Mean Radiant Temperature in urban spaces from solar calculations, climate and surface properties – theory and 'Mr.T' software

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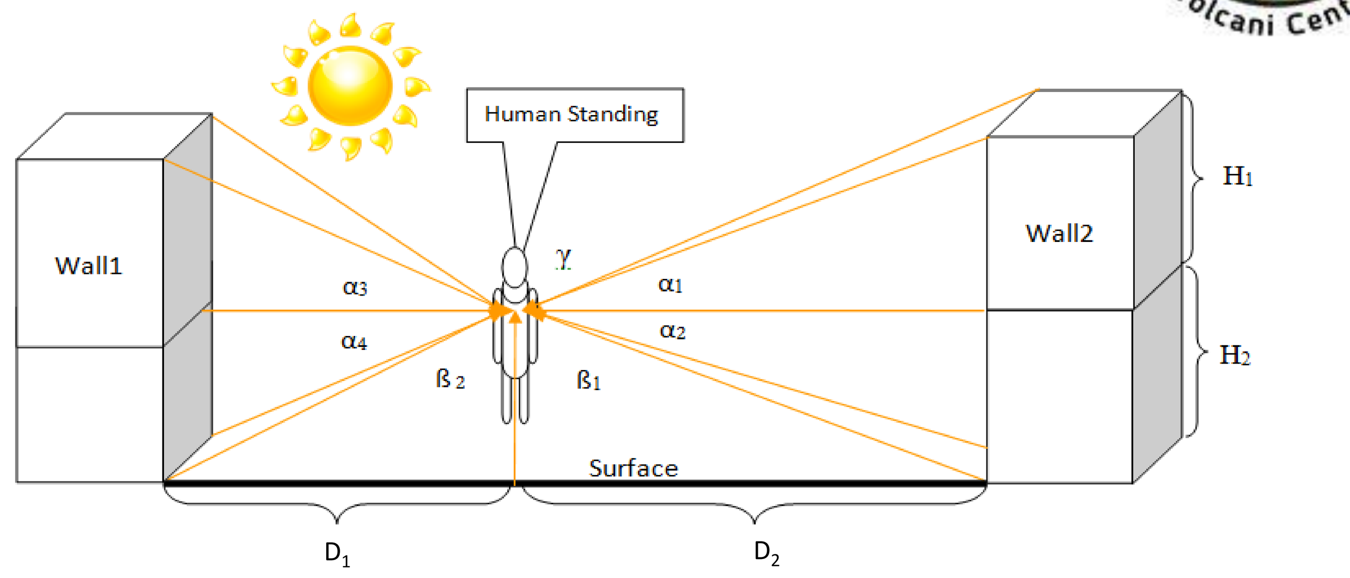
Mean radiant temperature (TMRT) is an important component of human thermal comfort indexes, but is difficult to measure and model. A method was developed to calculate instantaneous values of TMRT based on the geometry and dimensions of the urban canyon, vegetation leaf area index, meteorological data (temperature, relative humidity and solar radiation), surface emissivity and reflectivity, and surface temperatures in the urban canyon, which are easily measured with a handheld IR thermometer. The advantage of this method is that it can be used for experimental work in the urban canyon without the need for deploying several expensive radiometers, eg. four-flux net radiometers. The calculation procedure involves calculation of extraterrestrial, direct and diffuse solar radiation, sky long wave radiation, and reflections and emission of radiation from the various surfaces

A software package, named Mr. T, was developed as a final project of two engineering students, to include the various calculations and allow determining TMRT from the appropriate input data. The package has a friendly user interface and can accept data input manually or from EXCEL type spreadsheets. The calculation procedure and software were tested in two urban settings at and near Tel Aviv University and results were not significantly different from those obtained with four-flux net radiometers. The software package will be supplied freely to the research community. The calculation procedure and software should be important for use in determining thermal comfort in the appropriate models.



