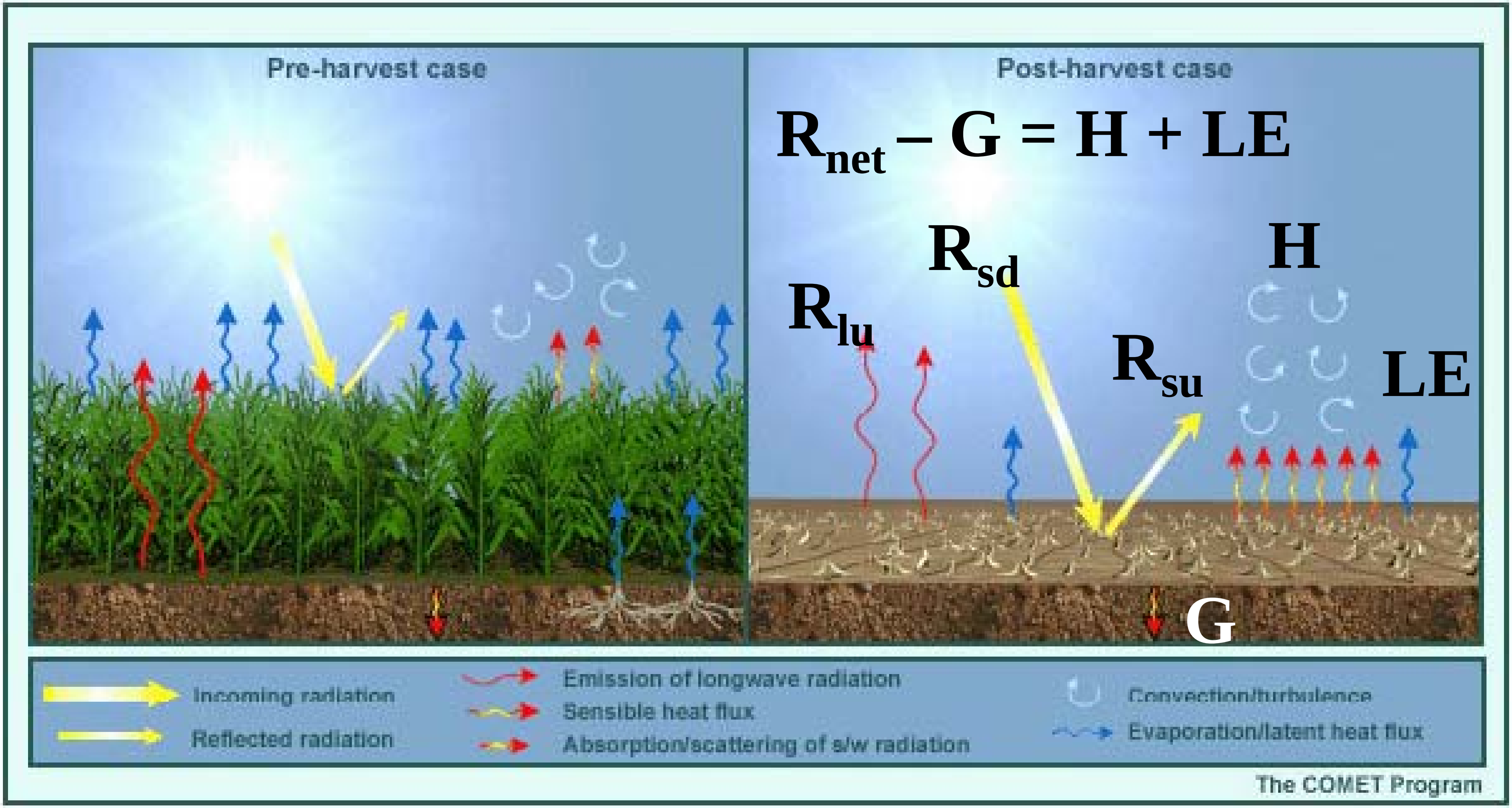
Soil Heat Flux

Conduction

Energy Balance



What is soil?

