sensors.</p> <p>For long-term installation and for filling up large gaps, use silicone construction sealant, glue or adhesive, that can be bought in construction depots. During curing of the silicone, typically 24 h, the sensor must be temporarily held in place by other means.</p> <p>We discourage the use of thermal paste because it tends to dry out. Silicone glue and double sided tape are more stable and reliable.</p> <p>Usually the cables are provided with an additional strain relief, for example using a cable tie mount as in figure 7.1.1.</p>
Added temperature sensors	<p>For Λ-value: temperature sensors should measure wall surface temperature. They are typically located close to the sensor attached to both sides of the wall.</p> <p>For R-value: temperature sensors should measure ambient air temperature. They are typically located close to the sensor at both sides of the wall, however not attached to the wall. Ambient air temperature sensors should be shielded from solar radiation.</p>
Avoiding spectral errors	<p>In case of exposure solar radiation or to artificial light sources, the spectral properties of the sensor surface must match those of the wall. This is attained by covering the sensor with paint or sheet material of the same colour as the wall.</p>



Figure 7.1.1 *Installation of HFP01 on a wall using two-sided "removable" carpet laying tape such as TESA 4939, and a strain relief of the cable using a cable tie mount equipped with the same carpet laying tape as adhesive. TC temperature sensors may be mounted in the same way.*

8 Making a dependable measurement

8.1 Uncertainty evaluation

A measurement with a heat flux sensor is called “dependable” if it is reliable, i.e. measuring within required uncertainty limits, for most of the time and if problems, once they occur, can be solved quickly.

In case of heat flux sensors, the measurement uncertainty is a function of:

- calibration uncertainty
- differences between reference conditions during calibration and measurement conditions, for example uncertainty caused temperature dependence of the sensitivity
- the duration of sensor employment (involving the non-stability)
- application errors: the measurement conditions and environment in relation to the sensor properties, the influence of the sensor on the measurand, the representativeness of the measurement location

It is not possible to give one figure for heat flux sensor measurement uncertainty. Statements about the overall measurement uncertainty can only be made on an individual basis, taking all these factors into account.

Guidelines for uncertainty evaluation:

1. The formal evaluation of uncertainty should be performed in accordance with ISO 98-3 Guide to the Expression of Uncertainty in Measurement, GUM.
2. Uncertainties are entered in measurement equation (equation is usually Formula 0.1: $E = U/S$), either as an uncertainty in E (non-representativeness, resistance error and deflection error) in U (voltage readout errors) or in S (non-stability, temperature dependence, calibration uncertainty).
3. In case of special measurement conditions, typical specification values are chosen. These should for instance account for environmental conditions (working temperature range).
4. Among the various sources of uncertainty, some are “correlated”; i.e. present during the entire measurement process, and not cancelling or converging to zero when averaged over time; the off-diagonal elements of the covariance matrix are not zero. Paragraph 5.2 of GUM.
5. Among the various sources of uncertainty, some are “uncorrelated”; cancelling or converging to zero when averaged over time; the off-diagonal elements of the covariance matrix are zero. Paragraph 5.1 of GUM.

8.2 Typical measurement uncertainty budget

Table 8.2.1 typical measurement uncertainties ($k = 2$) when measuring heat flux with HFP01 heat flux sensors.

APPLICATION	TYPICAL MEASUREMENT UNCERTAINTY BUDGET ($k = 2$)
Building physics	<p data-bbox="504 436 1350 490">Under ideal conditions, measurements of heat flux in building physics may attain uncertainties in the $\pm 6\%$ range.</p> <p data-bbox="504 521 1394 633">Contributions to the uncertainty budget: calibration, temperature dependence from 10 to + 30 °C, thermal conductivity of the surrounding environment from 0.5 to 1.5 W/(m·K), representativeness of the measurement location.</p> <p data-bbox="504 665 1326 687">The temperature difference measurement is accurate within 0.1 °C.</p> <p data-bbox="504 719 1385 866">ISO 9869 chapter 9 shows examples of uncertainty evaluation, for thermal resistance measurement. This uncertainty budget also includes contributions from the temperature measurements and dynamic effects. It arrives at typical uncertainties of the order of $\pm 20\%$ of on-site measurements of thermal resistances.</p> <p data-bbox="504 871 1394 987">Corrections may be applied according to chapter 8 of ISO 9869. These corrections include corrections for the thermal resistance and corrections for the finite dimension of the sensor. ISO also calls the latter the operational error, we use the term deflection error.</p>

