Open Source Hardware Engineering

Instruction Manual
-
Building a High Performance Fan-Aspirated Radiation Shield

Version 4.0

February, 2011

Copyright Information

Introduction

The author owns one of the original WMR100 weather stations. This unit has the outdoor temperature/humidity sensor integrated with the anemometer. The first problem with this setup is that the anemometer is supposed to be 30 feet above ground level while the temperature sensor should be 5 feet high. The other problem is that the temperature sensor is not fan aspirated, poorly shielded, and can exhibit significant temperature errors.

The new WMR100N offers a separate shielded temperature sensor (THGN810) – but tests conducted on that unit's radiation shield indicate it has equally poor or perhaps even worse performance. Radiation induced errors as large as 15 degrees Fahrenheit have been documented with that shield.

This document shows how to build a high performance custom, fan-aspirated radiation shield for a wireless remote sensor which. The unit is quite large and fairly expensive due to the use of some 6-inch diameter PVC pipe and fittings. The construction of a smaller, less expensive shield which performs nearly as well as this one is also detailed on the osengr.org web site.

Many weather station software programs such as Weather Station Data Logger can be configured to use any external wireless sensor for the “official” outdoor temperature reading when uploading data to the internet.

Features & Benefits

The key to both fan-aspirated designs is a coaxial configuration found on a web site in Greece (http://users.otenet.gr/~meteo/project_radiation-shield.html). While this design is significantly different, the original design provided the idea for the coaxial arrangement, and this is the key to its excellent performance. Another feature of this design is that the exhaust air (which has been warmed by solar heating) is directed ***away*** from the air intake port, thus eliminating another source of error that plagues some designs.

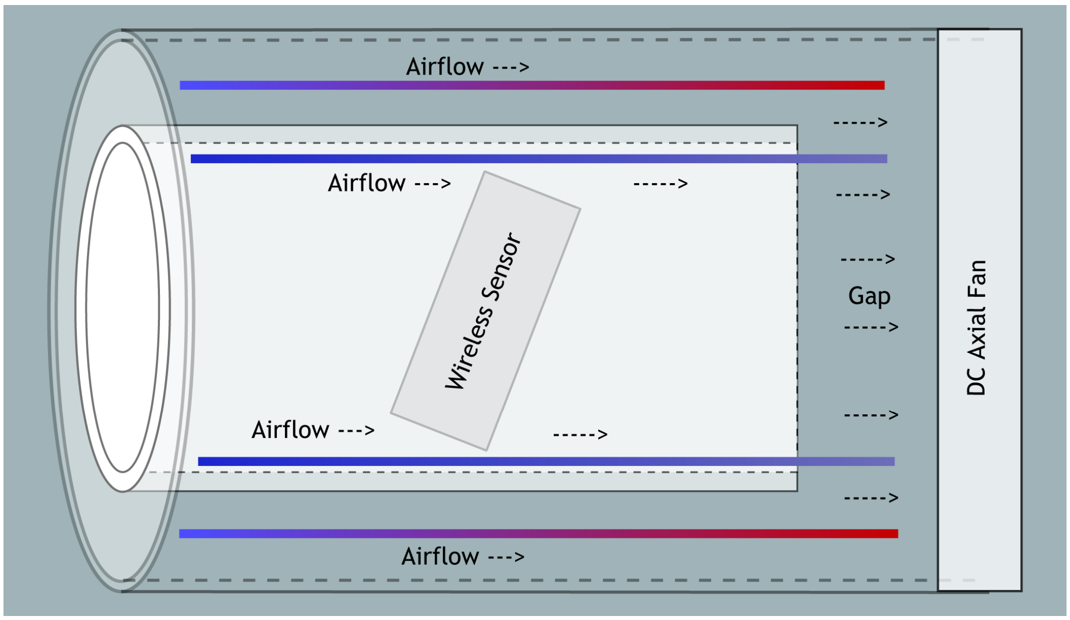

Figure 1. Coaxial Shield Concept

As shown in figure 1 above, this design uses two coaxial-mounted pipes: one smaller pipe is mounted inside a second larger pipe. The smaller pipe is shorter than the large pipe, so there is a gap at one end as shown. A DC powered axial fan mounted at the end of the large pipe sucks air through both pipes at the same time. The temperature sensor is mounted in the small pipe, in the airstream created by the fan.