Soil Thermal Properties

TABLE 8.2. Thermal properties of typical soil materials.

Material	Density ($Mg\ m^{-3}$)	Specific Heat ($J\ g^{-1}\ K^{-1}$)	Thermal Conductivity ($W\ m^{-1}\ K^{-1}$)	Volumetric heat capacity ($MJ\ m^{-3}\ K^{-1}$)
Soil minerals	2.65	0.87	2.5	2.31
Granite	2.64	0.82	3.0	2.16
Quartz	2.66	0.80	8.8	2.13
Glass	2.71	0.84	0.8	2.28
Organic matter	1.30	1.92	0.25	2.50
Water	1.00	4.18	$0.56 + 0.0018T$	4.18
Ice	0.92	$2.1 + 0.0073T$	$2.22 - 0.011T$	$1.93 + .0067T$
Air (101 kPa)	$(1.29 - 0.0041T) \times 10^{-3}$	1.01	$0.024 + 0.00007T$	$(1.3 - 0.0041T) \times 10^{-3}$

(Campbell and Norman, 1998)

Soil Specific Heat Capacity

$$\rho_s c_s = \phi_m \rho_m c_m + \theta \rho_w c_w + \phi_o \rho_o c_o$$

θ **is volumetric water content**

ϕ_m **is volume fraction of minerals**

ϕ_o **is volume fraction of organic material**

ρ_s **is (wet) bulk density of soil (Mg m^{-3})**

ρ_m **is density of minerals (Mg m^{-3})**

ρ_w **is density of water (Mg m^{-3})**

ρ_o **is density of organic material (Mg m^{-3})**

c_s **is specific heat of soil (J g^{-1} K^{-1})**

c_m **is specific heat minerals (J g^{-1} K^{-1})**

c_w **is specific heat of water (J g^{-1} K^{-1})**

c_o **is specific heat of organic material (J g^{-1} K^{-1})**

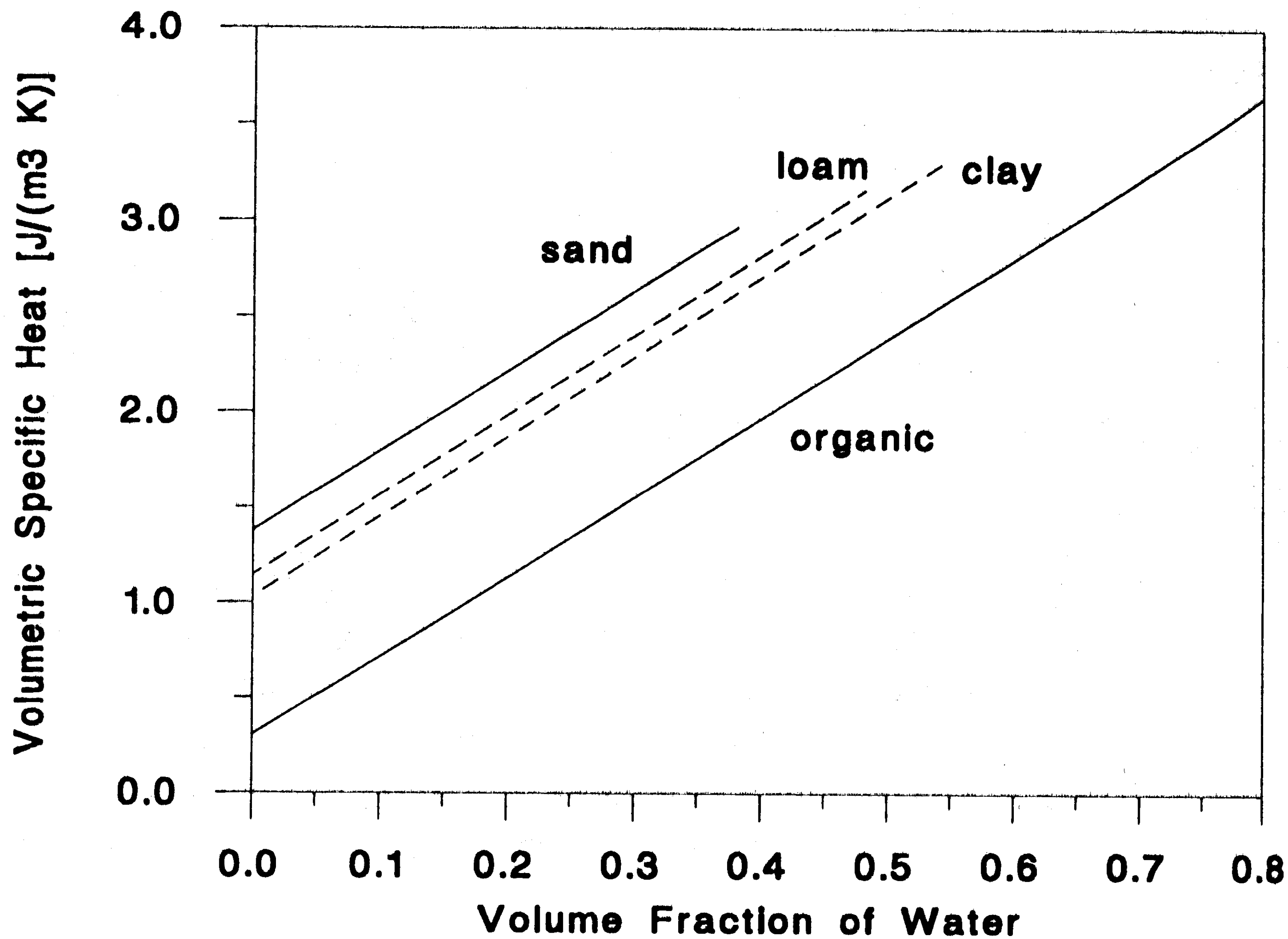


FIGURE 8.2. Volumetric heat capacity of organic and mineral soils. Differences are mainly due to differences in soil bulk density.