9 Maintenance and trouble shooting

9.1 Recommended maintenance and quality assurance

TRSYS01 measures reliably at a low level of maintenance. Unreliable measurement results are detected by scientific judgement, for example by looking for unreasonably large or small measured values. The preferred way to obtain a reliable measurement is a regular critical review of the measured data, preferably checking against other measurements, or by comparing results of the two heat flux sensors and two thermocouple pairs when mounted side by side.

Table 9.1.1 *Recommended maintenance of TRSYS01. If possible the data analysis is done on a daily basis.*

MINIMUM RECOMMENDED HEAT FLUX SENSOR MAINTENANCE			
	INTERVAL	SUBJECT	ACTION
1	every measurement	data analysis	Compare measured data between the measurement locations. Look for any patterns and events that deviate from what is normal or expected. Compare to acceptance intervals. Plot heat flux and temperature data against the other meteorological measurands. Inspect cable quality, inspect mounting
2	12 months	inspection	Side by side comparison of the two heat flux sensors and two thermocouple pairs when mounted side by side.
3	2 years	recalibration	Recalibration of heat flux plate, matched thermocouple pairs and MCU by the sensor manufacturer
4		lifetime assessment	Judge if the instrument will be reliable for another 2 years, or if it should be replaced
5	4 years		Replace the battery in the MCU

9.2 Trouble shooting

Table 9.2.1 *Trouble shooting for TRSYS*

General	<p>Inspect the sensors and MCU for any damage. Inspect the quality of mounting. Check the condition of the cables.</p> <p>Check the datalogger program in particular if the right sensitivity is entered. HFP01 sensitivity and serial number are marked on its cable.</p>
The HFP01 sensor does not give any signal	<p>Check if the sensor reacts to heat: Expose the sensor heat, for instance touching it with your hand. The signal should read $> 2 \times 10^{-3}$ V now. Touching or exposing the red side should generate a positive signal, doing the same at the opposite side the sign of the output voltage reverses.</p> <p>Disconnect from the MCU. Check the electrical resistance of the sensor between the green [-] and white [+] wires. Use a multimeter at the 100 Ω range. Measure the sensor resistance first with one polarity, then reverse the polarity. Take the average value. The typical resistance of the wiring is 0.1 Ω/m. Typical resistance should be the nominal sensor resistance of 1 to 4 Ω plus 1.5 Ω for the total resistance of two wires (back and forth) of each 5 m. Infinite resistance indicates a broken circuit; zero or a low resistance indicates a short circuit.</p> <p>Check the data acquisition by replacing the sensor with a spare unit.</p>
The TC matched thermocouple pair does not give any signal	<p>Check if the sensors react to heat: Expose the sensor heat, for instance touching it with your hand.</p> <p>Disconnect from the MCU. Check the electrical resistance of the sensors between the green [-] and white [+] wires. Use a multimeter at the 100 Ω range. Measure the sensor resistance first with one polarity, then reverse the polarity. Take the average value. The typical resistance of the wiring is 0.1 Ω/m. Typical resistance should be the nominal sensor resistance of 1 to 4 Ω plus 1.5 Ω for the total resistance of two wires (back and forth) of each 5 m. Infinite resistance indicates a broken circuit; zero or a low resistance indicates a short circuit.</p> <p>Check the data acquisition by replacing the sensor with a spare unit.</p>
There are doubts about the MCU measurement	<p>Compare measurement results to those with a calibrated multimeter. Short-circuit the input using a 10 Ω resistor. The heat flux signal should be 0 W/m², the temperature signal should reach the panel temperature.</p> <p>A voltage source may be built from a 1.2 VDC battery, and a 1:1000 voltage divider, creating a 1×10^{-3} V source. Calculate the expected heat flux and temperature.</p>
The sensor signals are unrealistically high or low	<p>Check the cable condition looking for cable breaks.</p> <p>Check the data acquisition by applying a 1×10^{-6} V source to it in the 1×10^{-6} V range. Look at the measurement result. Check if it is as expected.</p> <p>Check the data acquisition by short circuiting the data acquisition input with a 10 Ω resistor. Look at the output.</p>
The sensor signals show unexpected variations	<p>Check the presence of strong sources of electromagnetic radiation (radar, radio).</p> <p>Check the condition and connection of the shield.</p> <p>Check the condition of the sensor cable.</p> <p>Check if the cable is not moving during the measurement.</p>

9.3 Calibration and checks in the field

The recommended calibration interval of the TRSYS01 and its individual components is 2 years. Recalibration of sensors and MCU01 is ideally done by the sensor manufacturer.