To have an effect on the measured temperature, solar radiation absorbed by the outer pipe must be first be conducted through the wall of that pipe. The warmed inner wall must then transfer heat by convection across the air gap; this process is hindered by air flow between the two pipes created by the fan. Heat must then conduct through the wall of the inner pipe before finally being able to warm the sensed air temperature (by convection).

The inner pipe in the large design, and both pipes in the small design are designed for irrigation drainage and manufactured by Hancor company. They have a “triple wall” construction (shown in figure 2) which provides additional insulation, reducing the amount of heat that can be conducted through the pipe wall(s). As a result, this shield should perform significantly better than a shield constructed of metal tubes which would conduct much more heat through their walls.

The surface of the outer pipe will be heated by the sun, and will in turn heat some of the nearby air. Another source of error is caused by aspiration of this heated air (around the outside of the outer pipe) into the air intake. This can occur in calm wind conditions or if the intake is pointed downwind with a very light breeze. This design helps minimize this source of error since warmed air near the surface of the outer pipe will tend to get sucked into the gap between pipes instead of into the inner pipe (where the sensor is mounted).

According to the NWS, air should be sampled from an elevation of 5 feet above ground level. Many of the aspirated designs are vertically oriented, with the airflow going upwards. Depending on the speed of airflow, this can result in an *effective* sampling height quite a bit below the intake location – so how high should the intake be located? Sampling air at the wrong height will also cause errors. The larger design reduces this problem since air is aspirated at a 45-degree angle instead of vertically (see figure 2).

Parts List

This design uses a 4-inch pipe for the inner pipe with a 6-inch diameter pipe for the outer shield. Depending on the kind of pipe chosen, the 6-inch pipe can be a bit pricey. Thin-walled galvanized metal vent piping (ducting) might also work for the outer pipe, but that could also hurt performance since it conducts heat much better than PVC.

Parts List:

- 12-volt NMB 4710KL-04W-B10 fan (available from DigiKey)
- 12-volt 6-watt power supply wall wart (made by CUI inc, from DigiKey) -- or any convenient wall-wart supply that produces a 12V DC output at 0.12 amperes or more.
- 4-inch Hancor Triple-wall drain pipe
- 6-inch pipe, PVC, ABS, galvanized ducting or whatever you can find, plus two 45-degree elbows
- ¼-20 aluminum, brass or stainless steel screws, various lengths plus two nuts.
- 1, 1-1/4 or 1-1/2 inch PVC pipe tee
- Mosquito netting
- Tie-wraps (a.k.a. cable ties)
- White plastic primer paint
- Low voltage wiring long enough to reach from sensor location to power supply

Also required are an assortment of tools. Drills, hacksaw, grinder, ¼-20 tap, soldering iron, etc.

Construction Details.

Figure 2. Assembled Temperature Sensor

The vertical mounting pipe (1-inch PVC) has a smaller metal pipe inside it for stiffening.

Pipe Lengths

The center section only needs to be long enough to slide the elbows over and attach to the mounting cradle (about 7 inches is exposed here, plus the length that has been slipped inside the elbow fittings). The inlet section is about 18 inches long. The exhaust section is only long enough to keep rain out of the center section even in high winds, about 12 inches in the photo.

The inner pipe section in this example is 12 inches long. These lengths are longer than really necessary; the inner pipe could be as short as 6-8 inches with the outer pipe (intake section) being maybe 10-14 inches long -- only 4-8 inches longer than the inner pipe.

Figure 3. 6-Inch PVC Parts

Below is a photograph of the Hancor double wall pipe's cross section – showing the insulating properties of this pipe.

Figure 4. Hancor Triple-Wall Pipe

Sensor Mounting

In the photograph, the sensor is essentially "pinned" between two screws and cannot move inside the pipe. The sensor needs to be back far enough from the inlet end of the pipe that it will not get wet from rain.

Also, see the instruction manual for the smaller shield (inverted bird feeder) on the osengr.org web site. This describes a method of using mono-filament fishing line to secure the wireless sensor inside the inner pipe and is preferable to what is shown here.

The inner pipe does not need to continue very far past the sensor mounting point. In this example, the inner pipe is 12 inches long and the first mounting screw is about 1-2 inches from the inlet end of the pipe. The pipe extends several inches past the upstream end of the sensor which is probably more than necessary. This setup works well so just copy it – or experiment with shorter lengths if desired.

