Monthly averages of $(\tau\alpha)/(\tau\alpha)_n$ for solar thermal applications

JUNE 10, 2022

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Monthly averages of the normalized solar transmittance-absorptance product, $\frac{\overline{(\tau\alpha)}}{(\tau\alpha)_n}$

Design of solar thermal systems with flat plate collectors utilizing the *f*-chart method

The *f*-chart is well known for its simplicity and capability to properly design liquid or air solar thermal systems. It is known that the maximum efficiency of a solar thermal collector is given as $F_R(\tau\alpha)_n$ following the formulation of e.g. Duffie and Beckman (2020). The factor F_R stands for the collector heat removal efficiency, while $(\tau\alpha)_n$ is the product of the solar transmittance of the transparent covers and the solar absorptance of the collector plate at normal incidence. However, angular effects affect the performance of a collector as the angle of incidence of the solar rays changes during a day and from day to day during a month. One of the parameters required by the *f*-chart method is the monthly average of the normalized solar transmittance-absorptance product $\overline{(\tau\alpha)}/(\tau\alpha)_n$. This factor is incorporated into the method to account for the monthly changes of the performance of the solar thermal collector. The procedure proposed by Klein (1979) has been followed to produce the tables listed in the following pages and the calculations are performed on the average day of each month (Klein 1977). The correlations presented by Erbs et al. (1982) are used to calculate the monthly average diffuse fraction through the global radiance data at the horizontal level. The solar constant used in the calculations was set to 1367 W/m^2, while in order to remove uncertainties related to the different source of solar data, all solar radiance data are extracted from the PVGIS database (Huld et al. 2012).

The tables list the monthly average of the normalized solar transmittance-absorptance product for four different latitudes (35°, 38°, 41° and 45°) and eleven different slopes of a flat plate collector. Collector azimuth was assumed due south. There in one point to stress here concerning the calculation

