INSTRUCTION MANUAL

Q-7.1 Net Radiometer

Revision: 5/96

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RMA#_____
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Q-7.1 NET RADIOMETER

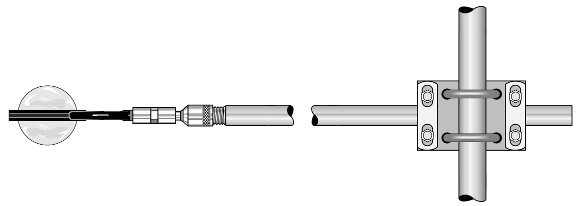
The Q-7.1 is a high-output thermopile sensor which measures the algebraic sum of incoming and outgoing all-wave radiation (i.e. short-wave and long-wave components). Incoming radiation consists of direct (beam) and diffuse solar radiation plus long-wave irradiance from the sky. Outgoing radiation consists of reflected solar radiation plus the terrestrial long-wave component.

1. SPECIFICATIONS

- 60-junction thermopile with low electrical resistance (4 ohms nominal) to reduce susceptibility to noise
- Nominal calibration factors 9.6 W m^{-2} mV^{-1} (for positive values), 11.9 W m^{-2} mV^{-1}(for negative values)
- Spectral response 0.25 to 60 µm
- Uncorrected wind effect: up to 6% reduction @ 7 m s^{-1} for positive fluxes, up to 1% reduction @ 7 m s^{-1} for negative fluxes.
- Time constant: Approximately 30 seconds
- Top and bottom surfaces painted black and protected from convective cooling by hemispherical heavy-duty polyethylene windshields (0.25 mm thick)
- Windshields do not require pressurization
- O-ring seals for easy windshield replacement
- Desiccant contained in support arm; volume of desiccant tube 45 cm^3; breather port on the end of the support arm.
- No power required
- Size of sensing head 57 x 72 x 177 mm; support arm 20 mm diameter, 750 mm long

2. INSTALLATION

Attach the square mounting plate to a vertical or horizontal pipe or rod that is less than 38 mm (1.5 inches) in diameter with the two larger U-bolts. Attach the radiometer support arm to the mounting plate with the two smaller U-bolts. The radiometer support arm does not need to be level. Fasten the cable to the pipe or rod with tape or plastic ties to prevent strain on the wires and damage to the instrument.



CAUTION: Ensure that the cable is tied to the support arm close to the ball joint. If the wires are allowed to flex where they emerge from the sensor head they will break. Sensors are shipped with an appropriate cable tie already installed.

In the northern hemisphere install the radiometer so that the sensor head is pointing south. Likewise, in the southern hemisphere point the sensor head to the north.

2.1 LEVELING

The Q-7.1 must be level. The bubble level is accurate to ±1° and the bubble should be within the bulls-eye. An error of 5° in leveling may cause a cosine response error of 6% under normal conditions; much greater errors are possible under other conditions (e.g. sunrise, sunset and winter use with low sun angles).

To level the Q-7.1, use a 5/8" wrench on the hexagonal coupling nut on the instrument stem to bend the ball joint between the support arm and the instrument. If the instrument does not stay in position, tighten the large hexagonal nut on the support arm slightly with a 15/16" wrench.

CAUTION: Do not attempt to bend the ball joint by holding the instrument head alone, as this may break the stem.

2.2 WIRING

If a differential measurement is made, connect the red (+) lead to the high side (e.g. 1H) of any datalogger differential channel and the black (-) lead to the low side (e.g. 1L). Also, connect a jumper wire between the low channel and analog ground to prevent common mode errors. Connect the clear (shield) lead to ground (G on the CR10(X), ground on the 21X and CR7).

If a single-ended measurement is made, connect the red lead to any datalogger single-ended channel (H or L) and the black lead to ground (AG on the CR10(X), ground on the 21X and CR7).

The black lead is negative with respect to the red lead when the net radiometer is mounted with the level up and there is more incoming radiation than outgoing.