Note: dimension vertical axis is MJ/(m^3 K) **(Campbell and Norman, 1998)**

Soil Conductivity

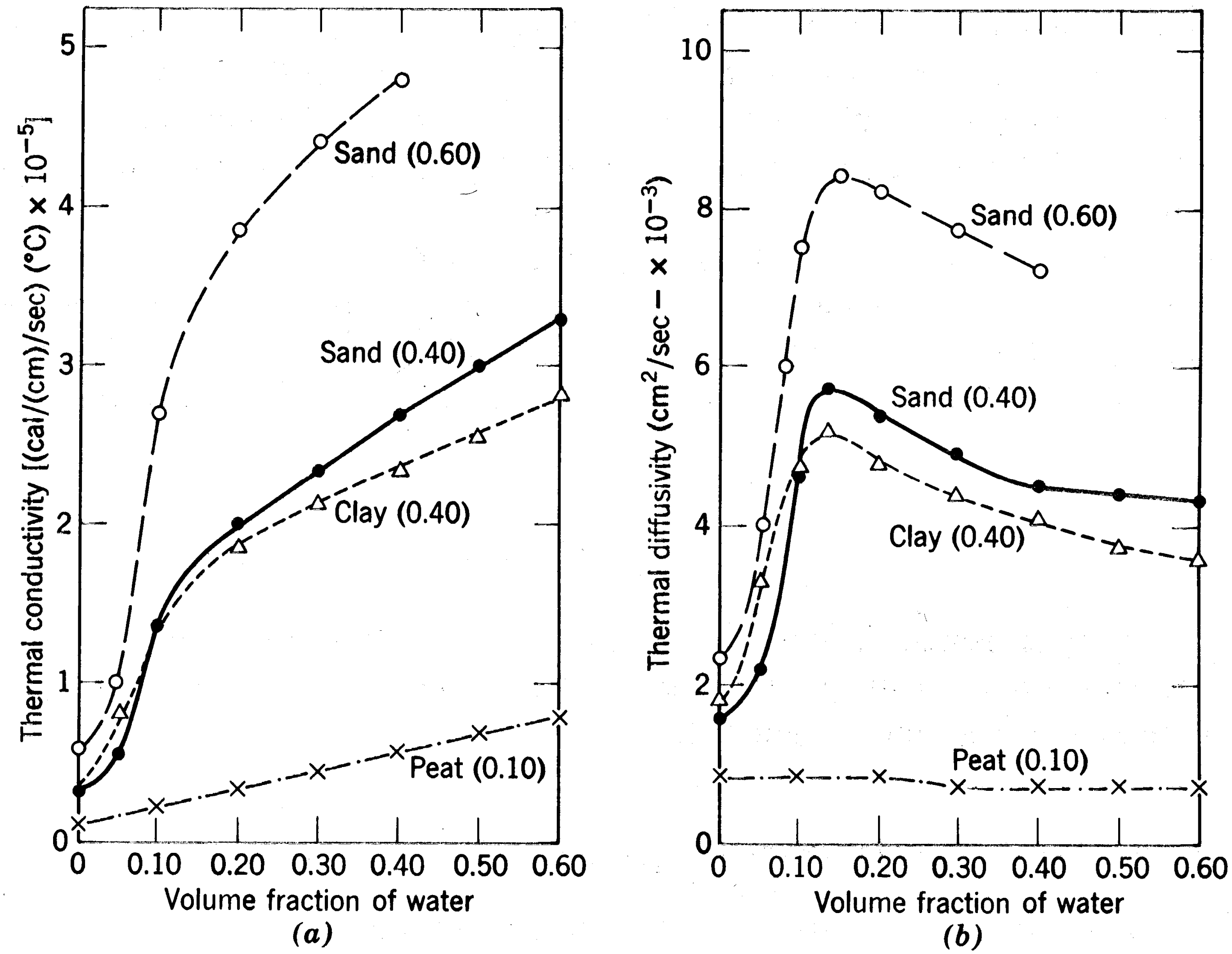


Figure 5.11 Soil thermal conductivity (*a*) and thermal diffusivity (*b*) as a function of water content for various soil types. Numbers refer to ~~porosity~~. (After van Duin, 1963.)

1 - POROSITY (Jury et al., 1991)

How would you calculate Soil Heat Flux?

$$G = -k_{Tsoil} \frac{\partial T}{\partial z}$$

G is soil heat flux (W m^{-2})
k_{Tsoil} is thermal conductivity (W m^{-1} K^{-1})
T is temperature (K)

$$G = -k_{Tsoil} \frac{\partial T}{\partial z}$$

Combined with soil heat flux divergence / soil heat storage equation:

$$\rho_s c_s \frac{\partial T}{\partial t} = -\frac{\partial G}{\partial z}$$

Heat equation:

$$\frac{\partial T}{\partial t} = D_{Tsoil} \frac{\partial^2 T}{\partial z^2}$$

$$D_{Tsoil} = \frac{k_{Tsoil}}{\rho_s c_s}$$

$$\frac{\partial T}{\partial t} = D_{Tsoil} \frac{\partial^2 T}{\partial z^2}$$

$$T(0,t) = T_{avg} + A(0)\sin(\omega(t - t_o))$$

$$T(z,t) = T_{avg} + A(0)\exp(-z/D)\sin[\omega(t - t_o) - z/D]$$

A(0) is amplitude of soil surface temperature

t_o is a phase shift that depends on whether t is local time

D is the damping depth (m)

ω is the angular frequency

$$D = \sqrt{\frac{2D_{Tsoil}}{\omega}}$$

$$\omega_{diurnal} = \frac{2\pi}{24 \times 3600} = 7.3 \times 10^{-5}\, s^{-1}$$

$$\omega_{annual} = \frac{2\pi}{365 \times 24 \times 3600} = 2 \times 10^{-7}\, s^{-1}$$

