General conclusions on accuracy of proposed models:

- Models based solely on ambient temperature perform the worst - too localized for application in other areas or climates while models based on precipitable water or water vapor pressure perform the best

Important note: although several models have been researched including various coefficients and recalibrations, difficult to identify one best model due to variation from geographic location and meteorological conditions

- *(ex// often, "most accurate" model presented in literature is the model that was developed for that region's data)*

Empirical clear sky models (can be based on relative humidity, water vapor pressure, ambient temperature, and / or dew point temperature):

- Out of ~45 unique models, most frequently studied model groups are **Berdahl & Martin (1984)**, **Brunt (1932)**, **Brutsaert (1975)**, and **Prata (1996)**. Other previously popular models such as Idso (1981) and Swinbank (1963) (based on ambient temperature only) are not recommended by most current literature.

**Li et al (2017) analyzed all of these models together and recalibrated coefficients

- Found that after recalibration, all four of these have nearly identical accuracies and show the same relationship in different forms
- Selects Brunt model to use for further developments due to high accuracy and simplicity

Berdahl & Martin (1984) - based on dew-point temperature			
General Formula	$\varepsilon = c_1 + c_2(T_{dp} / 100) + c_3(T_{dp} / 100)^2 + \Delta h + \Delta p$		
Variations	Hourly: $\Delta h = c_4\cos[2\pi t/24 + c_5]$	Pressure / elevation: $\Delta p = c_6(p - 1013)$	In transparency window: $\varepsilon_{in} = 1 - (1-\varepsilon)(c_7{*}\varepsilon + c_8)$
Original Coefficients	$c_1 = 0.711$, $c_2 = 0.56$, $c_3 = 0.73$, $c_4 = 0.013$, $c_5 = 0$, $c_6 = 0.00012$, $c_7 = 1.807$, $c_8 = 1.034$		
Comments	Most used model, including for RadiCool researchers (ex // Zhang et al (2018)), dew point temp data is readily available; hourly and pressure corrections do not always improve the accuracy; seems to be less affected by coefficient calibration		

Brunt (1932) - based on water vapor pressure	
General Formula	$\varepsilon = c_1 + c_2(P_w)^{1/2}$
Variations	Different coefficients proposed for daytime vs nighttime
Original Coefficients	$c_1 = 0.52$, $c_2 = 0.065$ (recalibrated version used by (Li et al papers))
Comments	When water vapor pressure data is not available, it is calculated with Magus expressions; based on literature review, coefficients can vary by 13% depending on calibration; simplest model & considered most accurate by several references

Brutsaert (1975) - based on water vapor pressure and ambient temperature	
General Formula	$\varepsilon = c_1(P_w / T_a)^{C2}$
Variations	none
Original Coefficients	$c_1 = 1.24$, $c_2 = 1/7$
Comments	Able to predict warm sky temperatures well but limited for cold skies; often compared to Brunt model and typically similar in accuracy (likely because both based on water vapor pressure); semi-empirical model obtained from the integration of radiative transfer equation and simplified

Prata (1996) - based on water vapor pressure and ambient temperature	
General Formula	$\varepsilon = 1- (1+w)\exp(-(c_1+c_2w)^{½})$, $w = c_3(P_w / T_a)$
Variations	none
Original Coefficients	$c_1 = 1.2$, $c_2 = 3$, $c_3 = 46.6$
Comments	Able to predict warm sky temperatures well but limited for cold skies; semi-empirical model obtained from the integration of radiative transfer equation and simplified; created to improve upon Brutsaert model and when compared with original coefficients, performs slightly better

[EnergyPlus] Clark and Allen (1978) - based on dew point temperature	
General Formula	$\varepsilon = c_1 + c_2\ln(T_{dp} / 273)$
Variations	none
Original Coefficients	$c_1 = 0.787$, $c_2 = 0.7641$
Comments	According to Dai & Fang et al (2014) , had a higher root mean square error and mean absolute percent error than the models described above

Empirical all sky models / cloud corrections (can include information about cloud cover fractions, cloud types + emittance, cloud base & surface temperature difference):

*All sky models or cloud corrections can be applied to any clear sky model. Different combinations of cloudy and clear sky models may result in different accuracies

Accuracy of all-sky models depend on accuracy, completeness, and availability of cloud coverage data, so it is difficult to determine the best model. Additionally, many references state that the high accuracy of the all-sky models are mainly the result of good clear-sky models and current empirical cloud corrections do not sufficiently explain the effect of clouds on emissivity.

- Several models use temperature, humidity, and cloud base height as estimates, but these do not explicitly describe the physics of the increase in atmospheric emittance

- Common problem among other existing models is that they are based on daytime values and use this average to create a constant emittance for nighttime (irradiance data not available at night)

Popular models: **Martin & Berdahl (1984)** and **Kasten and Czeplak (1980)**

Martin & Berdahl (1984) - based on fractional cloud cover, cloud emittance, and cloud base height	
General Formula	$\varepsilon = \varepsilon_0 + (1-\varepsilon_0)\varepsilon_c\, n \exp(-z_c/8.2)$, $0 \le n \le 1$
Variables	ε_0 = clear sky emittance n = fractional cloud coverage by 'non-transparent' clouds ε_c = cloud emittance z_c = cloud base height
Cloud emittances	Low & medium high: $\varepsilon_c \sim 1$ Cirrus: $\varepsilon_c = 0.74 - 0.084(z_c - 4)$ for $11 > z_c > 4$ km $\varepsilon_c = 0.15$ for $z_c > 11$
Comments	tends to overestimate; fits MODTRAN black cloud predictions; most explicitly reflects overcast physics compared to other models created around this time; cloud temperatures typically not recorded so cloud base height used instead as estimate; cloud type data not always available

Kasten and Czeplak (1980) - based on cloudiness factor (solar irradiation data)	
General Formula	$\varepsilon = \varepsilon_0 + c_1(1-\varepsilon_0)CF$, $CF = (1.4286 * G_{dif} / G_{Glob,H} - 0.3)^{1/2}$; $0 \le CF \le 1$
Variables	ε_0 = clear sky emittance c_1 = 0.8 (original) or 0.9 CF = cloudiness factor; if not in weather data, can be calculated G_{dif} = diffuse radiation on horizon $G_{Glob,\,H}$ = total radiation
Comments	Solar irradiation is zero at night but effect of clouds is still present so average value of daytime is used for nighttime emittance; coefficient changed from 0.8 to 0.9 for more recent papers

[EnergyPlus] Clark and Allen (1978) - based on opaque sky cover	
General Formula	$\varepsilon = \varepsilon_0 C$; $C = 1 + 0.0224n - 0.0035n^2 + 0.00028n^3$
Variables	ε_0 = clear sky emittance n = opaque sky cover; $0 \le n \le 10$
Comments	Authors report estimation of irradiance error as 10 W/m^2; compared to Martin-Berdahl, tends to overestimate and does better in dryer conditions

Li et al (2017) - based on cloud modification factor (solar irradiation data) and relative humidity	
General Formula	$\varepsilon = \varepsilon_0(1-c_1)CF^{c2} + c_3 CF^{c4}\varphi^{c5}$
Variables	ε_0 = clear sky emittance $c_1 = 0.78$, $c_2 = 1$, $c_3 = 0.38$, $c_4 = 0.95$, $c_5 = 0.17$ φ = relative humidity CF = cloud cover fractions
Comments	Most accurate out of Crawford & Duchon, Bilbao & De Miguel, and Alados et al; verified w/ measured data & complex spectral model; mean bias error of -4.94 W / m^2