Supplementary file

An urban module coupled with the Variable Infiltration Capacity model to improve hydrothermal simulations in urban systems

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1 Radiation calculation

VIC-urban calculates the radiation as a function of the urban geometry and sky-view factor for each surface within the urban canyon (i.e., ground and walls). It first calculates the incoming direct shortwave radiation of each surface based on the urban geometry and location (Section 1.2). Then it calculates the absorbed and outgoing radiation values according to the sky-view factor in solution of infinite radiation reflections between the ground, walls, and sky (Section 1.3 and 1.4). It worth noting that the radiations of the roof are calculated similar to that of bare soil, as the model assumes no obstruction of the roof (Section 1.1).

1.1 Radiations of the roof surface

For the roof surface, the radiative process is the same as that for bare soil. The net radiation can be calculated as:

$$R_{net,i} = (1-\alpha_i)(S_{in}^{dir} + S_{in}^{diff}) + \varepsilon_i (L_{in} - \sigma T_i^4), \tag{3}$$

where S_{in}^{dir} [W m^{-2}] is the incoming direct shortwave radiation, S_{in}^{diff} [W m^{-2}] is the diffuse shortwave radiation from the sky, L_{in} [W m^{-2}] is the incoming longwave radiation, $\sigma = 5.67*10^{-8}$ [W m^{-2} K^{-4}] is the Stefan-Boltzmann constant, and α_i [-], ε_i [-], and T_i [K] are the surface albedo, emissivity, and temperature of roof surface i, respectively. $(1-\alpha_i)(S_{in}^{dir} + S_{in}^{diff})$ is the absorbed shortwave radiation $(S_{net,i})$, and $\varepsilon_i (L_{in} - \sigma T_i^4)$ is the absorbed longwave radiation $(L_{net,i})$.

1.2 Incoming direct shortwave radiation in urban canyon

For the urban canyon, the VIC-urban model first calculates the input direct shortwave radiation of each urban surface with a function of the solar position and shading area. The shading areas of the ground X_{shadow} and wall Y_{shadow} are calculated as:

$$X_{shadow} = 1 - \max(1 - h_{can} \tan\theta_z |\sin\theta_a|, 0), \tag{4}$$

$$Y_{shadow} = \max(h_{can} - 1/(\tan\theta_z |\sin\theta_a|), 0) h_{can}^{-1}, \tag{5}$$

where h_{can} [-] is the canyon height normalized by the canyon width (H_{can}/W_{can}), θ_z [rad] is the solar zenith angle, and θ_a [rad] is the difference between the solar azimuth angle and the canyon orientation. The incoming direct solar radiations of the ground $S_{in,g}^{dir}$ and the sunlit wall $S_{in,wsun}^{dir}$ [W m^{-2}] can be calculated as:

$$S_{in,g}^{dir} = S_{in}^{dir}(1 - X_{shadow}), \quad (6)$$

$$S_{in,wsun}^{dir} = S_{in}^{dir}(1 - Y_{shadow}), \quad (7)$$

The shaded wall $S_{in,wshd}^{dir}$ does not receive any direct solar radiation, and is set to 0 [W m^{-2}].

1.3 Absorbed shortwave radiation in urban canyon

The VIC-urban model calculates the outgoing and absorbed shortwave radiation based on the infinite radiation reflection principle (Sparrow and Cess 1970). For each urban surface i in urban canyon, the incoming shortwave radiation $\mathrm{A_i}$ [W m^{-2}] is the sum of the incoming direct shortwave radiation originating from the sun, and the incoming diffuse shortwave radiation originating from the sky and surrounding surfaces. The outgoing shortwave B_i is the reflected incoming shortwave radiation, and can be calculated by Equation (8)-(10), specifically for the ground B_g, sunlit wall B_{wsun} and shaded wall B_{wshd} [W m^{-2}]:

$$B_g = \alpha_g(S_{in,g}^{dir} + F_{gs}S_{in,sky}^{diff} + F_{gw}B_{wsun} + F_{gw}B_{wshd}), \quad (8)$$

$$B_{wsun} = \alpha_w(S_{in,w}^{dir} + F_{ws}S_{in,sky}^{diff} + F_{wg}B_g + F_{ww}B_{wshd}), \quad (9)$$

$$B_{wshd} = \alpha_w(F_{sw}S_{in,sky}^{diff} + F_{wg}B_g + F_{ww}B_{wsun}), \quad (10)$$

where F_{ij} [-] is the view factor from surface i to j (Section 2.3.5). The subscripts *g, s, w, wsun*, and *wshd* denote the ground, sky, wall, sunlit wall, and shaded wall, respectively. Rearranging these equation yields the following:

$$B_g - \alpha_g(F_{gw}B_{wsun} + F_{gw}B_{wshd}) = \alpha_g(S_{in,g}^{dir} + F_{gs}S_{in,sky}^{diff}), \quad (11)$$

$$B_{wsun} - \alpha_w(F_{wg}B_g + F_{ww}B_{wshd}) = \alpha_w(S_{in,w}^{dir} + F_{ws}S_{in,sky}^{diff}), \quad (12)$$

$$B_{wshd} - \alpha_w (F_{wg} B_g + F_{ww} B_{wsun}) = \alpha_w F_{ws} S_{in,sky}^{diff}, \tag{13}$$

