Errata to
Ground Source Heat Pumps:
Design of Geothermal Systems for Commercial and Institutional Buildings
December 31, 2008

Page 22: In the next-to-last sentence of the second full paragraph of the right column, change "The worse case..." to "The **worst** case...."

Page 26: Change the equation in the left column from

$$R_b(\text{corrected}) + R_b(\text{Table 3.1}) + R_b(\text{Table 3.2}) = 0.09 + 0.03 = 0.12 \text{ h·ft·°F/Btu}$$ to $$R_\mathrm{b}(\text{corrected}) = R_\mathrm{b}(\text{Table 3.1}) + R_\mathrm{b}(\text{Table 3.2}) = 0.09 + 0.03 = 0.12 \text{ h·ft·°F/Btu}$$

(do not italicize the subscripts and change the first plus sign to an equals sign).

~~**Page 29:** Figure 3.2 is missing the label for the vertical axis. Add the following vertical axis label: "**G-Factor =** $\mathbf{R_g \times k_g}$"~~

~~**Page 29:** The label for the horizontal axis in Figure 3.2 is incorrect. Change "G-Factor = $R_g = G/k_g$" to the following: "$\mathbf{Fo = 4\alpha_g \tau / d^2}$"~~

Please see the errata sheet dated January 4, 2010 for corrected errata for Figure 3.2.

Page 30: In the first bullet in the left column, change "Insulate all the liquid lines to below the ground surface" to "**Insulate all liquid lines above ground surface.**"

Page 30: In Example 3.2, change the third sentence from "The disk on an electric meter is rotating at a rate of 2.82 revolutions per second" to "The disk on an electric meter **(**$\mathbf{K_h}$ **= 3.6 W-h/rev)** is rotating at a rate of 2.82 revolutions per second."

Page 30: In the Solution to Example 3.2, change "R_b = 0.09 h·ft·°F/Btu from Table 3.2" to "R_b = 0.09 h·ft·°F/Btu from Table **3.1**."

Page 31: In the first line of the left column,

$$\text{change} \quad W_c = K_h \times 3600 \text{ ft} = 3.6 \times 3600/2.82 \text{ sec}$$

$$\text{to} \quad \mathbf{W_c = K_h\ (W·h/rev) \times 3600\ (sec/h) / \tau\ (sec/rev) = 3.6 \times 3600/2.82\ sec} .$$

Page 31: Change the third sentence of the first paragraph in the left column from "From Table 3.4, a value of 1.4 Btu/h·ft·°F and, From Table 3.5, a value of 0.93 ft^2/day are selected" to "**From Table 3.3, values of 1.4 Btu/h·ft·°F and 0.93** $\mathbf{ft^2}$**/day are selected.**"

Page 31: In the equation in the left column that begins with "t = ", change the t to **τ**.

Page 31: In the equation in the left column that begins with "d = ", change "Table 3.2" to "**Table 3.1**."

Page 37: In the second-to last and last lines of the second paragraph in the left column, change "...during a peak four-hour period (0.167 hours)…" to "...during a peak four hour period (0.167 **days**)…."

Page 38: In the first equation in the left column, change

$$X = r/2\sqrt{\alpha\tau} = 1.25\text{ ft}/2\sqrt{.75\text{ ft}^2/\text{day} \times 3680\text{ days}} = .12$$

to $$X = r/2\sqrt{\alpha\tau} = \mathbf{12.5}\text{ ft}/2\sqrt{.75\text{ ft}^2/\text{day} \times 3680\text{ days}} = .12$$

Page 42: In the second sentence of the first paragraph of Section 4.2, change "Determination of the temperature penalty is a consuming calculation..." to "Determination of the temperature penalty is a **time-**consuming calculation…."

Page 43: In the second sentence of the last paragraph in the left column, change "will results in larger temperature changes" to "will **result** in larger temperature changes."

Page 59: In the row for 25 gpm in Table 5.7, all the head loss values should be shifted one column to the right. In other words:

gpm	3/4 in.	1 in.	1 1/4 in.	1 1/2 in.	2 in.	3 in.
20		20.1	6.4	3.3	1.11	
25			**9.6**	**4.9**	**1.66**	**0.25**
30			13.4	6.9	2.3	0.35

Page 61: In the first sentence of Example 5.3, change "...head loss though..." to "...head loss **through**...."

Page 61: In the line of Example 5.3 that begins with "@28.7 gpm," change "@ 28.7 gpm (86 gpm × 3 header loops)" to "@ 28.7 gpm (86 gpm ÷ 3 header loops)" (change × to ÷).

Page 116: In the second line of the left column, change "...is the dominate mode..." to "...is the **dominant** mode...."