Mean radiant temperature (T_{MRT}, °C) is defined by the relationship

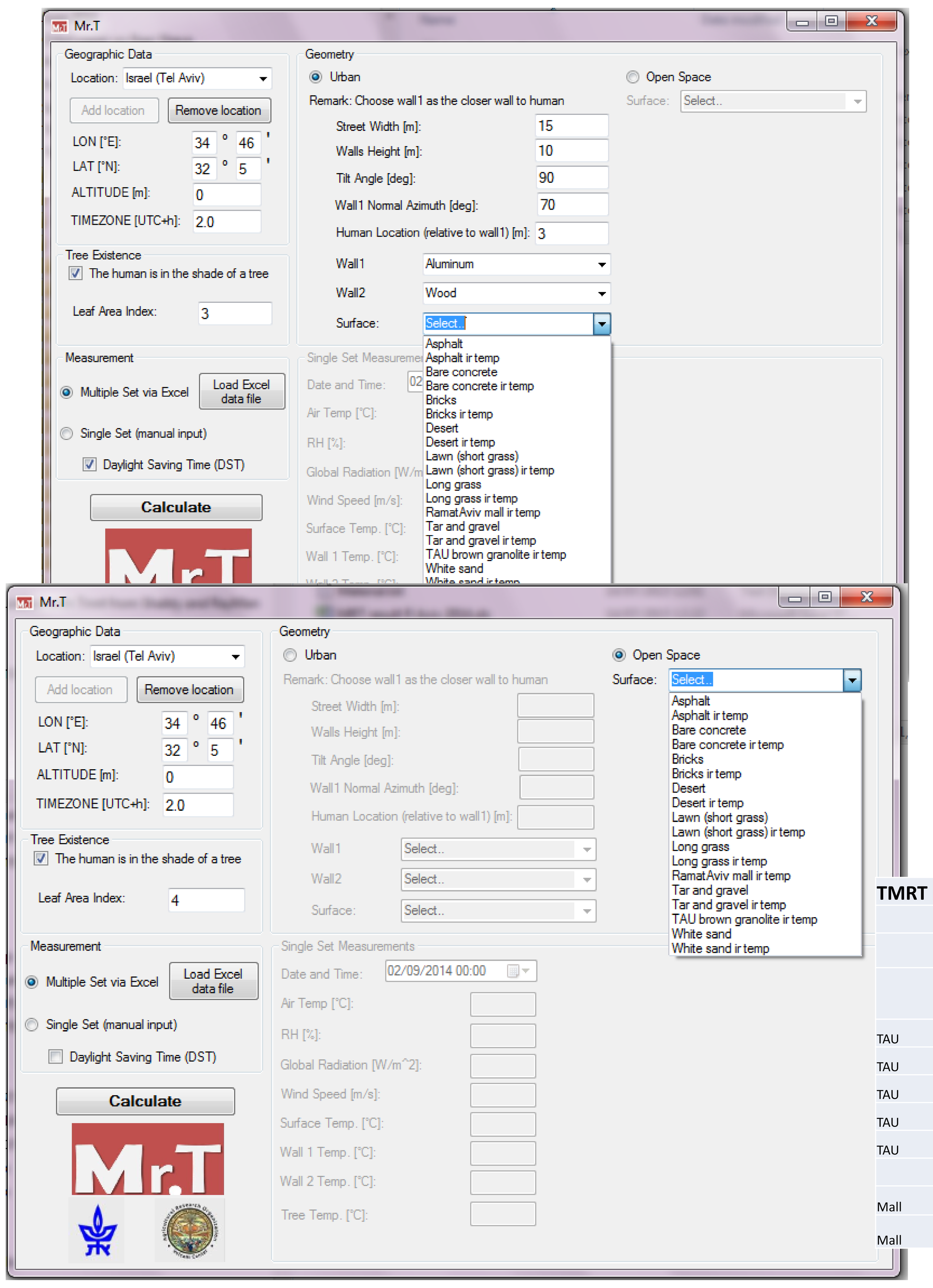
$$T_{MRT} = \left[\frac{K*abs + L*abs}{\varepsilon \cdot \sigma}\right]^{0.25} - 273.15$$

Where K*abs is the total of absorbed short and long wave radiant flux densities (W·m²), ε is emissivity of the human body (0.97) and σ is the Stefan-Boltzman constant (5.67 · 10^{-8} W·m^{2}·K^{4}). K*abs and L*abs can be computed by summing the appropriate radiative fluxes as