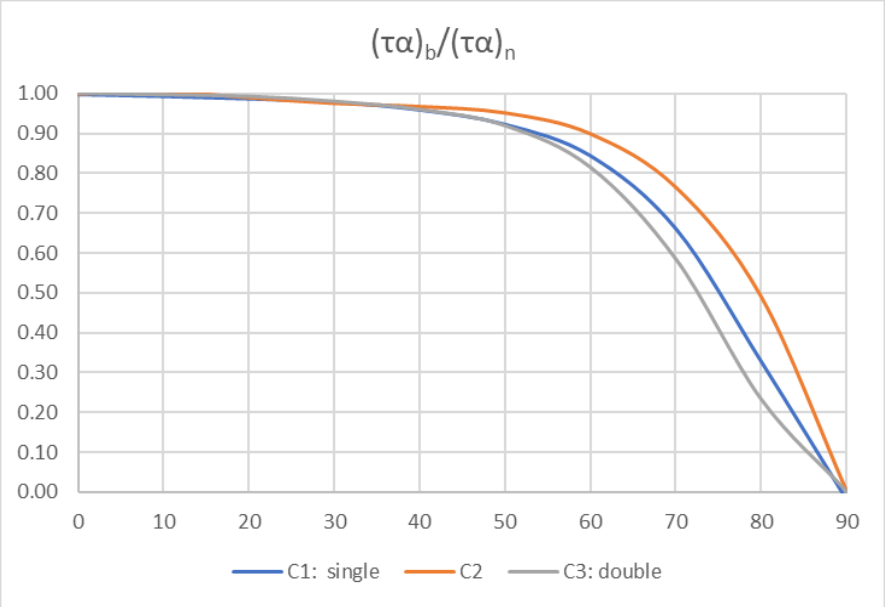

Figure 1 The angular responses adopted in the calculations

of the data. It refers to the adoption of the dependence of absorptance and transmittance on the angle of incidence of the incident radiation. Data shown in Table 1, Table 2, Table 3 and Table 4 adopt the original single glass response (C1) of the beam component reported by Klein (1979) and reproduced by Duffie and Beckman (2020). Data shown in Table 5, Table 6, Table 7 and Table 8 adopt a response curve based on a collector of improved performance (single glass, C2). Data shown in Table 9, Table 10, Table 11 and Table 12 adopt the original double glass response (C3) of the beam component reported by Klein (1979) and reproduced by Duffie and Beckman (2020). All three curves are shown to allow the reader to select according to his/her own data available (Figure 1). The results show that when the angular response of a collector is better than another, i.e. higher response at larger angles of incidence, then the monthly means are also larger, as one would expect. They also show that for a given site, the monthly means depend on the tilt angle. Low tilt angles lead to smaller incidence angles during summer months and thus, better average solar transmittance-absorptance products. On the other hand, low tilt angles lead to higher angles of incidence during winter months and thus, smaller average solar transmittance-absorptance products. The results are interchanged when the tilt angles are larger. Larger tilt angles lead to smaller incidence angles during the winter months resulting in higher averages of the solar transmittance-absorptance products. On the other hand, larger tilt angles lead to higher incidence angles during the summer months resulting in smaller averages of the solar transmittance-absorptance products. Formally, the monthly averages should be recalculated once a different angular performance (incident angle modifier) is adopted and arithmetic data (or a function to describe it) are available. Although, care has been taken to correctly calculate the monthly averages, the reader may use the results at his/her own risk.

Table 1 Monthly averages of the normalized solar transmittance-absorptance product (Lat=35°) for response curve C1

Response C1	Site: Latitude 35.3/Heraklion										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.81	0.86	0.89	0.92	0.93	0.94	0.94	0.94	0.94	0.94	0.92
February	0.85	0.88	0.90	0.92	0.93	0.93	0.93	0.93	0.92	0.91	0.89
March	0.87	0.90	0.91	0.92	0.92	0.92	0.92	0.91	0.89	0.87	0.83
April	0.90	0.91	0.91	0.91	0.91	0.91	0.90	0.88	0.86	0.82	0.75
May	0.90	0.91	0.91	0.91	0.90	0.89	0.88	0.86	0.82	0.77	0.71
June	0.91	0.91	0.91	0.91	0.89	0.88	0.87	0.84	0.79	0.73	0.70
July	0.91	0.92	0.91	0.91	0.90	0.89	0.88	0.85	0.80	0.74	0.69
August	0.90	0.91	0.92	0.92	0.91	0.90	0.90	0.87	0.84	0.79	0.71
September	0.89	0.91	0.91	0.92	0.92	0.91	0.91	0.90	0.88	0.85	0.79
October	0.86	0.89	0.91	0.92	0.92	0.93	0.93	0.92	0.92	0.90	0.87
November	0.82	0.87	0.90	0.92	0.93	0.94	0.94	0.94	0.94	0.93	0.92
December	0.80	0.85	0.89	0.92	0.93	0.94	0.94	0.95	0.95	0.94	0.93

Table 2 Monthly averages of the normalized solar transmittance-absorptance product (Lat=38°) for response curve C1

Response C1	Site Latitude 38.0/Athens										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.78	0.85	0.89	0.92	0.93	0.94	0.94	0.95	0.95	0.94	0.93
February	0.83	0.87	0.90	0.92	0.93	0.93	0.93	0.93	0.93	0.92	0.90
March	0.87	0.89	0.91	0.92	0.92	0.92	0.92	0.91	0.90	0.88	0.84
April	0.89	0.91	0.91	0.91	0.91	0.91	0.90	0.89	0.87	0.83	0.77
May	0.90	0.91	0.91	0.91	0.90	0.90	0.89	0.87	0.83	0.78	0.72
June	0.91	0.91	0.91	0.91	0.90	0.89	0.88	0.85	0.81	0.75	0.71
July	0.91	0.91	0.91	0.91	0.90	0.89	0.88	0.86	0.82	0.76	0.70
August	0.90	0.91	0.92	0.92	0.91	0.90	0.90	0.88	0.85	0.80	0.73
September	0.88	0.90	0.91	0.92	0.92	0.92	0.91	0.90	0.89	0.86	0.81
October	0.85	0.88	0.90	0.92	0.92	0.93	0.93	0.93	0.92	0.91	0.88
November	0.80	0.86	0.89	0.92	0.93	0.94	0.94	0.95	0.94	0.94	0.93
December	0.77	0.84	0.89	0.91	0.93	0.94	0.94	0.95	0.95	0.95	0.94

