

Designing Heat Meters using PIC16F9XX Microcontrollers

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INTRODUCTION

Heat in many parts of the world is supplied to rooms using hot water and radiators. A boiler in a basement or adjoining building heats water and pumps it throughout the building. Radiators in each room use convection and radiation to distribute heat. By changing the flow of water through the radiator, the amount of heat also varies proportionally. This technical brief will show the basic details to building an electronic heat meter.

HEAT METER FUNDAMENTALS

Water is heated by a boiler of some type. It is then pumped to the rooms in a building and then returns to the boiler to start the process over again. The idea behind a heat meter is to measure the amount of energy dissipated in the building by the hot water radiators. To measure this energy consumption, the heat meter must measure three parameters:

- Incoming temperature of water
- · Outgoing temperature of water
- Mass flow rate of water

We can obtain the temperature of the incoming and outgoing water using RTDs, thermocouples or similar devices. The mass flow rate can come from standard residential water meters. Once we know these parameters, we can calculate the amount of energy dissipated in the building using the following equation:

$$Q = m \times cp \times \Delta T$$

Where:

 $cp = specific heat (J/g^{\circ}C)$

$$\Delta T$$
 = is the differential temperature (°C)

Water meters output in three forms: cubic feet, gallons or cubic meters. We need to calculate the mass flow rate in terms of kilograms per second for use in our heat transfer equation. The following list shows the conversion factors from each of the three water meter outputs into kilograms. The electronic heat meter would then need to record this measurement over a particular time period. The specific heat and density of water change as a function of the temperature of the water and therefore depends on the output temperature of the boiler. For the examples below, lets assume that the boiler outputs hot water at a temperature of 40°C. Table 1 shows both the density and specific heat of water over temperature. At 40°C, the density of water is.991 grams/cm³. Table 1 shows the density of water versus temperature.

1 ft³ of water = 28,316.8467117cm³ x 0.991 gram/cm³ x 1 kg/1000 grams = 28.061995 kg 1 gallon of water = 3,785.4118 cm³ x 0.991 gram/cm³ x 1kg/1000 grams = 3.751343 kg 1 m³ of water = 1,000,000 cm³ x 0.991 gram/cm³ x 1kg/1000 grams = 991 kg

The most common residential water meters are designed to measure mass flow rates of 0-20 gallons per minute. This would equate to 1.25043 kg/s (20 gpm * 3.751343 kg/gal * 1m/60s). As an example, lets calculate the energy usage when the mass flow rate is 5 gallons per minute with an incoming temperature of 40°C and an outgoing temperature of 34°C.

Calculate the mass flow rate:

 $5 gpm \times 3.751343 kg/gal \times 1m/60s = 0.31261 kg/s$

Use specific heat of water 4.179 Joules/gram $^\circ C$ at a temperature of 40°C (Table 1).

Calculate the differential temperature:

 $40\,^{\circ}C - 34\,^{\circ}C = 6\,^{\circ}C$

Calculate the heat transfer rate:

$$Q = 0.31261 \text{ kg/s} \times 4.179 \text{ J/g} \,^{\circ}\text{C} \times 6 \,^{\circ}\text{C}$$

= 7.83843 J/s or W

In this example, we are transferring ~8W of heat into the room every second or 28.2 kW/hr.

HEAT METER DESIGN

Figure 1 shows an example heat meter circuit based on a PIC16F913 microcontroller. This device has an integrated 10-bit A/D converter and LCD module. The LCD module is capable of driving up to 4 COMs x 15 SEGs for a total of 60 pixels. Typical water and energy meters have 6 numeric digits for a total of 48 pixels leaving 12 pixels for other icons. The circuit will use relatively high resistors (~750 k Ω) in the resistor ladder of the LCD module. This will help to minimize the current consumption of the circuit.

This example uses two Type K thermocouples to measure the incoming and outgoing temperatures. Two MCP602 operational amplifiers (op amps) are used to create an instrumentation amplifier to signal condition the thermocouple outputs. These outputs are connected to the RA0 and RA1 analog inputs to the integrated 10-bit A/D. Timer1 is used to set up the periodic sample rate for temperature.

The water flow meter will have one of two type outputs typically. The first is a shaft where the speed of rotation is proportional to water flow. For this type of meter, a slotted wheel is attached to the shaft and an optoreflector is used to output a pulse every time the slot passes. The second type is where the meter has a magnet that circulates with the flow. A Hall effect sensor is used to detect the presence of the magnet and outputs a digital pulse stream. Both of these outputs can be tied to the clock input of a counter on the microcontroller. The TOCKI input on the PIC16F913 device has a Schmitt Trigger input buffer which helps to filter out any noise on these pulse outputs. Timer0 is used to count the number of pulses from the water meter. Every time the PIC16F913 samples the A/D inputs, the value of Timer0 is captured. The difference between the current value and the last value provides the flow rate for that time period.

Once we have all three measurements, the microcontroller calculates the energy usage and updates the display. The PIC16F913 microcontroller also has integrated data EEPROM which can be used to save the energy usage periodically.

CONCLUSION

Using a relatively simple circuit, a cost effective heat meter can be designed using a low-cost, low power microcontroller with LCD display. The PIC16F91X microcontrollers with integrated 10-bit A/D converter and LCD module are perfect for not just heat meters, but also gas, water and energy meters.

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Temperature – T (°C)	Density – ρ (kg/m ^o)	Specific Heat – C _P (KJ/Kg°C)
0	1000	4.217
5	1000	4.204
10	1000	4.193
15	999	4.186
20	998	4.182
25	997	4.181
30	996	4.179
35	994	4.178
40	991	4.179
45	990	4.181
50	988	4.182
55	986	4.183
60	980	4.185
65	979	4.188
70	978	4.190
75	975	4.194
80	971	4.197
85	969	4.203
90	962	4.205
95	962	4.213
100	962	4.216

TABLE 1: SPECIFIC HEAT AND DENSITY OF WATER VERSUS TEMPERATURE

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