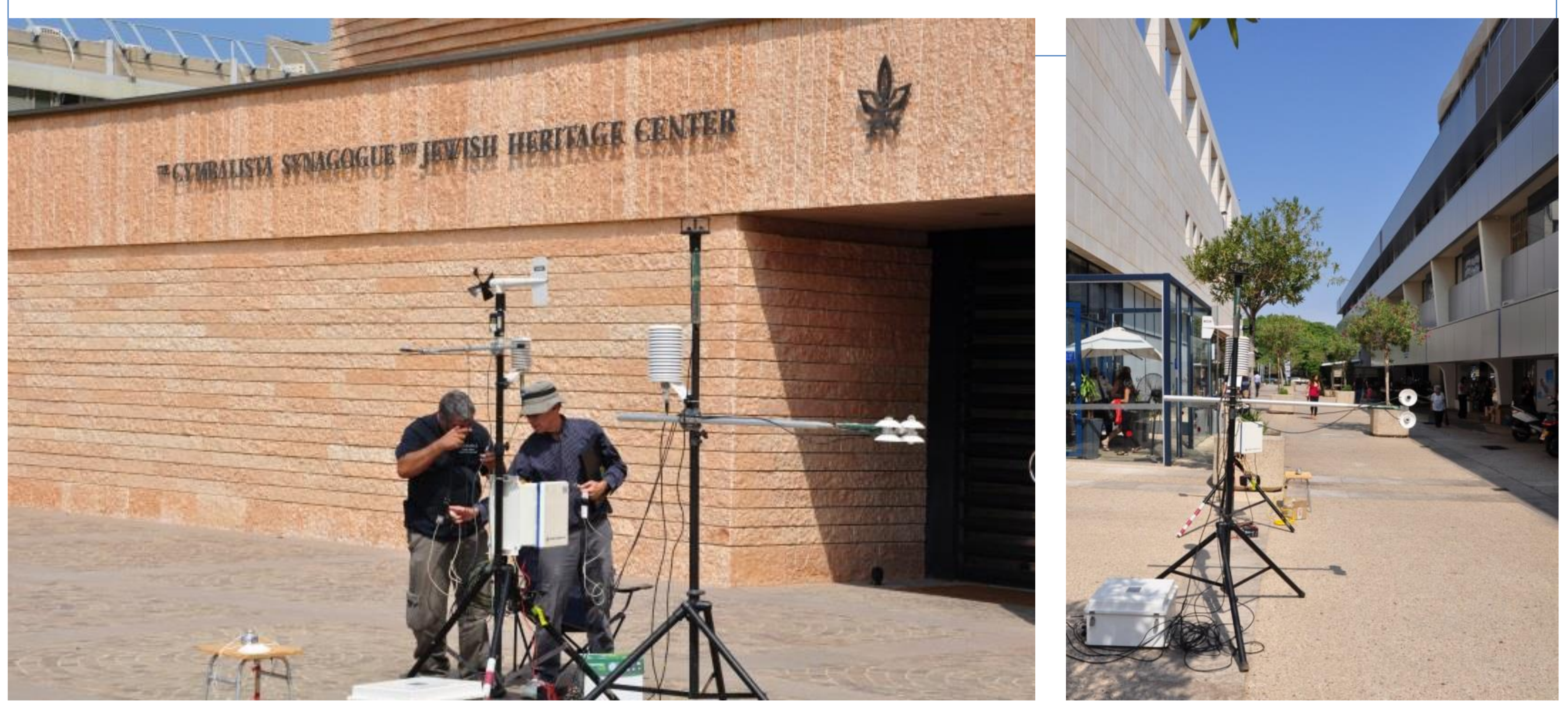
$$K* = \sum_{i=6}^{i=1} W_i \cdot \alpha_K \cdot K_i \;\; ; \;\; L* = \sum_{i=6}^{i=1} W_i \cdot \alpha_L \cdot L_i$$

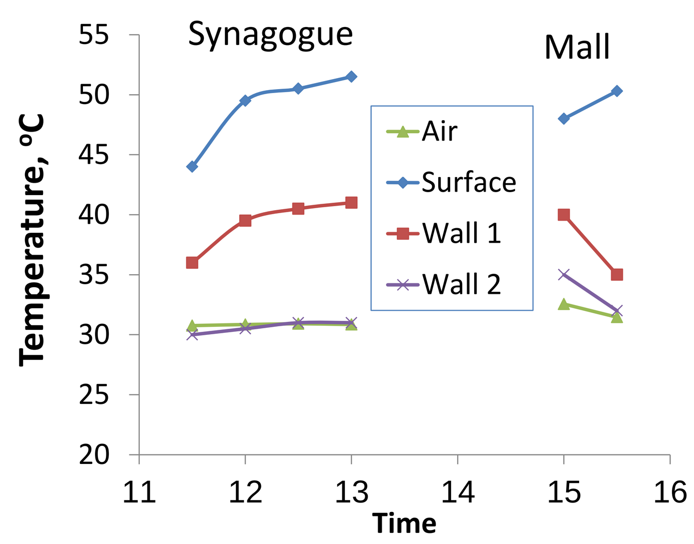
K_i and L_i are short and long wave radiant flux densities from direction i (solar and thermal radiation), α_k and α_l are the short and long wave absorption coefficients, and W_i is the angle factor for direction I, or the percentage of K_i and L_i received by the human body in each direction i. The standing man model was used in this study to determine mean radiant temperature, T_{mrt} (e.g. Thorsson et al., 2007). The basic geometry of the urban canyon is described in the figure above. The validation experiment is described below.