Table 3 Monthly averages of the normalized solar transmittance-absorptance product (Lat=41°) for response curve C1

Response C1	Site Latitude 40.6/Thessaloniki										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.77	0.84	0.88	0.91	0.93	0.94	0.94	0.95	0.95	0.95	0.94
February	0.82	0.87	0.90	0.91	0.93	0.93	0.93	0.93	0.93	0.92	0.91
March	0.86	0.89	0.90	0.91	0.92	0.92	0.92	0.91	0.90	0.88	0.85
April	0.89	0.90	0.91	0.91	0.91	0.91	0.90	0.89	0.87	0.84	0.79
May	0.90	0.91	0.91	0.91	0.90	0.90	0.89	0.87	0.84	0.80	0.75
June	0.90	0.91	0.91	0.91	0.90	0.89	0.88	0.86	0.83	0.78	0.72
July	0.90	0.91	0.91	0.91	0.90	0.90	0.89	0.87	0.83	0.78	0.72
August	0.90	0.91	0.91	0.91	0.91	0.91	0.90	0.89	0.86	0.82	0.76
September	0.87	0.90	0.91	0.92	0.92	0.92	0.91	0.91	0.89	0.87	0.83
October	0.84	0.88	0.90	0.91	0.92	0.93	0.93	0.93	0.92	0.91	0.89
November	0.78	0.85	0.89	0.91	0.93	0.94	0.94	0.95	0.95	0.94	0.93
December	0.75	0.83	0.88	0.91	0.93	0.94	0.94	0.95	0.95	0.95	0.94

Table 4 Monthly averages of the normalized solar transmittance-absorptance product (Lat=45°) for response curve C1

Response C1	Site Latitude 44.9/Salem, Oregon										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.76	0.83	0.87	0.91	0.93	0.93	0.94	0.94	0.95	0.95	0.94
February	0.80	0.86	0.89	0.91	0.92	0.93	0.93	0.94	0.93	0.93	0.92
March	0.85	0.88	0.90	0.91	0.92	0.92	0.92	0.91	0.91	0.89	0.87
April	0.88	0.90	0.91	0.91	0.91	0.91	0.91	0.90	0.88	0.86	0.82
May	0.89	0.90	0.91	0.91	0.90	0.90	0.89	0.88	0.86	0.83	0.78
June	0.89	0.90	0.91	0.90	0.90	0.89	0.89	0.87	0.85	0.81	0.76
July	0.89	0.91	0.91	0.91	0.90	0.90	0.89	0.88	0.85	0.81	0.75
August	0.89	0.90	0.91	0.91	0.91	0.91	0.90	0.89	0.87	0.84	0.79
September	0.86	0.89	0.90	0.91	0.92	0.92	0.92	0.91	0.90	0.88	0.85
October	0.82	0.86	0.89	0.91	0.92	0.93	0.93	0.93	0.93	0.92	0.90
November	0.77	0.84	0.88	0.91	0.93	0.93	0.94	0.94	0.94	0.94	0.93
December	0.75	0.82	0.87	0.90	0.92	0.93	0.94	0.95	0.95	0.95	0.94

Table 5 Monthly averages of the normalized solar transmittance-absorptance product (Lat=35°) for response curve C2