The system of Equations (11) to (13) can be written in matrix notation as:

$$T_{ij} B_i = C_i, \tag{14}$$

where:

$$C_i = \begin{bmatrix} \alpha_g (S_{in,g}^{dir} + F_{gs} S_{in,sky}^{diff}) \\ \alpha_w (S_{in,w}^{dir} + F_{ws} S_{in,sky}^{diff}) \\ \alpha_w F_{ws} S_{in,sky}^{diff} \end{bmatrix}, \tag{15}$$

$$B_i = \begin{bmatrix} B_g \\ B_{wsun} \\ B_{wshd} \end{bmatrix}, \tag{16}$$

$$T_{ij} = \begin{bmatrix} 1 & -\alpha_g F_{gw} & -\alpha_g F_{gw} \\ -\alpha_w F_{wg} & 1 & -\alpha_w F_{ww} \\ -\alpha_w F_{wg} & -\alpha_w F_{ww} & 1 \end{bmatrix}, \tag{17}$$

Subsequently, B_i is calculated with matrix inversion as:

$$B_i = [T_{ij}]^{-1} C_i, \tag{18}$$

The incoming shortwave radiation A_i and net absorbed shortwave radiation Q_i [W m^{-2}] of the ground and walls are calculated based on B_i :

$$\mathrm{A}_i = B_i / \alpha_i, \tag{19}$$

$$Q_i = \mathrm{A}_i - B_i, \tag{20}$$

1.4 Absorbed longwave radiation in urban canyon

The outgoing and absorbed longwave radiation of each urban surface is also calculated by the infinite radiation reflection method. For each urban surface i, the incoming longwave radiation A_i [W m^{-2}] is the sum of the longwave radiation from the sky and surrounding surfaces. The outgoing shortwave B_i is the sum of the emitted ($\varepsilon_i \sigma T_i^4$) and reflected incoming longwave radiation values:

$$B_g = \varepsilon_g \sigma T_g^4 + (1-\varepsilon_g)(F_{gs} L_{in} + F_{gw} B_{wsun} + F_{gw} B_{wshd}), \tag{21}$$

$$B_{wsun} = \varepsilon_w \sigma T_{wsun}^4 + (1-\varepsilon_w)(F_{ws} L_{in} + F_{wg} B_g + F_{ww} B_{wshd}), \tag{22}$$

$$B_{wshd} = \varepsilon_w \sigma T_{wshd}^4 + (1-\varepsilon_w)(F_{ws} L_{in} + F_{wg} B_g + F_{ww} B_{wsun}), \tag{23}$$

C_i and T_{ij} can be expressed as:

$$C_i = \begin{bmatrix} \varepsilon_g \sigma T_g^4 + (1-\varepsilon_g) F_{gs} L_{in} \\ \varepsilon_w \sigma T_{wsun}^4 + (1-\varepsilon_w) F_{ws} L_{in} \\ \varepsilon_w \sigma T_{wshd}^4 + (1-\varepsilon_w) F_{ws} L_{in} \end{bmatrix}, \tag{24}$$

$$T_{ij} = \begin{bmatrix} 1 & -(1-\varepsilon_g) F_{gw} & -(1-\varepsilon_g) F_{gw} \\ -(1-\varepsilon_w) F_{wg} & 1 & -(1-\varepsilon_w) F_{ww} \\ -(1-\varepsilon_w) F_{wg} & -(1-\varepsilon_w) F_{ww} & 1 \end{bmatrix}, \tag{25}$$

The incoming shortwave radiation $\mathrm{A_i}$ [W m^{-2}] can be calculated as:

$$\mathrm{A}_i = \left(B_i - \varepsilon_i \sigma T_i^4 \right) / (1-\varepsilon_i), \tag{26}$$