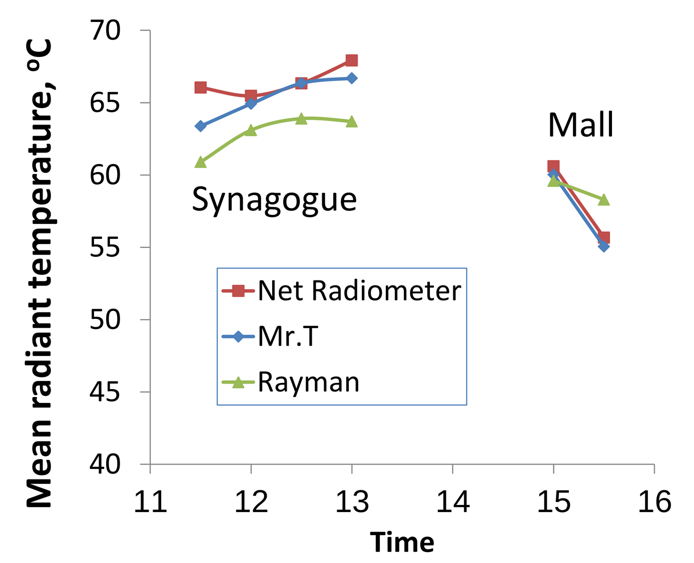
Below are screen shots of the 'Mr. T' user interface, which defines the scenarios for an urban canyon (upper shot) or an open space like a park (lower shot). Surface properties are in a lookup table which can be updated by the user.



Sites of the validation measurements with a 4-flux net radiometer. Left: The plaza outside the Cymbalista Synagogue at Tel Aviv University (TAU). Right: The Southern entrance to the Ramat Aviv Mall in the afternoon of August 31. The West facing wall was sunlit and the East facing wall was shaded. Results are on the right →







Below is the data file produced by the 'Mr. T' software for the validation data set. The columns shaded yellow are input to the program as an excel data file, and the columns shaded green are calculated and output by the software to the same file.

TMRT results from Mr. T Software package

	Location: 1Israel (Tel Aviv)			Geometry: Urban														
	Date [dd/MM/yyyy]	Time [hh:mm]	Air Temprature - Tair [°C]	Relative Humidity - RH [%]	Global Radiation [W/m^2]	Wind Speed [m/s]	Surface Temp. [°C]											
	Date	Time	T air	RH	Global	Wind	Ts	Wall1 Temp. [°C]	Wall2 Temp. [°C]	TMRT [°C]	SW radiation from side 1 [W/m^2]	SW radiation from side 2 [W/m^2]	SW radiation upwards [W/m^2]]	SW radiation downwards [W/m^2]	LW radiation from side 1 [W/m^2]]	LW radiation from side 2 [W/m^2]	LW radiation upwards [W/m^2]	LW radiation downwards [W/m^2]
TAU	31/08/2014	11:00	29.95	59.22	930	0.575	40	32.6	27.5	**61.22**	189.89	199.62	393.35	919.73	462.49	451.35	479.08	434.77
TAU	31/08/2014	11:30	30.76	54.26	933	1.142	44	36	30	**63.28**	190.42	199.94	394.3	923.32	481.06	466.24	503.7	443.61
TAU	31/08/2014	12:00	30.85	55.81	956	0.953	49.5	39.5	30.5	**64.75**	195.95	206.84	406.05	942.75	505.12	484.92	538.34	451.69
TAU	31/08/2014	12:30	30.91	56.06	984	1.059	50.5	40.5	31	**66.1**	200.93	209.9	414.84	976.3	510.48	488.9	545	454.37
TAU	31/08/2014	13:00	30.85	56.01	955	1.298	51.5	41	31	**66.43**	195.12	204.74	403.67	945.25	514.48	491.95	551.5	454.94
Mall	31/08/2014	15:00	32.56	50.35	744	0.792	48	40	35	**60.97**	170.95	154.4	297.59	780.64	499.58	400.88	515.66	384.8
Mall	31/08/2014	15:30	31.46	53.45	651.1	1.134	50.3	35	32	**56.08**	148.85	144.11	260.42	659.1	491.64	405.01	526.79	369.87