Response C2	Site Latitude 35.3/Heraklion										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.87	0.91	0.93	0.94	0.95	0.96	0.96	0.96	0.96	0.95	0.95
February	0.90	0.92	0.93	0.94	0.95	0.95	0.95	0.95	0.95	0.94	0.93
March	0.91	0.93	0.94	0.94	0.94	0.94	0.94	0.93	0.92	0.91	0.88
April	0.93	0.94	0.94	0.94	0.94	0.93	0.93	0.92	0.90	0.88	0.83
May	0.93	0.94	0.94	0.94	0.93	0.92	0.92	0.90	0.88	0.84	0.80
June	0.94	0.94	0.94	0.93	0.92	0.92	0.91	0.89	0.86	0.81	0.78
July	0.94	0.94	0.94	0.93	0.93	0.92	0.91	0.90	0.86	0.82	0.77
August	0.93	0.94	0.94	0.94	0.93	0.93	0.92	0.91	0.89	0.85	0.80
September	0.92	0.93	0.94	0.94	0.94	0.94	0.94	0.93	0.92	0.90	0.86
October	0.90	0.92	0.93	0.94	0.95	0.95	0.95	0.95	0.94	0.93	0.92
November	0.88	0.91	0.93	0.94	0.95	0.96	0.96	0.96	0.96	0.95	0.94
December	0.86	0.90	0.93	0.94	0.95	0.96	0.96	0.96	0.96	0.96	0.95

Table 6 Monthly averages of the normalized solar transmittance-absorptance product (Lat=38°) for response curve C2

Response C2	Site Latitude 38.0/Athens										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.85	0.90	0.92	0.94	0.95	0.96	0.96	0.97	0.96	0.96	0.95
February	0.89	0.91	0.93	0.94	0.95	0.95	0.95	0.95	0.95	0.94	0.93
March	0.91	0.92	0.93	0.94	0.95	0.95	0.94	0.94	0.93	0.92	0.89
April	0.92	0.93	0.94	0.94	0.94	0.94	0.93	0.92	0.91	0.88	0.84
May	0.93	0.94	0.94	0.94	0.93	0.93	0.92	0.91	0.89	0.85	0.81
June	0.93	0.94	0.94	0.93	0.93	0.92	0.91	0.90	0.87	0.83	0.79
July	0.93	0.94	0.94	0.94	0.93	0.92	0.92	0.90	0.88	0.83	0.79
August	0.93	0.94	0.94	0.94	0.94	0.93	0.93	0.92	0.90	0.87	0.81
September	0.92	0.93	0.94	0.94	0.94	0.94	0.94	0.93	0.92	0.90	0.87
October	0.90	0.92	0.93	0.94	0.95	0.95	0.95	0.95	0.94	0.93	0.92
November	0.86	0.90	0.93	0.94	0.95	0.96	0.96	0.96	0.96	0.95	0.95
December	0.84	0.89	0.92	0.94	0.95	0.96	0.96	0.97	0.97	0.96	0.95

Table 7 Monthly averages of the normalized solar transmittance-absorptance product (Lat=41°) for response curve C2

Response C2	Site Latitude 40.6/Thessaloniki										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.84	0.89	0.92	0.94	0.95	0.96	0.96	0.97	0.97	0.96	0.95
February	0.88	0.91	0.93	0.94	0.95	0.95	0.95	0.96	0.95	0.94	0.94
March	0.91	0.92	0.93	0.94	0.94	0.94	0.94	0.94	0.93	0.92	0.90
April	0.92	0.93	0.94	0.94	0.94	0.94	0.93	0.92	0.91	0.89	0.86
May	0.93	0.94	0.94	0.94	0.93	0.93	0.92	0.91	0.90	0.87	0.82
June	0.93	0.94	0.94	0.94	0.93	0.92	0.92	0.91	0.88	0.85	0.80
July	0.93	0.94	0.94	0.94	0.93	0.93	0.92	0.91	0.89	0.85	0.80
August	0.92	0.93	0.94	0.94	0.94	0.93	0.93	0.92	0.90	0.88	0.83
September	0.91	0.93	0.94	0.94	0.94	0.94	0.94	0.93	0.92	0.91	0.88
October	0.89	0.92	0.93	0.94	0.95	0.95	0.95	0.95	0.94	0.94	0.93
November	0.85	0.90	0.92	0.94	0.95	0.96	0.96	0.96	0.96	0.96	0.95
December	0.82	0.88	0.92	0.94	0.95	0.96	0.96	0.97	0.97	0.96	0.96