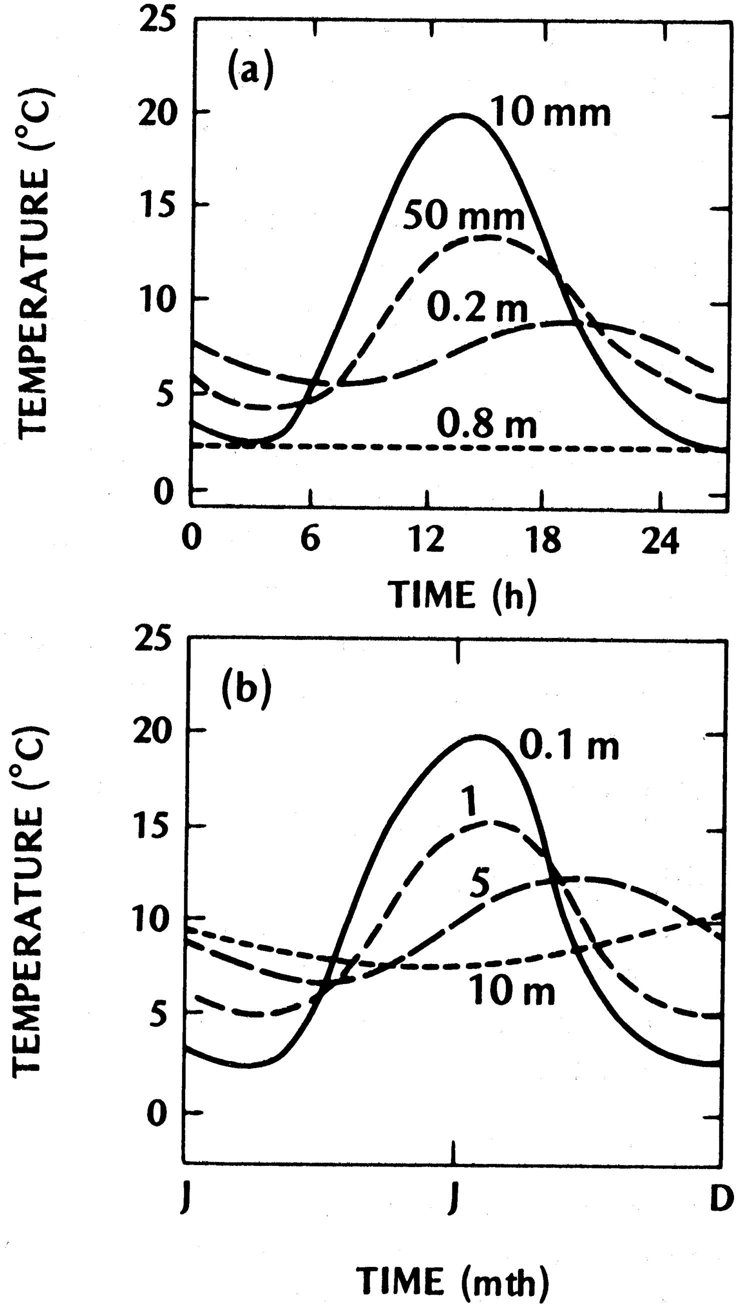


Figure 2.6 Generalized cycles of soil temperature at different depths for (a) daily and (b) annual periods.

(Oke, 1987)

