Ground-Source Heat Pump System,
Ideal Homes:

- **Assumptions Used in Calculation of COP**
- **Effects of Assumed-Negligible Energy Flows on COP Calculations**

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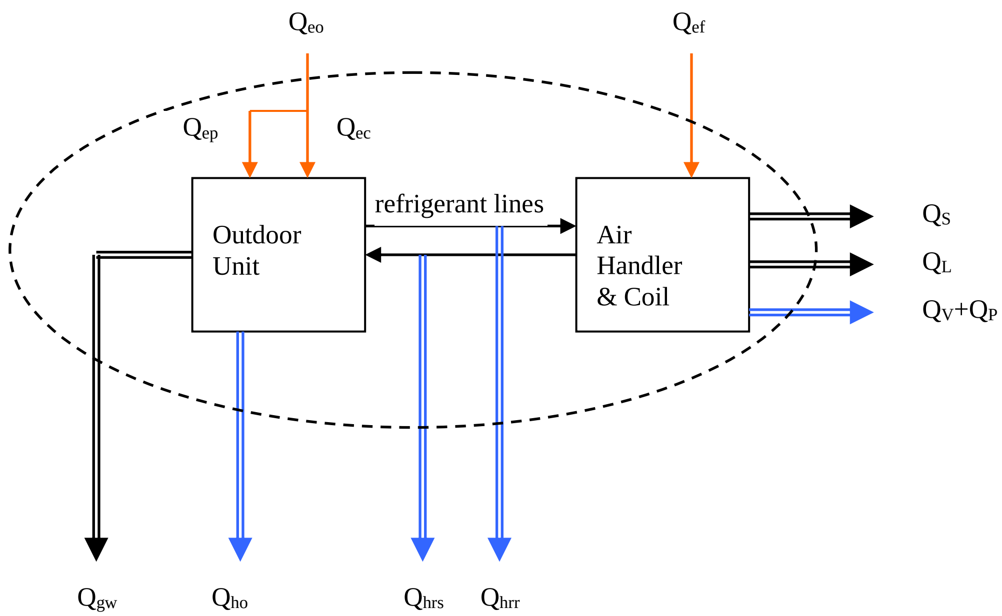

Fig. 1 Schematic representation of ground-source heat pump heating and cooling system showing energy flows in and out of the control volume (dashed line)

<u>Nomenclature</u>

A_{rs} = Heat transfer area, supply refrigerant line to surroundings (attic)
A_{rr} = Heat transfer area, return refrigerant line to surroundings (attic)
Cp_w = specific heat of water evaluated at $T=0.5(T_{fg}+T_{tg})$
Cp_a = specific heat of moist evaluated at $T=0.5(T_s+T_r)$, $\omega=0.5(\omega_s+\omega_r)$, $P=P_r$
f_o = fraction of Q_{eo} that is released as heat to the surroundings
h_{hrs} = Heat transfer coefficient, supply refrigerant line to surroundings (attic)
h_{hrr} = Heat transfer coefficient, return refrigerant line to surroundings (attic)
h_v = water heat of vaporization
m_w = mass flow rate of water
m_a = mass flow rate of moist air
P_r = total atmospheric pressure at air handler return
P_s = total atmospheric pressure at air handler supply
Q_{eo} = Electrical energy to outdoor unit
Q_{ep} = Electrical energy to ground water pump
Q_{ec} = Electrical energy to compressor
Q_{ef} = Electrical energy to air handler fan
Q_S = Sensible energy delivered by air handler to house
Q_L = Latent energy delivered by air handler to house
Q_V = Kinetic energy increase from return-side of air handler
Q_P = Pressure energy increase from return-side of air handler
Q_{gw} = Energy delivered to ground
Q_{ho} = Energy (heat) lost by outdoor unit to ambient air
Q_{hrs} = Energy (heat) lost by supply refrigerant line to surroundings (attic)
Q_{hrr} = Energy (heat) lost by return refrigerant line to surroundings (attic)
T_{attic} = Temperature of air in attic through which refrigerant lines run
T_r = Temperature of air at air handler return

T_s = Temperature of air at air handler supply
T_{rs} = Temperature, supply refrigerant line
T_{rr} = Temperature, return refrigerant line
T_{tg} = Temperature of water to ground
T_{fg} = Temperature of water from ground
V_r = Velocity of air at air handler return
V_s = Velocity of air at air handler supply
v_w = volume flow rate of water
ρ_a = density of moist air evaluated at $T=T_s$, $\omega=\omega_s$, $P=P_r$
ρ_w = density of water evaluated at $T=T_{fg}$
ω_r = humidity ratio of moist air at air handler return
ω_s = humidity ratio of moist air evaluated at air handler supply
ρ_r = density of moist air at air handler return
ρ_s = density of moist air at air handler supply

$m_w = v_w\rho_w$ (Eq. 1)
$Q_{gw} = m_wCp_w(T_{tg}-T_{fg})$ (Eq. 2)
$Q_S = m_aCp_a(T_s-T_r)$ (Eq. 3)
$Q_L = m_ah_v(\omega_s-\omega_r)$ (Eq. 4)
$Q_V = m_a(V_s^2/2-V_r^2/2)$ (Eq. 5)
$Q_P = m_a(P_s/\rho_s-P_r/\rho_r)$ (Eq. 6)
$Q_{ho} = f_oQ_{eo}$ (Eq. 7)
$Q_{hrs} = h_{rs}A_{rs}(T_{rs}-T_{attic})$ (Eq. 8)
$Q_{hrr} = h_{rr}A_{rr}(T_{rr}-T_{attic})$ (Eq. 9)
$V_s = V_r(\rho_r / \rho_s)$ (Eq. 10)