Table 8 Monthly averages of the normalized solar transmittance-absorptance product (Lat=45°) for response curve C2

Response C2	Site Latitude 44.9/Salem, Oregon										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.83	0.88	0.92	0.94	0.95	0.95	0.96	0.96	0.97	0.96	0.95
February	0.87	0.90	0.92	0.94	0.95	0.95	0.95	0.96	0.95	0.95	0.94
March	0.90	0.92	0.93	0.94	0.94	0.94	0.94	0.94	0.93	0.93	0.91
April	0.91	0.93	0.93	0.94	0.94	0.94	0.94	0.93	0.92	0.90	0.88
May	0.92	0.93	0.94	0.94	0.93	0.93	0.93	0.92	0.90	0.88	0.85
June	0.92	0.93	0.94	0.93	0.93	0.93	0.92	0.91	0.90	0.87	0.84
July	0.92	0.93	0.94	0.94	0.93	0.93	0.92	0.91	0.90	0.87	0.83
August	0.92	0.93	0.94	0.94	0.94	0.94	0.93	0.92	0.91	0.89	0.86
September	0.91	0.92	0.93	0.94	0.94	0.94	0.94	0.94	0.93	0.92	0.90
October	0.88	0.91	0.93	0.94	0.95	0.95	0.95	0.95	0.95	0.94	0.93
November	0.84	0.89	0.92	0.94	0.95	0.95	0.96	0.96	0.96	0.96	0.95
December	0.83	0.88	0.91	0.93	0.95	0.95	0.96	0.96	0.97	0.96	0.96

Table 9 Monthly averages of the normalized solar transmittance-absorptance product (Lat=35°) for response curve C3

Response C3	Site Latitude 35.3/Heraklion										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.77	0.84	0.88	0.91	0.92	0.93	0.93	0.94	0.94	0.93	0.92
February	0.82	0.86	0.89	0.91	0.92	0.92	0.92	0.92	0.91	0.90	0.87
March	0.86	0.88	0.90	0.91	0.91	0.91	0.90	0.90	0.88	0.85	0.80
April	0.88	0.90	0.90	0.90	0.90	0.89	0.89	0.87	0.84	0.79	0.71
May	0.89	0.90	0.90	0.90	0.88	0.88	0.87	0.84	0.79	0.72	0.66
June	0.90	0.90	0.90	0.89	0.88	0.87	0.85	0.82	0.76	0.68	0.66
July	0.90	0.91	0.90	0.90	0.88	0.87	0.86	0.82	0.77	0.69	0.64
August	0.89	0.90	0.91	0.90	0.90	0.89	0.88	0.85	0.81	0.75	0.66
September	0.87	0.89	0.90	0.91	0.91	0.90	0.90	0.89	0.86	0.82	0.76
October	0.83	0.87	0.89	0.91	0.91	0.92	0.92	0.91	0.90	0.89	0.85
November	0.78	0.85	0.88	0.91	0.92	0.93	0.93	0.94	0.93	0.93	0.91
December	0.76	0.83	0.88	0.91	0.92	0.93	0.93	0.94	0.94	0.94	0.92

Table 10 Monthly averages of the normalized solar transmittance-absorptance product (Lat=38°) for response curve C3