1.5 View factor calculation

The view factor is used to identify the radiation interaction among urban surfaces. The view factor can be calculated by analytically derived equations (Oleson et al. 2008; Ryu et al. 2011; Sparrow and Cess 1970):

$$F_{gs} = F_{sg} = \sqrt{1 + (\frac{h_{can}}{w_{can}})^2} - \frac{h_{can}}{w_{can}}, \tag{27}$$

$$F_{gw} = 0.5 \times (1 - F_{gs}), \tag{28}$$

$$F_{ww} = \sqrt{1 + (\frac{w_{can}}{h_{can}})^2} - \frac{w_{can}}{h_{can}}, \tag{29}$$

$$F_{wg} = F_{ws} = 0.5 \times (1 - F_{ww}), \tag{30}$$

$$F_{sw} = \frac{h_{can}}{w_{can}} F_{ws}, \tag{31}$$

where the $w_{can} = 1$ [-] is the canyon width normalized by the canyon width (W_{can} / W_{can}), and h_{can} [-] is the canyon height normalized by the canyon width (H_{can} / W_{can}). The subscripts s, g, and w denote the sky, ground, and wall, respectively, and F_{ij} [-] is the view factor from surface i to j.

2 Turbulent fluxes

In the VIC-urban model, the total turbulent fluxes in urban areas are calculated as the area-weighted average of the roof and urban canyon (Equation 32), and the turbulent fluxes in urban canyon are calculated by Equation (33). The calculation of the turbulent fluxes of individual surfaces is shown in Section 2.4.1 and 2.4.2.

$$X_{urban} = f_{roof} X_{roof} + f_{canyon} X_{canyon}, \tag{32}$$

$$X_{canyon} = w_{can} X_{ground} + h_{can} (X_{wsun} + X_{wshd}) + Q_{can}, \tag{33}$$

where X [W m^{-2}] is the turbulent flux (i.e., latent or sensible heat), f_{roof} and f_{canyon} [-] are the roof and canyon fractions, respectively, and Q_{can} [W m^{-2}] is the anthropogenic heat input.

2.1 Sensible and latent heat

The turbulent fluxes between urban surface i and the surrounding air mass, including sensible heat H_i and latent heat LE_i fluxes, can be calculated according to Shuttleworth (2012):

$$H_i = \rho_a C_p \frac{T_i - T_a}{r}, \tag{34}$$

$$\lambda E_i = \lambda \rho_a \frac{q_{sat,T_i} - q_a}{r}, \tag{35}$$

where ρ_a [kg m^{-3}] is the air density, C_p [J kg^{-1} K^{-1}] is the specific heat capacity of air at a constant pressure, T_i and T_a [K] are the temperature of surface i and air, respectively, r [s m^{-1}] is the sum of resistance values from surface i to the air, λ [J kg^{-1}] is the latent heat of vaporization, q_{sat,T_i} [-] is the saturation specific humidity at temperature T_i, and q_a [-] is the specific humidity of air.

The turbulent fluxes of the ground and roof can be calculated based on Equations (34) and (35), respectively, the r [s m^{-1}] of the ground is the aerodynamic resistance from ground to canyon reference height Z_{calc} [m] (i.e., the sum of the urban canopy displacement height $h_{d,can}$ [m] and roughness length $z_{om,can}$ [m], refer to Section 2.4.5), and r [s m^{-1}] of the roof is the aerodynamic resistance from roof to atmospheric reference height Z_{atm} [m]. For walls, the model separates the wall into two levers when it is higher than 4 m. The height of the first layer is $min(4, H_{can})$, that of the second layer is $max(H_{can} - 4, 0)$, and the latent heat of the wall is assumed to equal 0. r [s m^{-1}] of the wall includes vertical aerodynamic resistance from the mid-height of the layers to Z_{calc} and the horizontal aerodynamic resistance at the mid-height of layers (Section 2.4.3). The turbulent heat from the walls to the canyon air can be calculated as the area-weighted average of the two layers (H_{w1} and H_{w2}):

$$H_w = \frac{min(4, H_{can})}{H_{can}} H_{w1} + \frac{max(H_{can} - 4, 0)}{H_{can}} H_{w2} \tag{36}$$

2.2 Conductive heat flux

VIC-urban considers two physical layers for calculating the conductive heat flux into and out of the building envelope (wall and roof) and ground. The conductive heat fluxes of the two layers (G_1 and G_2) are calculated based on the temperature of layer 2 T_{l2} and the prognostic surface temperature T_i:

$$G_1(t) = -\lambda_1 \frac{(T_{int}(t) - T_i(t))}{z_1}, \tag{37}$$

$$G_2(t) = -\lambda_2 \frac{(T_{l2}(t) - T_{int}(t))}{z_2}, \tag{38}$$

where λ_1 and λ_2 [J K^{-1} m^{-1} s^{-1}] are the heat conductivities of layers 1 and 2, respectively, and z_1 and z_2 are the thicknesses of layer 1 and 2, respectively. T_{int} is the internal temperature between layers 1 and 2, and can be calculated based on Equation (37) and (38). T_{l2} is the temperature of layer 2, which is the temperature of the interior building for the roof and walls, and is the temperature of the third layer of soil for the ground.