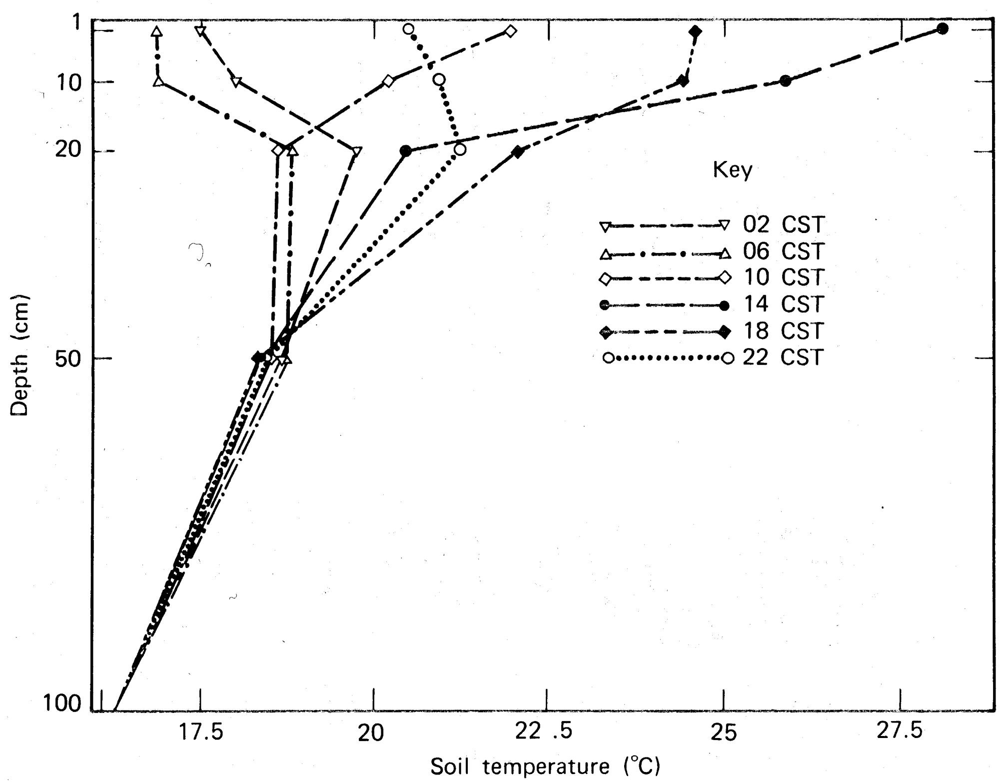


Figure 2.3. Vertical temperature profiles in soil during the course of a typica summer day at Argonne, Illinois, July 27, 1955 (after Carson and Moses, 1963)

(Rosenberg, 1974)

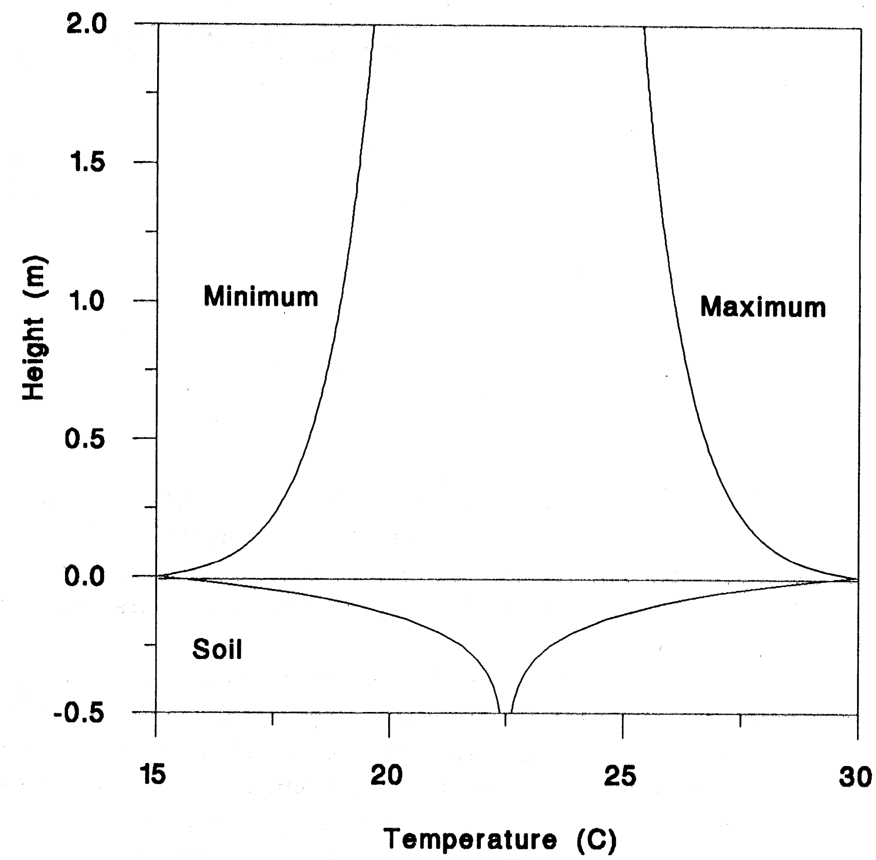


FIGURE 2.1. Hypothetical profiles of maximum and minimum temperature above and below soil surface on a clear, calm day.