Photo Fisheye SVF Aerial Photo - park

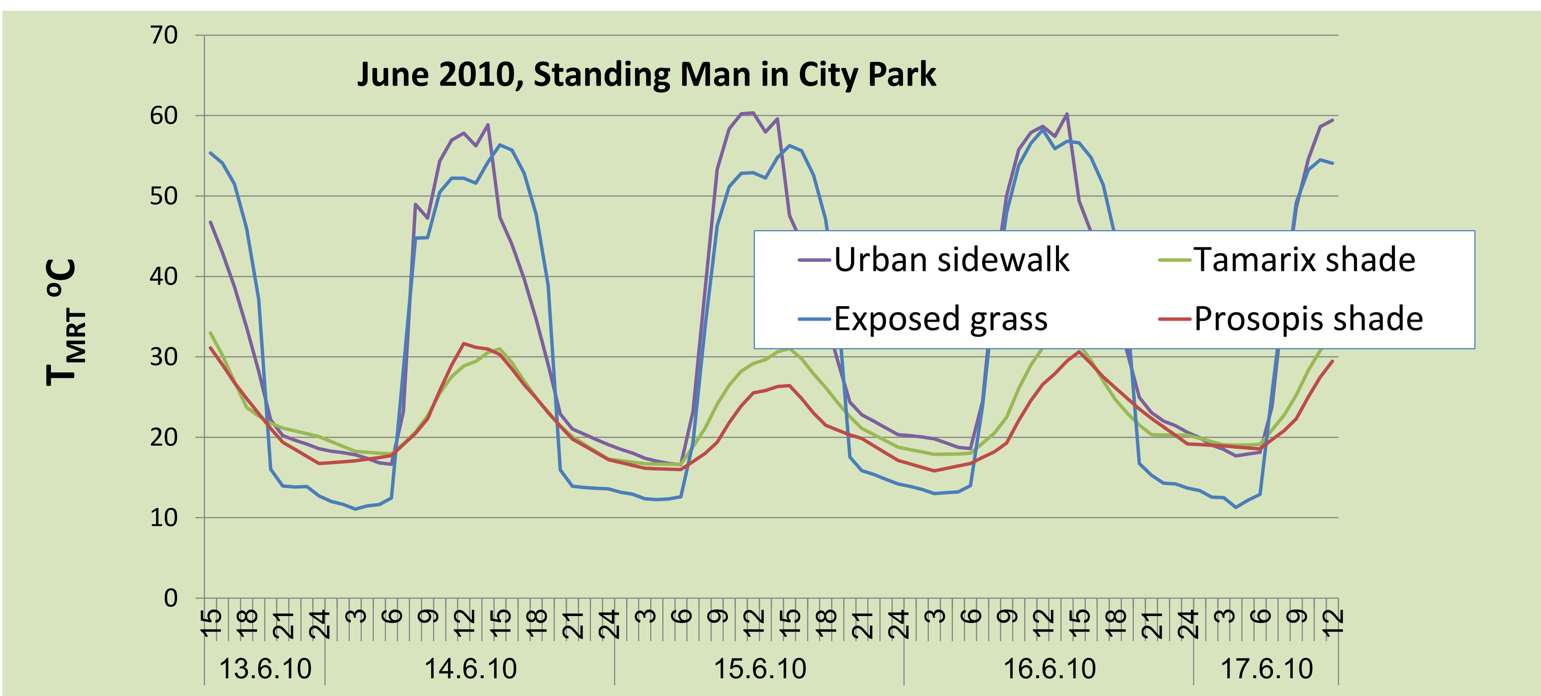
Urban area SVF=0.508

Prosopis SVF=0.07

Tamarix SVF=0.17

Grass SVF=0.75

The T_{mrt} calculation procedure was initially developed and implemented as a series of Excel spread sheets for a project that investigated the influence of vegetation on urban climate (Bar et al., 2013). On the left is a description of several of the experimental sites studied in Beer Sheva, Israel. Below are results of T_{mrt} for a 'standing man' in the parks and an urban sidewalk in the summer. T_{mrt} in the shade of trees (Prosopis and Tamarix) in the city park is reduced by more than 25ºC .



References:
Bar, P., Tanny, J., Cohen, S., Mayer, H. and Potchter, O. 2013. The contribution of vegetation to urban heat island mitigation in the global climate change era. Final Report. GIF Project 955-36.8/2007
Thorsson, S., Lindgerg, F., Eliasson, I. And Holmer B. 2007. Different methods for estimating the mean radiant temperature in an outdoor urban setting. Int. J. Climatol. 27:1983.

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