2.3 Aerodynamic resistances

The vertical aerodynamic resistance r [s m^{-1}] above the canyon (canyon and roof) can be calculated based on a simplified parametrization (Mascart et al. 1995). The aerodynamic resistance of the roof is calculated from the roof height H_{can} to the atmospheric reference height Z_{atm}, and the aerodynamic resistance of the canyon is calculated from the canyon reference height Z_{calc} to Z_{atm}:

$$r_{ah} = \frac{1}{C_n F_h(Ri_B) u_a}, \tag{39}$$

where the u_a [m s^{-1}] is the wind speed at Z_{atm} (Section 2.4.4), C_n and $F_h(Ri_B)$ are the neutral transport coefficient and empirical function accounting for the atmospheric stability, respectively, and the two are calculated as:

$$C_n = \frac{k^2}{\ln[(z_{atm}-d)/z_{om}]^2}, \tag{40}$$

$$F_h(Ri_B) = \begin{cases} \left[1 - \frac{15Ri_B}{1+ch\sqrt{|Ri_B|}}\right]\left[\frac{\ln[(z_{atm}-d)/z_{om}]}{\ln[(z_{atm}-d)/z_{oh}]}\right], if\,(Ri_B \le 0) \\ \left[\frac{1}{1+15Ri_B\sqrt{1+5Ri_B}}\right]\left[\frac{\ln[(z_{atm}-d)/z_{om}]}{\ln[(z_{atm}-d)/z_{oh}]}\right], if\,(Ri_B > 0) \end{cases}, \tag{41}$$

where k is the von Karman constant, d [m] is the zero-plane displacement, and z_{om} and z_{oh} [m] are the roughness lengths of heat and momentum, respectively (Section 2.4.5). ch and Ri_B are calculated as Equation (42) and (45), respectively. The Ri_B is the bulk Richardson number, which describes the boundary layer stability condition ($Ri_B > 0$ indicates stable conditions, and $Ri_B \le 0$ indicates unstable conditions):

$$ch = 15ch^{''} C_n[(z_{atm}-d)/z_{oh}]^{ph}\left[\frac{\ln[(z_{atm}-d)/z_{om}]}{\ln[(z_{atm}-d)/z_{oh}]}\right], \tag{42}$$

$$ch^{''} = -0.0781\mu^3 + 0.5360\mu^2 + 4.3431\mu + 3.2165, \tag{43}$$

$$ph = -0.0026\mu^3 + 0.0327\mu^2 - 0.1571\mu + 0.5802, \tag{44}$$

$$Ri_B = f^2 \frac{g(\theta_a - \theta_s)(z_{atm}-d)}{0.5(\theta_a + \theta_s)u_a^2}, \tag{45}$$

$$f^2 = [1 - z_{om}/(z_{atm}-d)^2]/[1 - z_{oh}/(z_{atm}-d)], \tag{46}$$

$$\theta_i = T_i(P_a/100000)^{R_d/C_p} \tag{47}$$

where $\mu = \ln(z_{om} / z_{oh})$, $R_d = 287.05$ [J kg^{-1} K^{-1}] is the water vapor gas constant, C_p [J kg^{-1} K^{-1}] is the specific heat capacity of air at a constant pressure, θ_a and θ_s [K] are the potential air and surface temperatures, respectively. The potential temperature is used here to consider influence of humidity on the boundary layer stability, as the potential temperature neglects the density stratification due to humidity gradients (Meili et al. 2020).

The vertical aerodynamic resistance r [s m^{-1}] in the urban canyon, i.e., ground and walls, is calculated similarly to the vegetation under-canopy resistance, reported by Mahat et al. (2013) and Fatichi et al. (2012b). The vertical aerodynamic resistance of the ground is calculated from the ground roughness length $z_{om,g}$ to the canyon reference height Z_{calc}, and the vertical aerodynamic resistance of the walls is calculated from the mid-height of the layers to Z_{calc}:

$$r_{ah} = \frac{H_{can} e^{\hat{\beta}}}{\hat{\beta} K_{H_{can}}} \left(e^{-\hat{\beta}\frac{Z_{can,ref}}{H_{can}}} - e^{-\hat{\beta}\frac{Z_{calc}}{H_{can}}}\right) + \frac{1}{k^2 u_{Z_{can,ref}}} \ln\left(\frac{Z_{can,ref}}{z_{om,g}}\right)^2, \tag{48}$$

$$\hat{\beta} = \frac{\ln(u_{atm} / u_{H_{can}})}{Z_{atm} / H_{can} - 1}, \tag{49}$$