(Campbell and Norman, 1998)

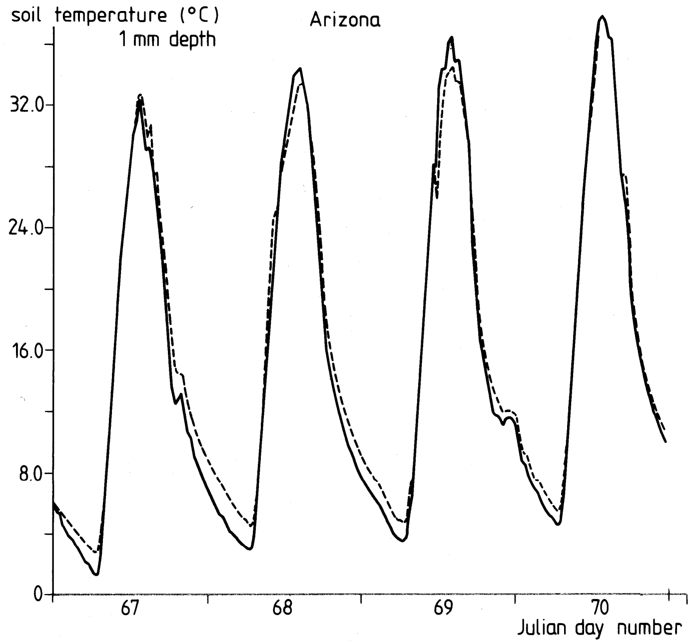


Figure 5.35 Measured (———) and simulated (----) 'surface' temperature, ARIZONA.

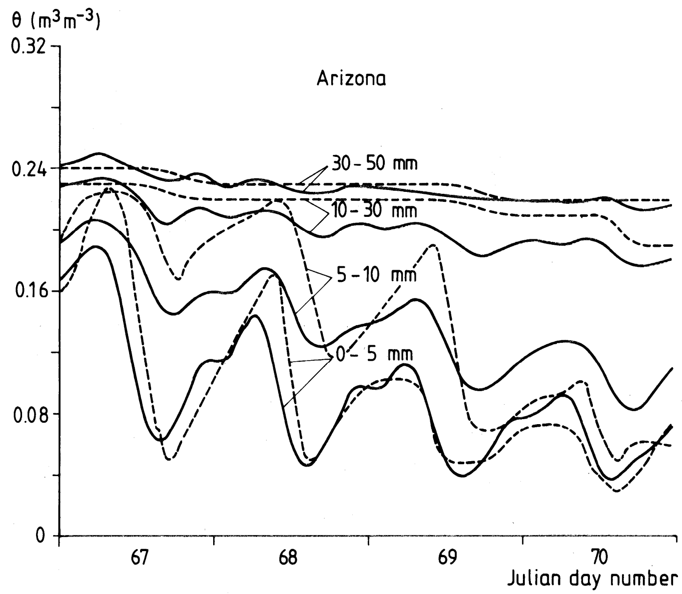


Figure 5.36 Measured (———) and simulated (----) soil moisture contents for various depths intervals, ARIZONA.

(Ten Berge, 1986)

Simple Rules for G

G for day and ten-day periods; relatively small

$$G \approx 0$$

G for hourly or shorter periods;

daytime

$$G = 0.1 R_n$$

nighttime

$$G = 0.5 R_n$$

Measuring G

Natural Soil: Heat flux plates and soil temperature measurements can be used together

$$G = G_{heat\ plate\ at\, 0.08\, m} + C_s \int_0^{0.08} \frac{\partial T_s}{\partial t} dz$$

Buildings: ??