Page 124: Change Equation 7.3 from

$$\text{EWT} = t_{\text{resv}} + t_{\text{approach}} + \Delta t_{\text{resv header}} + \Delta t_{\text{ground header}}$$

to $$\text{EWT} = t_{\text{resv}} + t_{\text{approach}} + \Delta t_{\text{resv header}} + \Delta t_{\text{ground header}} \mathbf{+ t_{\text{rise pump}}}$$

(add "+ $t_{\text{rise pump}}$" to the end).

Page 130: In the third bullet of the left column, change "...when makeup water is available..." to "…when makeup water is **un**available…."

Page 157: In the fifth line of Example D.1, change "= 8.81 Btu·in./h·ft^3·°F" to "= 8.81Btu·in./h·$\text{ft}^{\mathbf{2}}$·°F" (change "ft^3" to "ft^2").

Errata to
Ground-Source Heat Pumps:
Design of Geothermal Systems for Commercial and Institutional Buildings
January 4, 2010

Page 29: A previous errata sheet (dated December 31, 2008) stated to correct Figure 3.2 to show a vertical axis label of "G-Factor = Rg × kg" and a horizontal axis label of "$Fo = 4\alpha_g\tau/d^2$"; this is incorrect. **The *vertical* label for Figure 3.2 should read "$Fo = 4\alpha_g\tau/d^2$" and the *horizontal* label should read "G-Factor = Rg × kg."**

Page 34: The 4th sentence of the 2nd paragraph under the 3.8 heading reads "Table 2.3 provides sufficient data for a range of units that will accommodate the loads of the seven zones" but should read as follows, with a new 5th sentence added: "Table 2.3 provides **the performance of one heat pump from a product line that has** a range of units that will accommodate the loads of the seven zones. **Note that zone 3 is served by the heat pump whose performance is shown in Table 2.3.**"

Page 36: In Table 3.8, there should be no divider lines between the header cells "Design," "Loads," and "MBtu/h"; these should all be one heading in one cell (like in Table 3.9).

Page 36: In Table 3.10, the heating hours listed for Zone 1 read "360" but should read "**350**" and the cooling load tons listed for zone 7 read "–3.8" but should read "**–2.8**."

Pages 63–64: There are multiple corrections to numbers listed in equations on pages 63–64; instead of describing each one, the text (starting mid-way down the left column on page 63 and ending before Section 5.7 on page 64) is reproduced below with the changes indicated in red.

For 86 gpm mains:

$$d = \mathbf{3\ in.},\ \text{SDR 11},\ [\Delta h/100\text{ft}] = 2.4\ \text{ft water}/100\text{ft}$$

For 71 gpm section:

$$d = \mathbf{3\ in.},\ \text{SDR 11},\ [\Delta h/100\text{ft}] = 1.7\ \text{ft water}/100\text{ft}$$

For 57 gpm section:

$$d = \mathbf{3\ in.},\ \text{SDR 11},\ [\Delta h/100\text{ft}] = 1.1\ \text{ft water}/100\text{ft}$$

For 7 gpm section:

$$d = \mathbf{1\ in.},\ \text{SDR 11},\ [\Delta h/100\text{ft}] = 3.0\text{ft water}/100\text{ft}$$

Step 3, Finding equivalent lengths and head losses—The greatest head loss in a building loop (non-reverse-return) is normally to the most remote loop. In this case, some of the heat pumps in the equipment room have head loss exceeding the maximum recommended value of 12 ft. It is possible the water flow path through HP2 may have the largest loss and will be checked. Also, the connection on pumps in the 75 to 100 gpm range are normally 2 in., so the main piping will be reduced from 3 in. at the pump suction and discharge. All straight lengths used are approximate.

Interior header (3 in. SDR 11) loss:

$$L_{eqv} = 2 \times (10\text{ft} + 5\text{ft}) + 2 \times 31\text{ft} + 4 \times 32\text{ft} = 220\text{ft}$$

(Branch Tees) (Elbows)

$$@86gpm,\ \Delta h/100\text{ft} = 2.4\ \text{ft 1mpwater}/100\text{ft}$$
$$\Delta h_{3\text{ in. main}} = 2.4\text{ft}/100\text{ft} \times 220\text{ft} = \mathbf{5.3\ ft\ water}$$

Pump piping (2 in. SDR 11) loss:

$$L_{eqv} = 10\text{ft} + 1 \times 15\text{ft} + 2 \times 12\text{ft} = 49\text{ft}$$

(Branch Tee) (Elbows)

$$@86\text{gpm},\ \Delta h/100\text{ft} = 16.1\ \text{ft water}/100\text{ft}$$
$$\Delta h_{2\text{ in. pump}} = 16.1\text{ft}/100\text{ft} \times 49\text{ft} = \mathbf{7.9\ ft\ water}$$