$$K_{H_{can}} = k^2 u_{atm} \frac{H_{can} - h_{d,can}}{\ln((Z_{atm} - h_{d,can}) / z_{om,can})}, \tag{50}$$

$$u_{Z_{can,ref}} = u_{H_{can}} \exp(-\hat{\beta}(1 - Z_{can,ref} / H_{can})), \tag{51}$$

where H_{can} [m] is the canyon height, $\hat{\beta}$ is the attenuation coefficient of the exponential wind profile (Section 2.4.4), $K_{H_{can}}$ the eddy diffusion coefficient at the canyon height, $Z_{can,ref}$ [m] the height close to the ground where exponential wind profile changes to a logarithmic wind profile, and is assumed as 1.5 m, $u_{Z_{can,ref}}$ [m s^{-1}] the wind speed at $Z_{can,ref}$, $h_{d,can}$ [m] is the urban canopy displacement height, $z_{om,can}$ [m] is the urban canopy roughness length, and $z_{om,g}$ [m] is the ground roughness length. The under-canopy resistance depends on the turbulence and stability of the roughness sublayer, and is adjusted based on the atmospheric stability:

$$r_{ah} = \begin{cases} \dfrac{r_{ah}}{(1-5Ri)^{3/4}}, if\,(Ri \le 0) \\ \dfrac{r_{ah}}{(1-5Ri)^{2}}, if\,(Ri_B > 0) \end{cases}, \tag{52}$$

$$Ri = \frac{g(T_{can} - T_s)Z_{can,ref}}{(0.5(T_{can} + T_s) + 273.15)u_{Z_{can,ref}}^2}, \tag{53}$$

where R_i is the Richardson number in the canyon. T_{can} [K] is the canyon temperature, and T_s [K] is the surface temperature. $h_{d,can}$ [m] the urban canopy displacement height, $z_{om,can}$ [m] the urban canopy roughness length, and $z_{om,g}$ [m] the ground roughness length.

The horizontal aerodynamic resistance [s m^{-1}] from the wall surface to the canyon air is calculated as (Masson 2000; Rowley et al. 1930; Wang et al. 2013):

$$r_w = C_p \rho_a (11.8 + 4.2\sqrt{u(Z_{p,can})^2 + v(Z_{p,can})^2}\,)^{-1}), \tag{54}$$

where $u(Z_{p,can})$ and $v(Z_{p,can})$ [m s^{-1}] are the horizontal and vertical wind speeds at height $Z_{p,can}$ (e.g., the mid-height of the wall layers), ρ_a is the air density, and C_p is specific heat capacity of air.

2.4 Wind profile

The wind speed profile is used for the resistance calculation, it is assumed logarithmic above the urban canopy (H_{can} to Z_{atm}), exponential in the urban canyon ($Z_{can,ref}$ to H_{can}), and logarithmic close to the ground surface (Mahat et al. 2013; Masson 2000):

$$u(z) = \begin{cases} \dfrac{u_{atm}^*}{k}\ln\left(\dfrac{z - h_{d,can}}{z_{om,can}}\right) & Z_{atm} \ge z \ge H_{can}, \\ u_{H_{can}} \exp\left(-\hat{\beta}\left(1 - \dfrac{z}{H_{can}}\right)\right) & H_{can} \ge z \ge Z_{can,ref}, \\ \dfrac{u_{Z_{can,ref}}^*}{k}\ln\left(\dfrac{z}{z_{om,g}}\right) & Z_{can,ref} \ge z, \end{cases} \tag{55}$$

$$\hat{\beta} = \frac{\ln(u_{atm}/u_{H_{can}})}{Z_{atm}/H_{can} - 1}, \tag{56}$$

where $k = 0.4$, is the von Karman constant, $h_{d,can}$ [m] is the urban canopy displacement height, $z_{om,can}$

[m] is the urban canopy roughness length, $z_{om,g}$ [m] is the ground roughness length, u^* is the friction velocity, Z_{atm} [m] is the atmospheric reference height, H_{can} [m] is the canyon height, and $Z_{can,ref}$ [m] the height close to the ground where the exponential wind profile changes to a logarithmic profile, and is assumed as 1.5 m. $\hat{\beta}$ controls the vertical gradient of the wind speed in the urban canyon (Fatichi et al. 2012a, b).