3. PROGRAMMING

Measure the output of the Q-7.1 with either Instruction 2 (Differential Volts) or Instruction 1 (Single-Ended Volts). Use the 250 mV range for the CR10(X) and the 500 mV range for the 21X or CR7. The slow integration with 60 Hz rejection yields a more noise-free reading.

For still air, net radiation (Q*) can be computed from the thermopile voltage (V_t) by:

If $V_t > 0$, $Q^*(Wm^{-2}) = V_t(mV) \times F_p$

If $V_t < 0$, $Q^*(Wm^{-2}) = V_t(mV) \times F_n$

where F_p and F_n are the positive and negative calibration factors respectively.

The calibration factors and serial number are given on a label under the sensor head.

The above formula give the correct readings for conditions of zero wind speed. Additional corrections can be applied to reduce errors for non-zero wind speeds.

3.1 CORRECTING ERRORS CAUSED BY WIND EFFECT

Most sensors which measure long wave radiation are subject to some degree of error caused by convective cooling as air moves past the sensors. The response of the Q-7.1 sensor has been determined by the manufacturer using a specially constructed wind tunnel. Curves fitted to experimental data by the manufacturer are given in Figure 1. These functions show the change in reading in response to increasing wind speed.

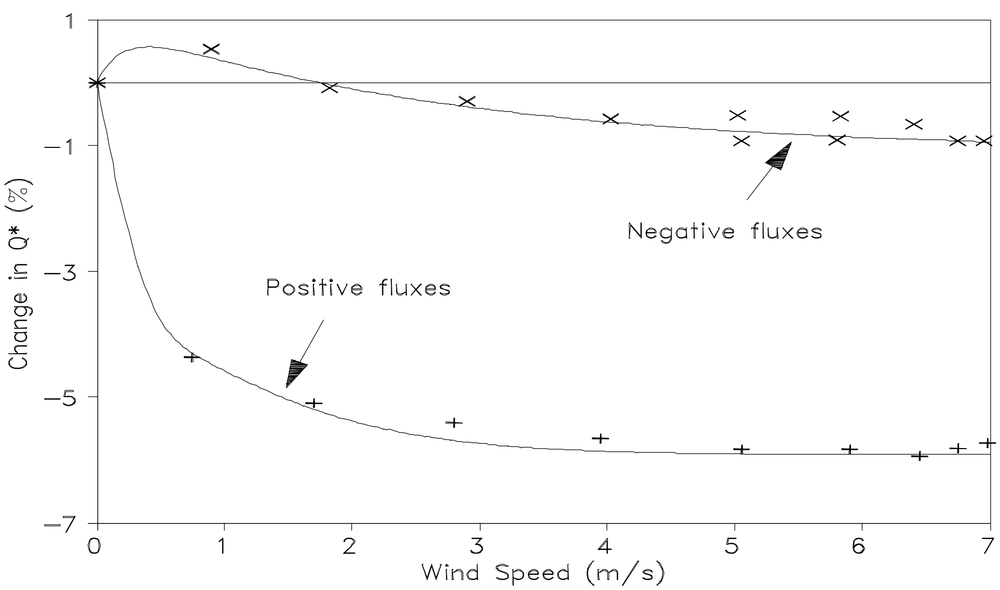


FIGURE 1. Percentage Change in Reading as a Function of Wind Speed

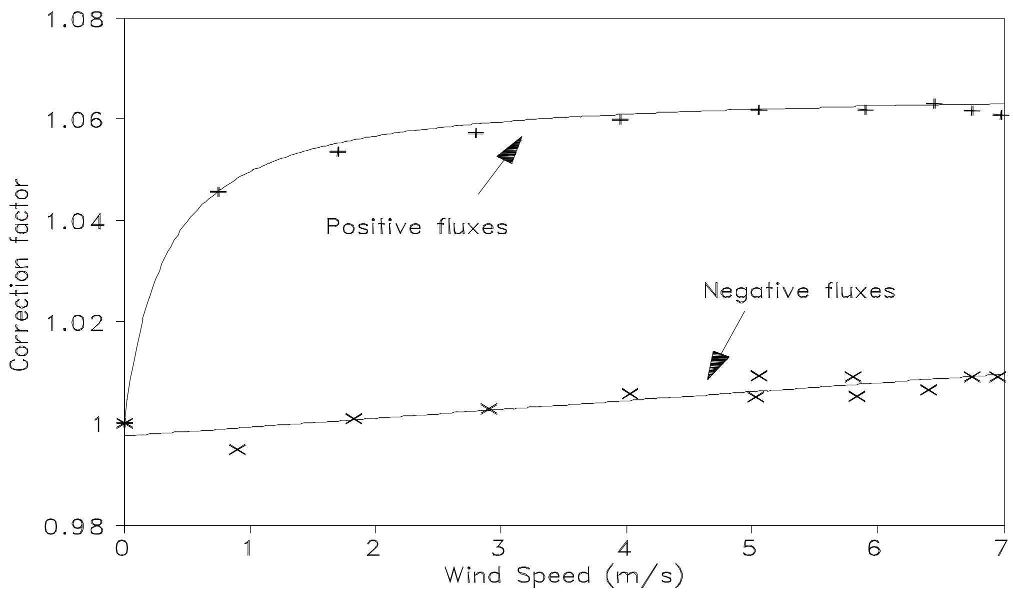


FIGURE 2. Correction Functions as a Function of Wind Speed

The inverse of this data gives the required correction factors to give the correct reading as a function of wind speed (u). Figure 2 shows the manufacturer's data plus correction curves fitted by Campbell Scientific, using functions which can be easily encoded in a datalogger. Note that the functions fitted and shown in both graphs have been amended slightly to allow for a small under-estimate of the error (about 2% of the error) which is the result of a known error of the calibration technique in the wind tunnel.

The correction function for positive fluxes is:

$$\text{Correction factor} = 1 + \frac{(0.066 \times 0.2 \times u)}{\left(0.066 + (0.2 \times u)\right)}$$

For negative fluxes a linear function is used:

$$\text{Correction factor} = (0.00174 \times u) + 0.99755$$

If the wind speed is not measured it is often sufficient to correct the original calibration constant using a fixed correction factor. The manufacturer suggests using fixed correction factors of 1.045 for positive fluxes and 1.000 for negative fluxes.