Response C3	Site Latitude 38.0/Athens										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.74	0.82	0.87	0.91	0.93	0.93	0.94	0.94	0.94	0.94	0.93
February	0.80	0.86	0.89	0.91	0.92	0.92	0.92	0.92	0.92	0.91	0.89
March	0.85	0.88	0.90	0.91	0.91	0.91	0.91	0.90	0.88	0.86	0.81
April	0.88	0.89	0.90	0.90	0.90	0.90	0.89	0.87	0.85	0.80	0.73
May	0.89	0.90	0.90	0.90	0.89	0.88	0.87	0.85	0.81	0.74	0.68
June	0.89	0.90	0.90	0.89	0.88	0.87	0.86	0.83	0.78	0.71	0.66
July	0.89	0.90	0.90	0.90	0.89	0.88	0.87	0.84	0.79	0.71	0.65
August	0.89	0.90	0.91	0.90	0.90	0.89	0.88	0.86	0.83	0.77	0.68
September	0.86	0.89	0.90	0.91	0.91	0.91	0.90	0.89	0.87	0.84	0.78
October	0.82	0.87	0.89	0.91	0.92	0.92	0.92	0.92	0.91	0.89	0.86
November	0.76	0.83	0.88	0.91	0.92	0.93	0.94	0.94	0.94	0.93	0.92
December	0.72	0.81	0.87	0.90	0.93	0.93	0.94	0.95	0.95	0.94	0.93

Table 11 Monthly averages of the normalized solar transmittance-absorptance product (Lat=41°) for response curve C3

Response C3	Site Latitude 40.6/Thessaloniki										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.72	0.81	0.87	0.90	0.92	0.93	0.94	0.94	0.95	0.94	0.93
February	0.79	0.85	0.88	0.90	0.92	0.92	0.92	0.93	0.92	0.91	0.89
March	0.84	0.87	0.89	0.90	0.91	0.91	0.91	0.90	0.89	0.87	0.83
April	0.87	0.89	0.90	0.90	0.90	0.90	0.89	0.88	0.85	0.82	0.75
May	0.88	0.89	0.90	0.90	0.89	0.88	0.88	0.85	0.82	0.77	0.70
June	0.89	0.90	0.90	0.89	0.88	0.88	0.87	0.84	0.80	0.73	0.68
July	0.89	0.90	0.90	0.90	0.89	0.88	0.87	0.85	0.80	0.74	0.67
August	0.88	0.90	0.90	0.90	0.90	0.89	0.89	0.87	0.84	0.79	0.71
September	0.85	0.88	0.90	0.90	0.91	0.91	0.90	0.89	0.88	0.85	0.80
October	0.81	0.86	0.89	0.90	0.91	0.92	0.92	0.92	0.91	0.90	0.87
November	0.74	0.82	0.87	0.90	0.92	0.93	0.93	0.94	0.94	0.94	0.92
December	0.70	0.80	0.86	0.90	0.92	0.93	0.94	0.95	0.95	0.95	0.94

Table 12 Monthly averages of the normalized solar transmittance-absorptance product (Lat=45°) for response curve C3

Response C3	Site Latitude 44.9/Salem, Oregon										
Month/Tilt angle	**0**	**10**	**20**	**30**	**40**	**45**	**50**	**60**	**70**	**80**	**90**
January	0.71	0.80	0.86	0.89	0.92	0.93	0.93	0.94	0.94	0.94	0.93
February	0.77	0.83	0.87	0.90	0.91	0.92	0.92	0.93	0.93	0.92	0.90
March	0.83	0.86	0.88	0.90	0.90	0.91	0.91	0.90	0.89	0.88	0.85
April	0.86	0.88	0.89	0.90	0.90	0.90	0.89	0.88	0.87	0.84	0.79
May	0.87	0.89	0.89	0.89	0.89	0.89	0.88	0.86	0.84	0.79	0.73
June	0.87	0.89	0.89	0.89	0.88	0.88	0.87	0.85	0.82	0.77	0.72
July	0.88	0.89	0.90	0.90	0.89	0.89	0.88	0.86	0.82	0.77	0.70
August	0.87	0.89	0.90	0.90	0.90	0.90	0.89	0.88	0.85	0.81	0.75
September	0.84	0.87	0.89	0.90	0.91	0.91	0.91	0.90	0.89	0.86	0.82
October	0.79	0.84	0.88	0.90	0.91	0.92	0.92	0.92	0.92	0.91	0.89
November	0.73	0.81	0.86	0.89	0.92	0.92	0.93	0.94	0.94	0.94	0.93
December	0.70	0.78	0.85	0.89	0.92	0.93	0.93	0.94	0.94	0.94	0.94

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