On-site performance verification is possibly by mounting heat flux sensors and thermocouple pairs side by side. Alternatively heat flux sensors may be stacked.

The MCU01 may be checked by supplying a small voltage signal to its input.

Hukseflux main recommendations for field calibrations are:

1. typical duration of test > 24 h
2. typical heat fluxes used for comparison: > 20 W/m²
3. to correct deviations of more than ± 10 %. Lower deviations should be interpreted as acceptable and should not lead to a revised sensitivity.

9.4 Storage

MCU01 and sensors should be stored in a dry place.

10 Appendices

10.1 Variable names and description

Table 10.1.1 *Explanation of variables and parameters used in the MCU program*

PARAMETERS USED IN TRSYS01 PROGRAM		
PARAMETER	DESCRIPTION	UNITS
PTemp	Panel temperature	°C
Timestamp	Date and time	YYYY-MM-DD HH:MM:SS
Record	Number of the record	-
HF1	Heat flux of heat flux plate 1	W/m ²
T11	Temperature T11 of thermocouple 1	°C
DT1	Temperature difference between two ends of thermocouple 2	°C
E_HF1	Sensitivity heat flux plate 1	x 10 ⁻⁶ V/(W/m ²)
HF2	Heat flux of heat flux plate 2	W/m ²
T21	Temperature T21 of thermocouple 2	°C
DT2	Temperature difference between two ends of thermocouple 2	°C
E_HF2	Sensitivity heat flux plate 2	x 10 ⁻⁶ V/(W/m ²)
UHF1	Voltage heat flux plate 1	x 10 ⁻⁶ V
UHF1	Voltage heat flux plate 2	x 10 ⁻⁶ V

10.2 TRSYS03 extension

TRSYS03 is a special version of TRSYS01 that contains 2 heat flux sensors of model HFP01, 2 pairs of matched thermocouples for differential temperature measurements, one SR05-A1-TMBL pyranometer for most common solar radiation observations and a MCU for measurement and control.

The software 'TRSYS03 v2106.CR1' has been developed especially for the TRSYS03 system.

In the numerical and graphical display of Loggernet for TRSYS03 more parameters are available than for the normal TRSYS01. All values listed in Table 10.1.1 are available in the TRSYS03, with the inclusion of the variables in Table 10.2.1.

Table 10.2.1 *Explanation of variables and parameters used in the MCU program*

PARAMETERS USED IN TRSYS01 PROGRAM		
PARAMETER	DESCRIPTION	UNITS
SOL	Solar irradiance	W/m ²
USOL	Voltage SR05-A1-TMBL	x 10 ⁻⁶ V
E_SOL	Sensitivity SR05-A1-TMBL	x 10 ⁻⁶ V/(W/m ²)

10.3 EU declaration of conformity



We, Hukseflux Thermal Sensors B.V.
Delftechpark 31
2628 XJ Delft
The Netherlands

in accordance with the requirements of the following directive:

2014/30/EU The Electromagnetic Compatibility Directive

hereby declare under our sole responsibility that:

Product model: TRSYS01
Product type: High-accuracy building thermal resistance measuring system

has been designed to comply and is in conformity with the relevant sections and applicable requirements of the following standards:

Emission: EN 61326-1 (2006)
Immunity: EN 61326-1 (2006)
Emission: EN 61000-3-2 (2006)
Emission: EN 61000-3-3 (1995) + A1 (2001) + A2 (2005)
Report: 08C01340RPT01, 06 January 2009

A handwritten signature in blue ink, appearing to be 'Eric Hoeksema', written over a faint grid background.

Eric HOEKSEMA
Director
Delft
September 08, 2015