If the wind speed is measured, the functions above can be programmed into the datalogger to give a real-time correction of net radiation for the effects of wind speed. Note that the wind speed is expressed in units of meters per second. If the wind speed is measured in units other than meters per second, convert the wind speed to meters per second before inputting it into the above correction functions.

If AC power is available, a special ventilator (RV2) is available for the Q-7.1 which gives a typical wind speed of 3.3 ms^{-1}. Positive and negative fixed corrections are 1.06 and 1.0033 respectively. The fan is also useful for reducing the risk of external condensation (dew) on the windshields.

The above corrections were calculated at sea level under conditions close to standard temperature and pressure. The magnitude of the wind speed error will vary in relation to the air density and the heat capacity of air. These changes are generally small enough to be ignored unless extreme temperatures or atmospheric pressures are experienced.

3.2 PROGRAMMING EXAMPLE WITH FIXED WIND SPEED CORRECTION

The following CR10(X) program measures the output of a Q-7.1. A static wind correction is applied to each measurement.

Example 1. CR10(X) Program with the Static Wind Speed Correction

```
;Measure the Q7.1.
;
01:   Volt (Diff) (P2)***
      1:     1       Reps
      2:    24**     ± 250 mV 60 Hz
                     Rejection Range
      3:     1*      DIFF Channel
      4:     3*      Loc [ Rn_W_m2   ]
      5:     1       Mult
      6:     0       Offset

02:   IF (X<=>F) (P89)
      1:     3*      X Loc [ Rn_W_m2   ]
      2:     3       >=
      3:     0       F
      4:    30       Then Do

;Enter the positive multiplier (p.ppp).
;
03:   Z=X*F (P37)
      1:     3*      X Loc [ Rn_W_m2   ]
      2:     p.ppp   F
      3:     3*      Z Loc [ Rn_W_m2   ]

04:   Z=X*F (P37)
      1:     3*      X Loc [ Rn_W_m2   ]
      2:     1.045   F
      3:     3*      Z Loc [ Rn_W_m2   ]

05:   Else (P94)

;Enter the negative multiplier (n.nnn).
;
06:   Z=X*F (P37)
      1:     3*      X Loc [ Rn_W_m2   ]
      2:     n.nnn   F
      3:     3*      Z Loc [ Rn_W_m2   ]

07:   End (P95)
```

* Proper entries will vary with program, and datalogger channel and input location assignments.