Energy balance:

$$-Q_{gw}-Q_S-Q_L-Q_P-Q_V+Q_{eo}+Q_{ef}-Q_{hrs}-Q_{hrr}-Q_{ho} = 0 \quad \text{(Eq. 11)}$$

Definition of COP:

$$COP = (-Q_S-Q_L+Q_P+Q_V)/ (Q_{eo}+Q_{ef}) \quad \text{(Eq. 12)}$$

Combine Eq. 1 and Eq. 2:

$$COP = (Q_{gw}-Q_{eo}-Q_{ef}+Q_{hrs}+Q_{hrr}+Q_{ho})/ (Q_{eo}+Q_{ef}) \quad \text{(Eq. 13)}$$

Table 1. Effects of Assumed-Negligible Energy Flows on COP Calculation

Assumption	*Effect on COP*		*Effect on COP*		*Effect on COP*		*Effect on COP*	
(Base Case: $Q_P = Q_V = Q_{hrs} = Q_{hrr} = Q_{ho} = 0$)	*(Air-side heating)*		*(Air-side cooling)*		*(Water-side heating)*		*(Water-side cooling)*	
Run-Time Fraction ==>	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0
P_s-P_r = 55 Pa	-0.0%	-0.0%	-1.6%	-0.0%	0.0%	0.0%	0.0%	0.0%
f_o = 0.1	0.0%	0.0%	0.0%	0.0%	-1.9%	+2.2%	+2.9%	+2.9%
$h_{hrs}A_{rs} = h_{hr}A_{rr}$ = 4.9 Btu/hr-°F, $T_{rs} = T_{rr}$ = 130 °F (heating), $T_{rs} = T_{rr}$ = 30 °F (cooling)	0.0%	0.0%	0.0%	0.0%	-1.5%	-1.6%	-1.4%	-1.8%

ALL	-0.0%	-0.0%	-1.6%	-0.0%	-3.4%	-3.7%	+1.5%	+1.1%

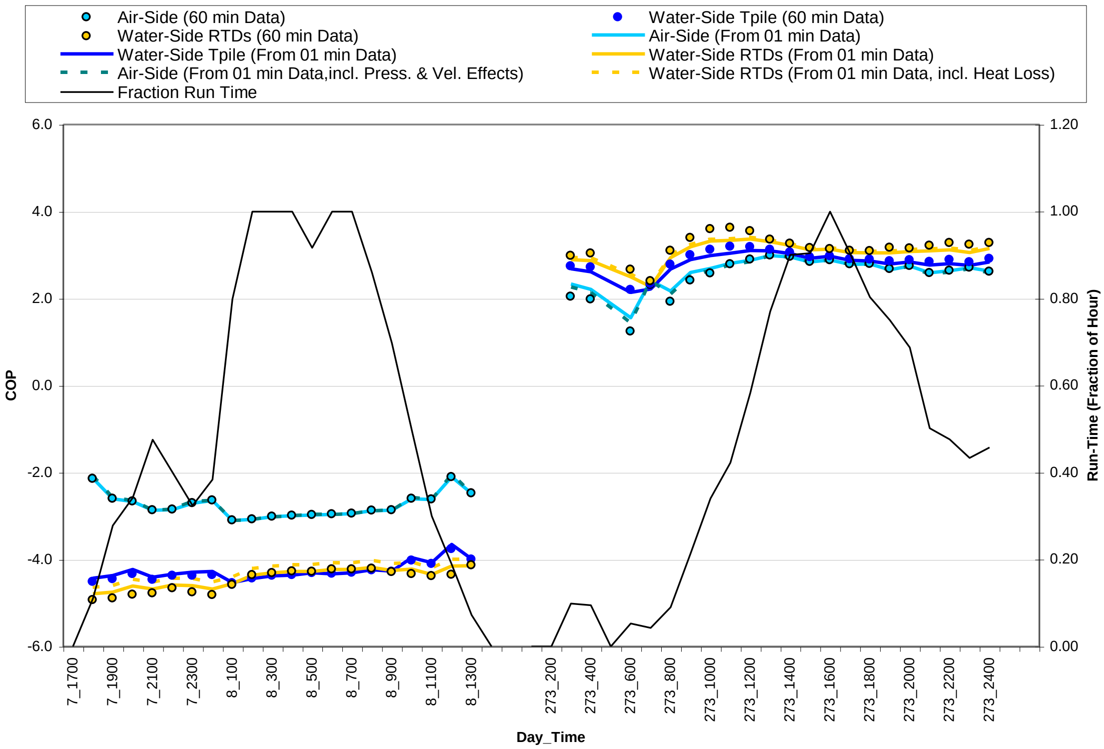

Fig. 2 A period of heating (left-hand half of graph) and of cooling. Solid lines represent 60-minute data derived from 1-minute data. Circles represent 60-minute data calculated within datalogger program. Dashed lines represent data with heat loss, pressure and velocity effects otherwise ignored.