Figure 5. Sensor Mounting

Fan mounting

Be sure to mount the fan so that it sucks air up into the pipe – you don't want to blow air out of the pipe. The mounting ears on the intake side of the fan (not visible in the photo) had to be trimmed back slightly in order to fit inside the pipe. I did this with a grinding wheel. Do not trim the ears on the exhaust end. Cut some pieces of plastic (fiberglass is used in the photo) and use RTV to secure them. These seal the gaps between fan and pipe so air cannot "cheat" and go around the fan.

This fan is fairly "wimpy" and better performance might be achieved with a faster version of the fan (readily available). However, tests seem to indicate the current fan is more than adequate and it doesn't make much noise.

Fan Lifetime

Experience indicates that the fan specified here will have a lifetime of perhaps 2-3 years. It is not designed for the humidity levels it sees during periods of rain and it will eventually die from exposure to excessive humidity. If you can find another fan rated for condensing a condensing environment it will last longer than the one shown here.

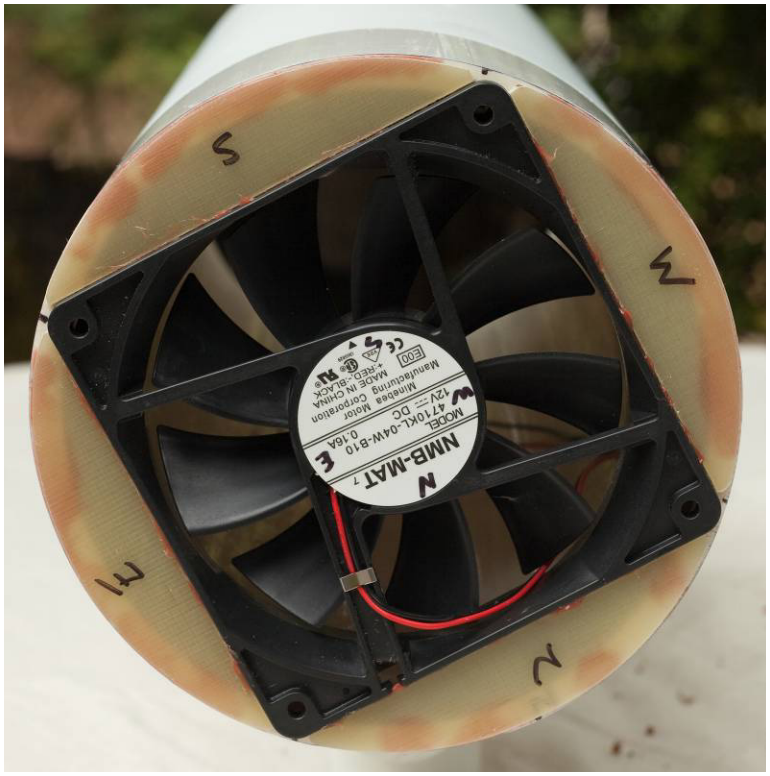

Figure 6. Fan Mounting

Mounting the Inner Pipe

Mounting studs are shown in figure 7. Use a ¼-20 tap to thread the holes in all locations; it may also work to simply force-thread the screws into the plastic but a tap is preferable, especially on the PVC pipe. Other screw sizes and materials can be used if desired. Aluminum, brass, stainless steel or nylon is preferred for corrosion resistance. Stainless steel and nylon are a poor conductors of heat so that is another point in their favor.

If a thinner walled piping or ducting is used for the outer pipe, it may not be possible to tap the holes. In this case, nuts will need to be used (two nuts per screw) to secure the screws in the outer pipe.

Figure 7. Mounting Screws for Inner Pipe

Inner Pipe Location

Figure 8 shows the inner pipe secured in place by the mounting studs. The end of the inner pipe is flush with the end of the outer pipe. The inner pipe should be 4-6 inches shorter than the outer pipe. This encourages the fan to suck equally through both pipes.

This view (figure 8) shows how the design minimizes the effects of solar radiation. Here you can see how air is sucked through both the inner pipe, ***and*** the gap between the two pipes: this is the key to the unit's performance.