** On the 21X and CR7 use 500 mV input range.

*** For a Single-Ended measurement use Instruction 1.

3.3 PROGRAMMING EXAMPLE WITH DYNAMIC WIND SPEED CORRECTION

The following CR10(X) program measures an R. M. Young wind sentry anemometer model 03101 and a Q-7.1. The wind speed is used to give a real-time wind correction to net radiation. The wind speed must be measured before the wind corrections are applied.

Example 2. CR10(X) Program with the Dynamic Wind Speed Correction

```
;Measure the 03101 wind sentry.
;
01:   Pulse (P3)
      1:     1       Reps
      2:     1*      Pulse Channel 1
      3:    21       Low Level AC, Output Hz
      4:     1*      Loc [ ws_m_s    ]
      5:      .75    Mult
      6:      .2     Offset

02:   IF (X<=>F) (P89)
      1:     1*      X Loc [ ws_m_s    ]
      2:     1       =
      3:      .2     F
      4:    30       Then Do

03:   Z=F (P30)
      1:     0       F
      2:     0       Exponent of 10
      3:     1*      Z Loc [ ws_m_s    ]

04:   End (P95)

;Measure the Q7.1.
;
05:   Volt (Diff) (P2)***
      1:     1       Reps
      2:    24**     ± 250 mV 60 Hz
                     Rejection Range
      3:     1*      DIFF Channel
      4:     2*      Loc [ Rn_mV     ]
      5:     1       Mult
      6:     0       Offset

06:   IF (X<=>F) (P89)
      1:     2*      X Loc [ Rn_mV     ]
      2:     3       >=
      3:     0       F
      4:    30       Then Do

;Apply the positive calibration and
;wind speed correction.
;
```

```
07:  Do (P86)
     1:   1*       Call Subroutine 1*

08:  Else (P94)

;Apply the negative calibration and
;wind speed correction.
;
09:  Do (P86)
     1:   2*       Call Subroutine 2*

10:  End (P95)

*Table 3 Subroutines

;Positive calibration and wind
;speed correction.
;
01:  Beginning of Subroutine (P85)
     1:   1*       Subroutine 1

02:  Z=X*F (P37)
     1:   1*       X Loc [ ws_m_s    ]
     2:     .2     F
     3:   6*       Z Loc [ C         ]

03:  Z=X*F (P37)
     1:   6*       X Loc [ C         ]
     2:     .066   F
     3:   4*       Z Loc [ A         ]

04:  Z=X+F (P34)
     1:   6*       X Loc [ C         ]
     2:     .066   F
     3:   5*       Z Loc [ B         ]

05:  Z=X/Y (P38)
     1:   4*       X Loc [ A         ]
     2:   5*       Y Loc [ B         ]
     3:   7*       Z Loc [ Corr_Fact ]

06:  Z=Z+1 (P32)
     1:   7*       Z Loc [ Corr_Fact ]

;Enter the positive multiplier (p.ppp).
;
07:  Z=X*F (P37)
     1:   2*       X Loc [ Rn_mV     ]
     2:   p.ppp    F
     3:   3*       Z Loc [ Rn_W_m2   ]

08:  Z=X*Y (P36)
     1:   3*       X Loc [ Rn_W_m2   ]
     2:   7*       Y Loc [ Corr_Fact ]
     3:   3*       Z Loc [ Rn_W_m2   ]

09:  End (P95)

;Negative calibration and wind
;speed corrections
;
10:  Beginning of Subroutine (P85)
     1:   2*       Subroutine 2*

11:  Z=X*F (P37)
     1:   1*       X Loc [ ws_m_s    ]
     2:     .00174 F
     3:   4*       Z Loc [ A         ]

12:  Z=X+F (P34)
     1:   4*       X Loc [ A         ]
     2:     .99755 F
     3:   7*       Z Loc [ Corr_Fact ]

;Enter the negative multiplier (n.nnn).
;
13:  Z=X*F (P37)
     1:   2*       X Loc [ Rn_mV     ]
     2:   n.nnn    F
     3:   3*       Z Loc [ Rn_W_m2   ]

14:  Z=X*Y (P36)
     1:   3*       X Loc [ Rn_W_m2   ]
     2:   7*       Y Loc [ Corr_Fact ]
     3:   3*       Z Loc [ Rn_W_m2   ]

15:  End (P95)
```