71 gpm section (3 in. SDR 11) loss:

$$L_{eqv} = 2 \times 5\text{ft} + 2 \times 7\text{ft} = 24\text{ft}$$

(Straight Tee)

$$@71\text{gpm}, \Delta h/100\text{ft} = 1.7 \text{ ft water}/100\text{ft}$$

$$\Delta h_{71 \text{ gpm}} = 1.7\text{ft}/100\text{ft} \times 24\text{ft} = \mathbf{0.4 \text{ ft water}}$$

57 gpm section (3 in. SDR 11) loss:

$$L_{eqv} = 2 \times 10\text{ft} + 2 \times 7\text{ft} = 34\text{ft}$$

(Straight Tee)

$$@57\text{gpm}, \Delta h/100\text{ft} = 1.1 \text{ ft water}/100\text{ft}$$

$$\Delta h_{57 \text{ gpm}} = 1.1\text{ft}/100\text{ft} \times 34\text{ft} = \mathbf{0.4 \text{ ft water}}$$

7 gpm section (1 in. SDR 11) loss:

$$L_{eqv} = 2 \times (5\text{ft} + 30\text{ft} + 30\text{ft}) + 2 \times 3\text{ft} + 6 \times 10\text{ft} = 196\text{ft}$$

(Straight Tee) (Elbows)

$$@7\text{gpm}, \Delta h/100\text{ft} = 3.0 \text{ ft water}/100\text{ft}$$

$$\Delta h_{7\text{gpm}} = 3.0\text{ft}/100\text{ft} \times 196\text{ft} = \mathbf{5.9 \text{ ft water}}$$

$$\Delta h_{ballvalves} = 2 \times 2.31 \times [7\text{gpm}/C_v]^2 = 2 \times 2.31 \times [7/35]^2 = 0.2 \text{ ft water}$$

Step 4, Losses through other components—This requires using Equations 5.6 for the heat pump (if losses given for flow rates other than the design value) and Equation 5.7 for the motorized zone valve (C_v = 6), two valves (C_v = 105) and check valve (C_v = 100) at the pump, and the Y-strainer (C_v = 70). Values for C_v not listed can be found in Table 5.8.

$$\Delta h_{\text{heat pump}} = \mathbf{7 \text{ ft water}}$$

$$\Delta h_{\text{zone valve}} = 2.31 \times [\text{gpm}/C_v]^2 = 2.31 \times [7/6]^2 = \mathbf{3.1 \text{ ft water}}$$

$$\Delta h_{\text{pump fittings}} = 2 \times 2.31 \times [86/105]^2 + 2.31 \times [86/100]^2 + 2.31 \times [86/70]^2 = 3.1 + 1.7 + 3.5 = \mathbf{8.3 \text{ ft water}}$$

Thus,

$$\Delta h_{\text{int-HP4}} = 5.3 + 7.9 + 0.4 + 0.4 + 5.9 + 0.2 + 7 + 3.1 + 8.3 = \mathbf{38.5 \text{ ft water.}}$$

However, the losses through the HP2 loop should be checked to see if they are greater. To find this, the losses through the main and pump piping are added to

$$\Delta h_{\text{heat pump}} = \mathbf{19 \text{ ft water}}$$

$$\Delta h_{\text{zone valve}} = 2.31 \times [23/37]^2 = 0.9\text{ft water}$$

$$\Delta h_{\text{take-off}} = 8.5\text{ft}/100\text{ft}(1¼ \text{ in. @ } 23\text{gpm}) \times (2 \times 17\text{ft} + 2 \times 18.5 + 2 \times 5) = \mathbf{6.9 \text{ ft water}}$$

(Branch Tee) (Elbows)

$$\Delta h_{\text{int-HP2}} = 5.3 + 7.9 + 8.3 + 19.0 + 0.9 + 6.9 = \mathbf{48.3 \text{ ft water}}$$

Thus, flow through HP2 is the critical path, and a pump must be selected to provide the sum of the loss through this loop and the exterior loop.

$$\textbf{Required pump head} = \Delta h_{\textbf{ground loop}}$$

$$\Delta h_{int} = \mathbf{10.1 + 48.3}$$

$$\approx \mathbf{58 \text{ ft water.}}$$

The required head can be further reduced by eliminating any large losses. The primary culprit appears to be the 19 ft loss through HP2 (and HP1). Options are:

1. Reduce flow in HP2 (and HP1) to 18 gpm (2.4 gpm/ton) so that the losses would be 12 ft. The capacity of the machine would be lowered about 2% (see Table 2.4), which may be acceptable in the zones.
2. Select another manufacturer's heat pump with a lower head loss.

If the loss through HP2 (and HP1) were reduced from 19 ft to 12 ft, the required pump head would be:

$$\textbf{Required pump head} = \Delta h_{\textbf{ground loop}}$$

$$\Delta h_{int} = \mathbf{10.1 + 41.3}$$

$$\approx \mathbf{51 \text{ ft water.}}$$