2.5 Roughness length and zero displacement height

The urban canopy displacement height $h_{d,can}$ [m] and roughness length $z_{om,can}$ [m] are calculated as follows:

$$h_{d,can} = (1+\alpha_A^{-\lambda_p}(\lambda_p - 1))H_{can}, \tag{57}$$

$$z_{om,can} = H_{can}(1-\frac{h_{d,can}}{H_{can}})\exp(-(\frac{0.5}{k^2}\beta_A C_{Db}(1-\frac{h_{d,can}}{H_{can}})\frac{W_{roof}}{W_{roof}+W_{can}})^{-0.5}), \tag{58}$$

where $k = 0.4$ [-] is the von Karman constant, $\alpha_A = 4.43$ [-], $\beta_A = 1$ [-], and $C_{Db} = 1.2$ [-]. H_{can} is the urban canyon height, and λ_p is the plan area index of the urban roughness elements, which is calculated as:

$$\lambda_p = \frac{W_{roof}}{W_{roof}+W_{can}}, \tag{59}$$

The momentum roughness lengths of the ground $z_{om,g} = 0.003$ [m], and impervious roof $z_{om,r} = 0.01$ [m], are defined according to Wieringa (1993) and Wang et al. (2013), respectively . The roughness lengths of heat and water vapor $z_{oh,i}$ are assumed to be one tenth of the momentum roughness length.

Supplemental Table 1

Parameters and values for sensitivity analysis.

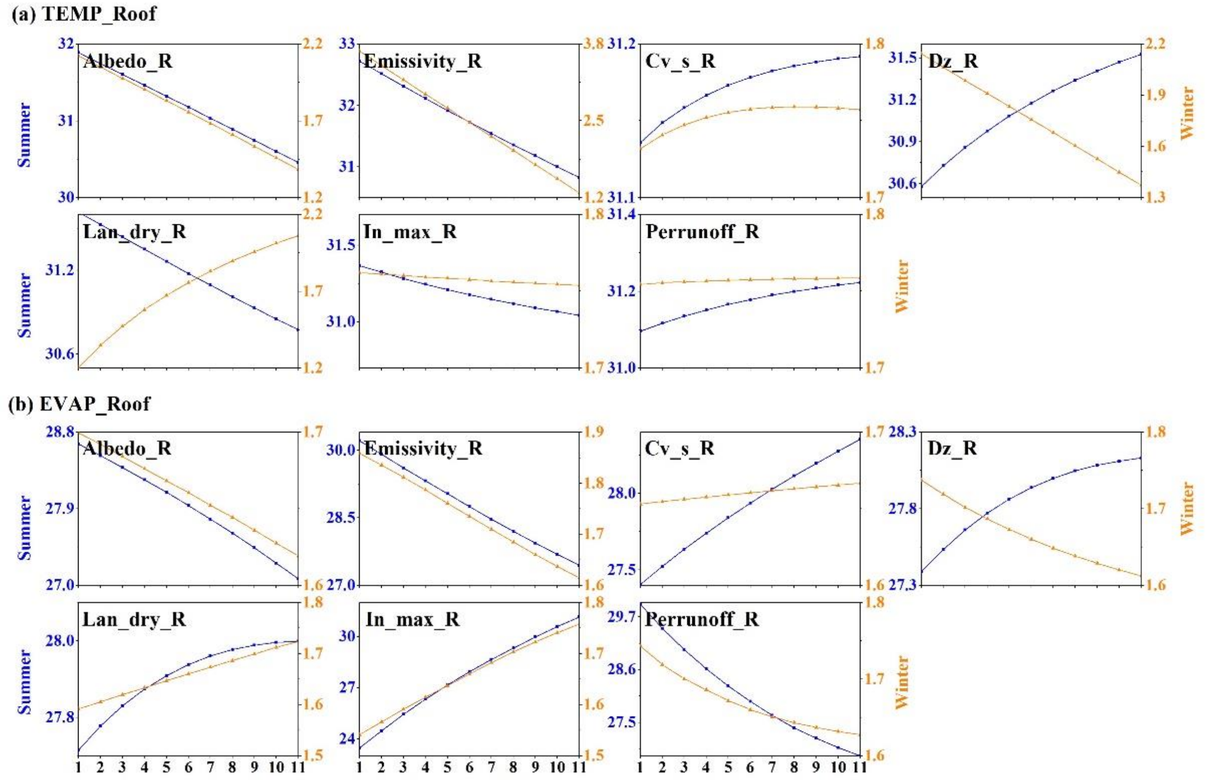
Parameters	70%	76%	82%	88%	94%	Initials	106%	112%	118%	124%	130%
Albedo_R	0.18	0.19	0.21	0.22	0.24	0.25	0.27	0.28	0.30	0.32	0.33
Emissivity_R*	0.45	0.50	0.55	0.60	0.65	0.70	0.76	0.81	0.86	0.91	0.96
Perrunoff_R	0.35	0.38	0.41	0.44	0.47	0.50	0.53	0.56	0.59	0.62	0.65
Lan_dry_R	2.30	2.49	2.69	2.89	3.09	3.28	3.48	3.68	3.87	4.07	4.27
Cv_s_R	662754	719562	776370	833177	889985	946792	1003600	1060407	1117215	1174022	1230830
Dz_R	0.16	0.17	0.19	0.20	0.21	0.23	0.24	0.25	0.27	0.28	0.30
In_max_R	0.35	0.38	0.41	0.44	0.47	0.50	0.53	0.56	0.59	0.62	0.65
Width_canyon	4.67	5.07	5.47	5.87	6.27	6.67	7.07	7.47	7.87	8.27	8.67
Width_roof	3.73	4.05	4.37	4.69	5.01	5.33	5.65	5.97	6.29	6.61	6.93
Albedo_G	0.19	0.21	0.22	0.24	0.25	0.27	0.29	0.30	0.32	0.34	0.35
Emissivity_G*	0.44	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.91	0.96
Albedo_W	0.21	0.23	0.25	0.27	0.28	0.30	0.32	0.34	0.36	0.38	0.39
Emissivity_W*	0.41	0.47	0.52	0.58	0.63	0.68	0.74	0.79	0.85	0.90	0.95
Perrunoff_G*	0.52	0.55	0.58	0.60	0.63	0.68	0.74	0.79	0.85	0.90	0.95
Lan_dry_G	0.33	0.36	0.39	0.42	0.45	0.48	0.51	0.53	0.56	0.59	0.62
Cv_s_G	1113478	1208919	1304360	1399801	1495242	1590683	1686124	1781565	1877006	1972447	2067888
Lan_dry_W	0.71	0.77	0.83	0.90	0.96	1.02	1.08	1.14	1.20	1.26	1.32
Cv_s_W	824686	895374	966061	1036748	1107436	1178123	1248810	1319498	1390185	1460873	1531560
Dz_W	0.21	0.23	0.25	0.26	0.28	0.30	0.32	0.34	0.35	0.37	0.39
In_max_G	0.42	0.46	0.49	0.53	0.56	0.60	0.64	0.67	0.71	0.74	0.78
Kimp_G	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04