* Proper entries will vary with program, and datalogger channel and input location assignments.

** On the 21X and CR7 use 500 mV input range.

*** For a Single-Ended measurement use Instruction 1.

4. MAINTENANCE

4.1 DESICCANT

The Q-7.1 is supplied with heavy duty polyethylene windshields (approximately 0.25 mm thick); no pressurization is required.

Air spaces inside the windshields are connected to a dryer filled with silica gel (referred to as the desiccant tube) to prevent internal condensation. The desiccant tube is located in the support arm and is accessible by removing the end plug and vinal cap.

Inspect the silica gel monthly to ensure it is still blue and white. If the color changes to pink and white, replace it with dry silica gel (this may have to be done more frequently in wet weather). Wet (pink and white) silica gel can be dried by removing it from the desiccant tube and baking at 130°C until it returns to a blue and white color. Remove the desiccant tube end cap to remove and replace the silica gel.

> **CAUTION:** After the desiccant tube has been replaced, install the end plug and vinal cap. Be sure the holes in the vinal cap point towards the ground.

If the Q-7.1 is installed at a remote site it may be convenient to have a spare desiccant tube for quick replacement (be sure to remove the outer end caps from both tube ends before installing). Spare desiccant tubes are available from Radiation Energy Balance Systems.

4.2 CONDENSATION

Condensation on net radiometer windshields causes incorrect measurements. This is because water does not transmit longwave energy. An example of this problem can be seen by comparing measured net radiation values from two different net radiometers at night, one on which dew is allowed to form and another on which dew is prevented. Without dew both instruments would indicate a similar net radiation level, e.g. -50 W m^{-2}. However, on the instrument on which dew was allowed to form a net radiation level of about zero would be indicated, while the other radiometer would maintain the reading of -50 W m^{-2}. The RV2 ventilator can be used to prevent dew from forming on the windshields.

4.2.1 Causes of Internal Condensation

If condensation develops inside the domes check the following:

Desiccant

Make sure that the desiccant is dry (i.e. still blue and white).

If it has turned pink, replace it with dry desiccant or bake it until it is dry (see section 4.1 above). If the desiccant is pink only at the tube end nearest the sensor head, this indicates a leak somewhere on the sensor.

Windshields and O-rings

Check that the windshields and O-rings are in good condition and are properly seated against the radiometer frame (see below).

If there is still no obvious reason for the internal condensation, check for possible leaks in the sensor as follows:

1. Remove the desiccant tube.

2. Immerse the radiometer in water and blow gently into the open end of the support arm. A stream of bubbles will indicate the location of any leaks.

3. Dry the instrument with a soft facial tissue. If the windshields get dented, reinflate them by blowing into the end of the support arm.

> **CAUTION:** When drying the windshields, dabbing rather than wiping them will help to prevent scratches.

4.2.2 Possible Internal Condensation Problems After Installation

There is a small possibility that condensation may occur on the inside of the windshields when the Q-7.1 is first installed in the field. This condensation is caused by evaporation of hydrocarbon solvents used in the manufacturing process and may be more apparent after several hot, sunny days if ambient temperatures are low enough.

If you notice condensation inside the windshields after the first few days of sunshine following installation, remove the windshields as described below. Allow the solvent vapor or condensation to escape or evaporate from the inner air space for 15 minutes then replace the windshields.