Solar heating will cause a significant increase in air temperature between the two pipes. However, with aspiration the temperature rise will be minimal (perhaps a few degrees Farenheit). The small temperature rise present on the ***outside*** of the inner pipe will then have much less effect on the air being sucked through the ***inside*** of the inner pipe. This temperature rise is further lessened by the insulating properties of the double-wall inner pipe.

If building the smaller version of this shield, the assembled pipe in figure 8 would be mounted vertically with the top covered with a larger flower pot base which is suspended perhaps a half-inch above the top end of the pipe.

Figure 8. Coaxial Setup

Bug screen or mosquito netting is used to cover intake and exhaust ends. This keeps bugs and spiders out of the unit.

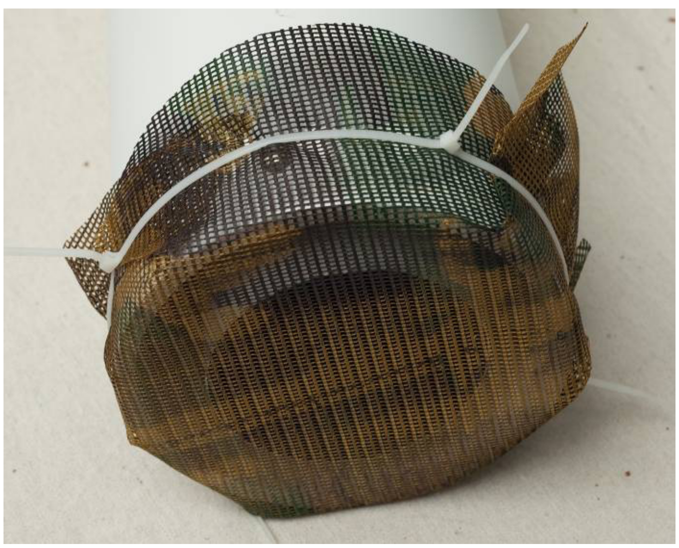

Figure 9. Bug Screen

Fan Wiring

The fan wires can be routed through a small hole drilled in the elbow. Be sure to drill the hole on the underside so that gravity will keep water from entering. Optionally, the wires can be routed down the pipe and through the bug screen.

Figure 10. Fan Wiring Detail

Mounting Cradle

Cut a section of the 6-inch pipe and attach a smaller pipe tee with two bolts and nuts. Use tie-wraps to hold the center section in the cradle. The open end of the smaller pipe tee can then be slipped over a vertical mounting pipe. Other mounting techniques are possible -- use your imagination.

Figure 11. Mounting Cradle

Wrap-Up

Paint the outside of the 6-inch outer pipe with white plastic primer paint. This will help to keep the pipe healthy in the presence of UV from the sun. Depending on the color of the bare pipe, it may also increase the reflectivity which will minimize solar heating. White spray paint looks black in the infra-red portion of the spectrum, which may be more important on a clear night (cooling from the cold sky) but that's what was used in this example.

The outer pipe warmed by the sun (or cooled by the night sky) will be surrounded by heated (or chilled) air. In calm-wind conditions this air will tend to rise, away from the pipe inlet. In light winds, the heated air will have less effect if the unit is oriented with the air intake upwind. One enhancement would be to mount the unit on a pivot and add a wind vane -- using the wind to help orient the air intake upwind. It is not clear how much difference this would make.

When the sensor battery needs changing, the bug netting can be carefully slipped of if the tie-wraps are not overly tight. Then loosen some of the exterior mounting studs and remove the inner pipe. Only one of the screws in the inner pipe needs to be removed to extract the sensor.

Flow Rate Calculations

The 4710KL-B10 fan data sheet shows a flow rate of 53 CFM for a static pressure of 0.02" of water, and about half that for 0.04" static pressure. The ID of the 6" schedule 40 PVC pipe is 6.031". The inner Hancor pipe has OD/wall thickness of 4.200/0.165"

The area inside the main pipe is 28.6 sq-in. The area occupied by the Hancor pipe is 2.1 sq-in. The area occupied by the sensor is (THGR810N) about 2.2 sq-in. Total area available for airflow is then 28.6-2.1-2.2 or 24.3 sq-in or 0.169 sq-ft.

An airflow of 53 cu-ft/min passing through an area of 0.169 sq-ft requires a velocity of roughly 314 ft/min or 5.2 ft/sec. At half the airflow that would be 2.6 ft/sec.