* The parameter does not increase proportionally due to the upper limit of the value

Supplemental Table 2

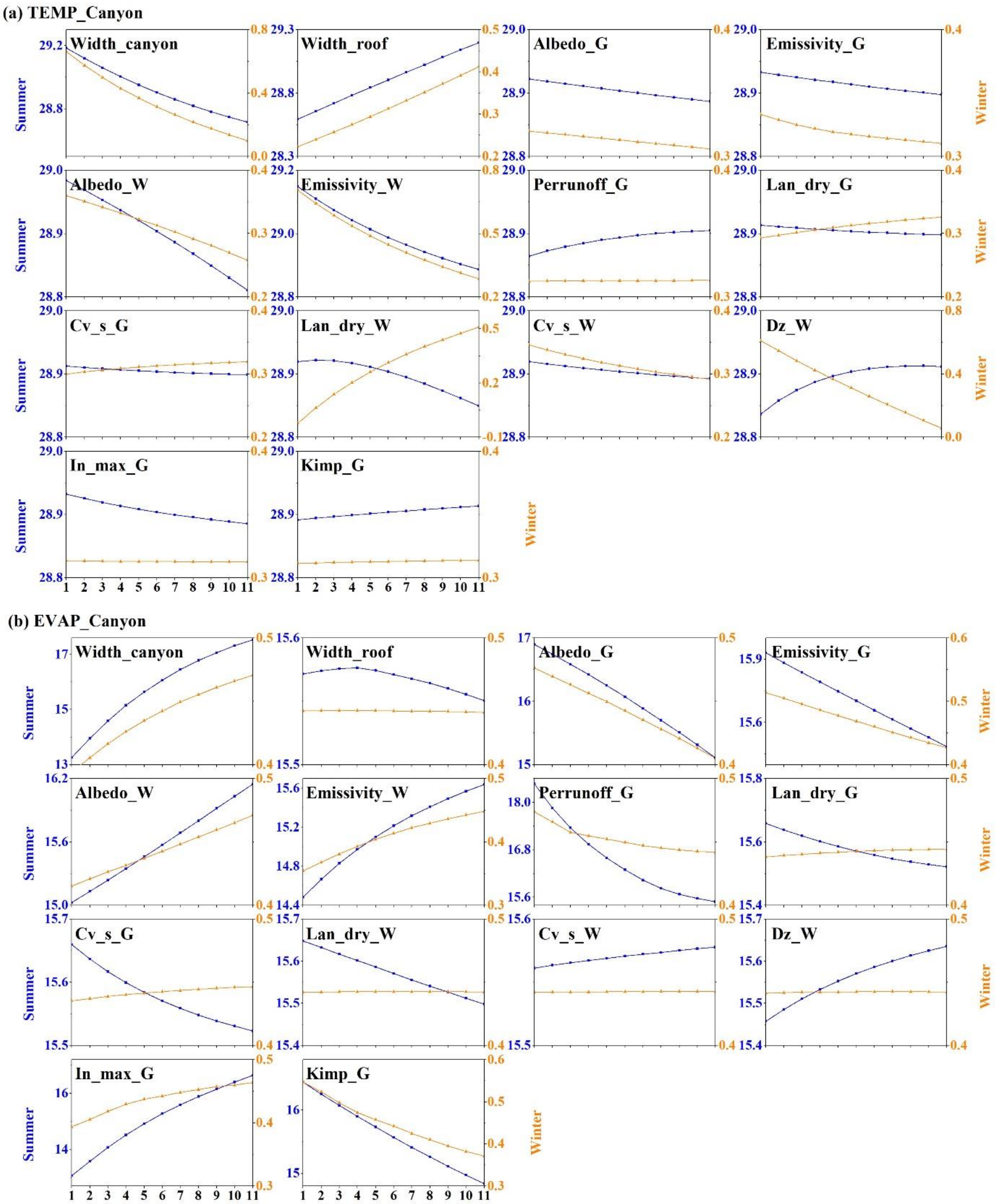
The sensitivity coefficient values of urban environment to parameters change at annual scale, and summer and winter seasons.