4.3 CLEANING

The windshields may be washed with a camel hair brush or with a paper tissue and distilled water.

> **CAUTION:** Coarse paper or cloth will scratch the windshields and should be avoided.

4.4 WINDSHIELD REPLACEMENT

Polyethylene deteriorates with exposure to solar radiation. Inspect the windshields frequently and replace as required (probably every 3-6 months).

Always check for:

1. Condensation inside the windshields, possibly indicating a leak.

2. Cracking or crazing of the windshields (which usually appears first along the base).

Prompt replacement is essential if any of these conditions occur. Also, if the windshields are removed for any reason after more than one month's use, replace them with new ones. The windshields should always be replaced as a set. Windshield replacement may cause a slight change in calibration, although this is unlikely to exceed 3%.

> **CAUTION:** There are very fine wires inside the head of the Q-7.1 which are very susceptible to corrosion if subjected to moisture, e.g. standing water. It is essential to carry out the preemptive maintenance mentioned above to prevent serious damage to the sensor.

Replace the windshields as follows:

1. Remove the mounting screws and clamping rings.

2. Replacement windshields are pre-cut and punched with holes. Make sure the O-rings are in their grooves before clamping the new windshields into place as described in step 3.

3. Gently tighten the screws in the following sequence: first, third, fifth, second, fourth, sixth. It does not matter which screw you treat as the first. Continue the sequence until the windshields are evenly in contact with the clamping rings and frame.

4. Tighten the screws in the same sequence until no space remains between either windshield flange and its corresponding mounting ring or frame surface. Make sure both upper and lower windshields are completely seated on the frame around the entire periphery.

> **CAUTION:** Do not attempt to dismantle the instrument body. If internal attention is needed, contact Campbell Scientific, Inc. for repair.

If the windshields become dented, remove the dents as follows:

1. Remove the vinal cap from the support arm.

2. Blow gently into the end plug breather hole to inflate the windshields.

Remember to replace the support arm vinal cap. Orient the vinal cap so the holes point towards the ground.

> **CAUTION:** When replacing the windshields, take great care not to touch or mark the black surfaces of the thermopile as this may affect the performance of the instrument. Take care also to avoid overtightening the mounting screws.

4.4.1 Bird Damage

One other cause of damage to windshields is birds pecking at the domes. A simple measure to prevent this is to attach two or three 8 inches cable ties to the support arm at the end near the sensor head, with the free ends of the ties pointing upwards to form an array of 'spikes'. This may discourage birds from landing on the arm. If this does not work you may have to resort to more drastic techniques such as installing an artificial snake on the support arm or commercial bird scarers.

4.5 CALIBRATION

Q-7.1 net radiometers show excellent stability over long periods, but for serious use, regular calibration checks are recommended. The calibration can be checked in the field by mounting another net radiometer alongside and comparing results. The instruments should be examined carefully if the results differ by more than a few percent. Under normal circumstances, a calibration check every six months is adequate providing the sensitive thermopile surface has not been marked, damaged or exposed to the weather.

If the calibration can not be checked in the field, Radiation Energy Balance Systems recommends recalibration every six months, depending on the climate where the sensors are used.

Each instrument is calibrated by the manufacturer in a temperature-controlled calibration chamber by comparison to a transfer standard. The chamber uses a combination of tungsten-halide source and black body chambers. The transfer standard is calibrated by comparison to a precision pyranometer using a partial shading technique developed by Radiation Energy Balance Systems. The long wave calibration of the standard has also been verified using black body chambers.

Care should, however, be taken when comparing readings with sensors from different manufacturers or even older models from Radiation Energy Balance Systems. This is because in recent years academic studies have reported inadequacies both in the design and calibration of net radiometers from most manufacturers. Radiation Energy Balance Systems aim to keep at the forefront of such developments and have published corrections for the calibration of older sensors. However, these corrections cannot fully bring the instruments to the same level of performance as the new sensors. It is, however, possible to upgrade and recalibrate the sensor heads of older models.

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