Parameters	TEMP-Roof (%)			EVAP-Roof (%)			TEMP-Canyon (%)			EVAP-Canyon (%)		
	A	S	W	**A**	S	W	**A**	S	W	**A**	S	W
Albedo_R	**−10.9**	−7.6	−68.8	**−9.3**	−9.4	−8.0	**0.0**	0.0	0.0	**0.7**	0.5	0.1
Emissivity_R	**−21.0**	−9.9	−154.3	**−16.8**	−15.9	−23.3	**0.0**	0.0	−0.1	**2.0**	1.3	1.5
Perrunoff_R	**0.5**	0.7	0.4	**−18.5**	−18.6	−11.5	**0.1**	0.1	0.1	**−9.5**	−10.5	−3.5
Lan_dry_R	**−0.7**	−4.5	85.6	**2.5**	1.7	13.4	**0.0**	0.0	0.1	**−0.5**	−0.3	−0.8
Cv_s_R	**0.7**	0.3	2.4	**5.0**	5.7	1.4	**0.0**	0.0	0.1	**−0.7**	−0.6	−0.3
Dz_R	**2.0**	5.1	−71.5	**2.8**	4.4	−12.4	**0.0**	0.0	0.0	**−0.3**	−0.4	0.6
In_max_R	**−1.2**	−1.7	−0.8	**41.1**	46.9	21.9	**0.0**	0.0	0.1	**−4.2**	−3.7	−1.1
Width_canyon	-	-	-	-	-	-	**−5.4**	−2.7	−258.1	**44.1**	47.2	29.3
Width_roof	-	-	-	-	-	-	**4.4**	3.5	103.6	**0.1**	−0.2	−0.5
Albedo_G	-	-	-	-	-	-	**−0.3**	−0.2	−7.5	**−19.7**	−19.1	−26.6
Emissivity_G	-	-	-	-	-	-	**−0.3**	−0.2	−11.9	**−7.5**	−4.7	−30.7
Albedo_W	-	-	-	-	-	-	**−1.6**	−1.0	−53.6	**13.5**	12.1	21.2
Emissivity_W	-	-	-	-	-	-	**−3.9**	−1.5	−144.7	**16.0**	12.8	38.8
Perrunoff_G	-	-	-	-	-	-	**0.2**	0.2	0.3	**−28.8**	−29.7	−11.7
Lan_dry_G	-	-	-	-	-	-	**0.1**	−0.1	17.8	**−0.6**	−1.5	2.3
Cv_s_G	-	-	-	-	-	-	**0.0**	−0.1	10.5	**−1.2**	−1.5	4.3
Lan_dry_W	-	-	-	-	-	-	**2.5**	−0.4	336.9	**−1.6**	−1.6	0.1
Cv_s_W	-	-	-	-	-	-	**−0.5**	−0.2	−28.8	**0.3**	0.2	0.3
Dz_W	-	-	-	-	-	-	**−2.6**	0.4	−265.3	**2.0**	1.9	0.3
In_max_G	-	-	-	-	-	-	**−0.2**	−0.3	−0.5	**36.9**	39.1	26.9
Kimp_G	-	-	-	-	-	-	**0.1**	0.1	1.2	**−23.5**	−17.1	−64.3



Supplemental Figure 1

Roof temperature and evaporation changes with parameters changes during the summer and winter seasons.



Supplemental Figure 2

Canyon temperature and evaporation changes with parameter changes during the summer and winter seasons.