Energy output of solar collectors

Higher Education Package for Nearly Zero Energy and Smart Building Design

Miklós Horváth PhD
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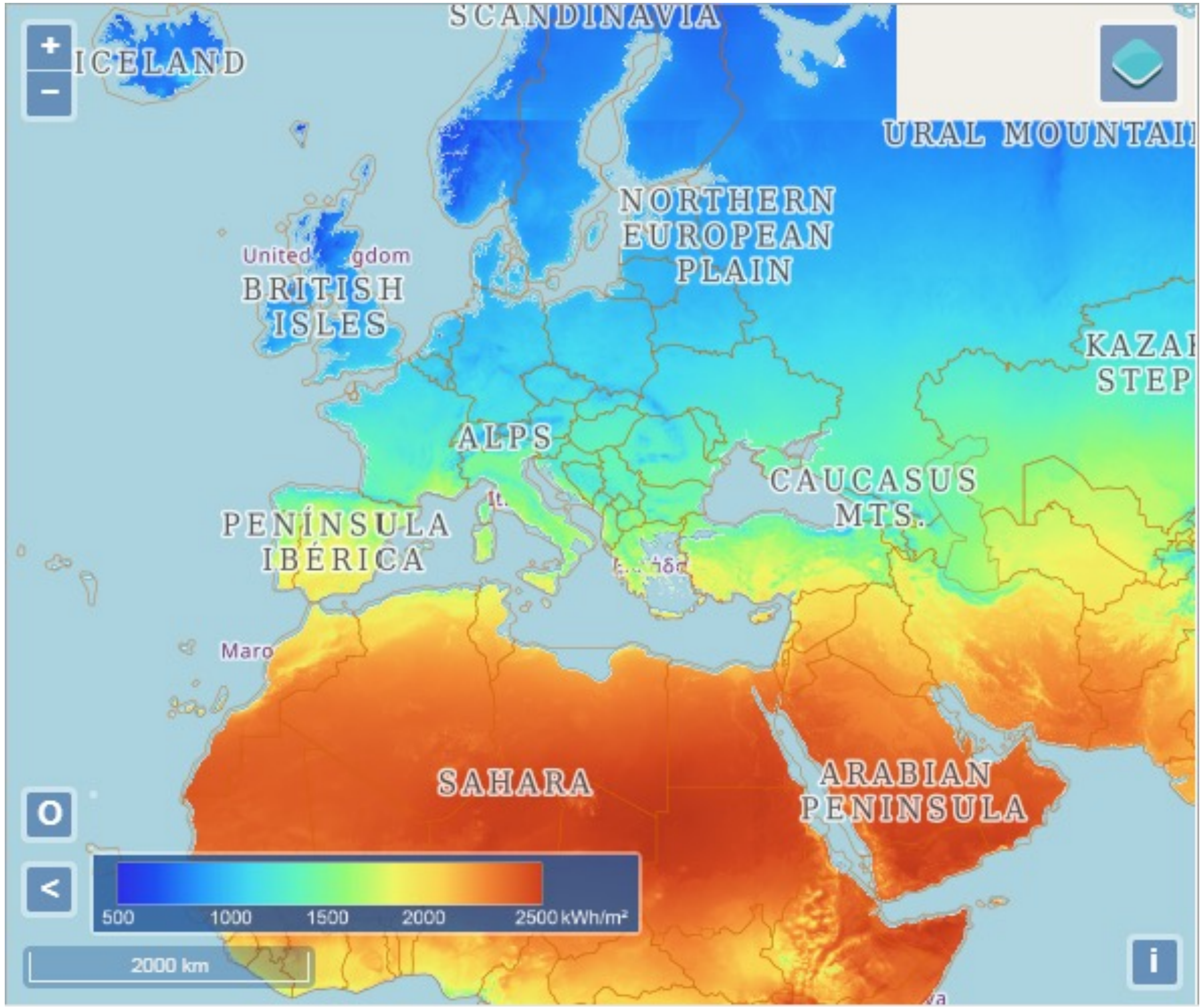
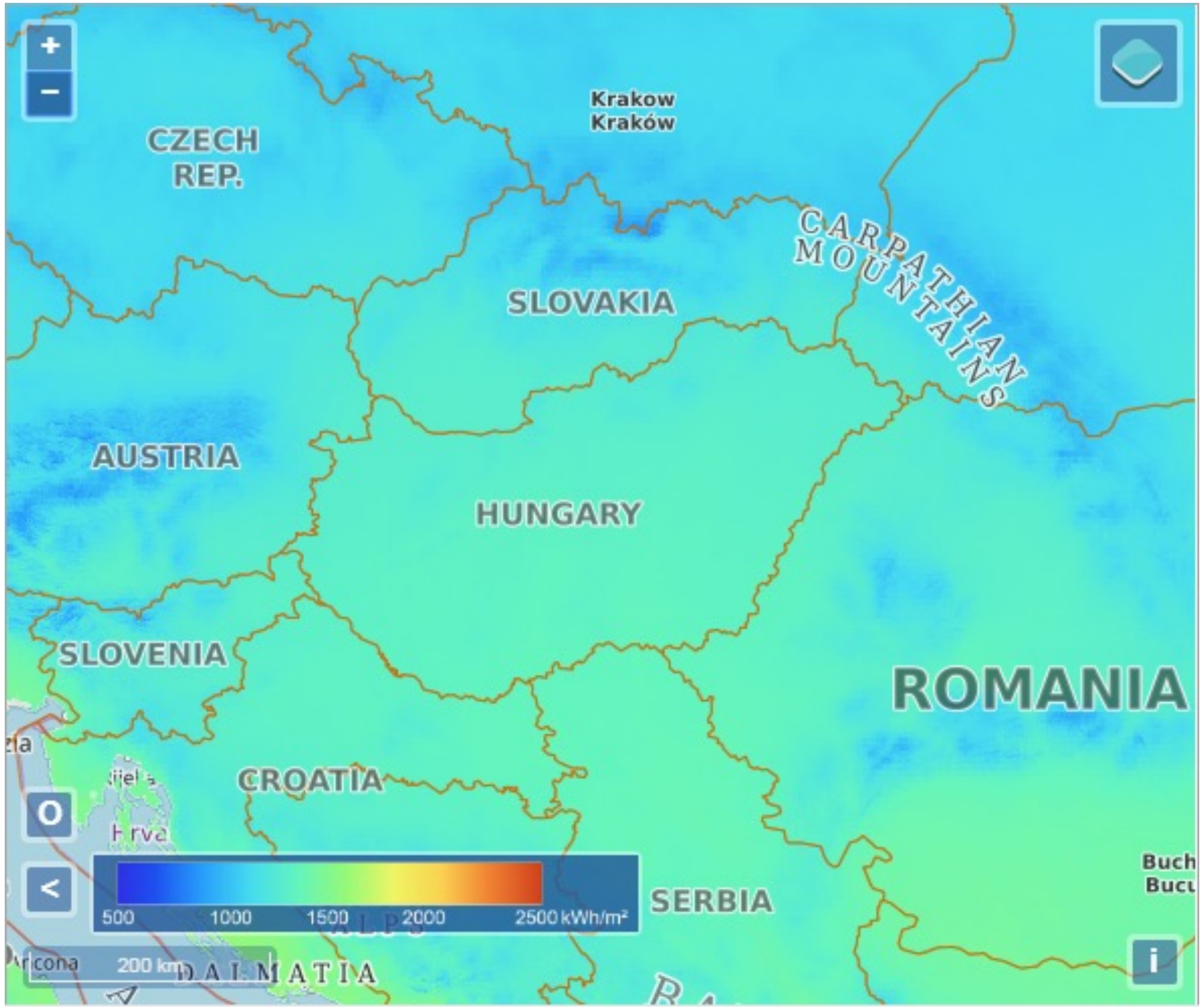
Co-funded by the Erasmus+ Programme of the European Union

Available solar radiation



Source: http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP

Available solar radiation



Source: http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP

Energy output of solar collectors

Meteorological data (yearly, monthly, daily, hourly)

- Solar raditaion
- External temperature

Solar collector type

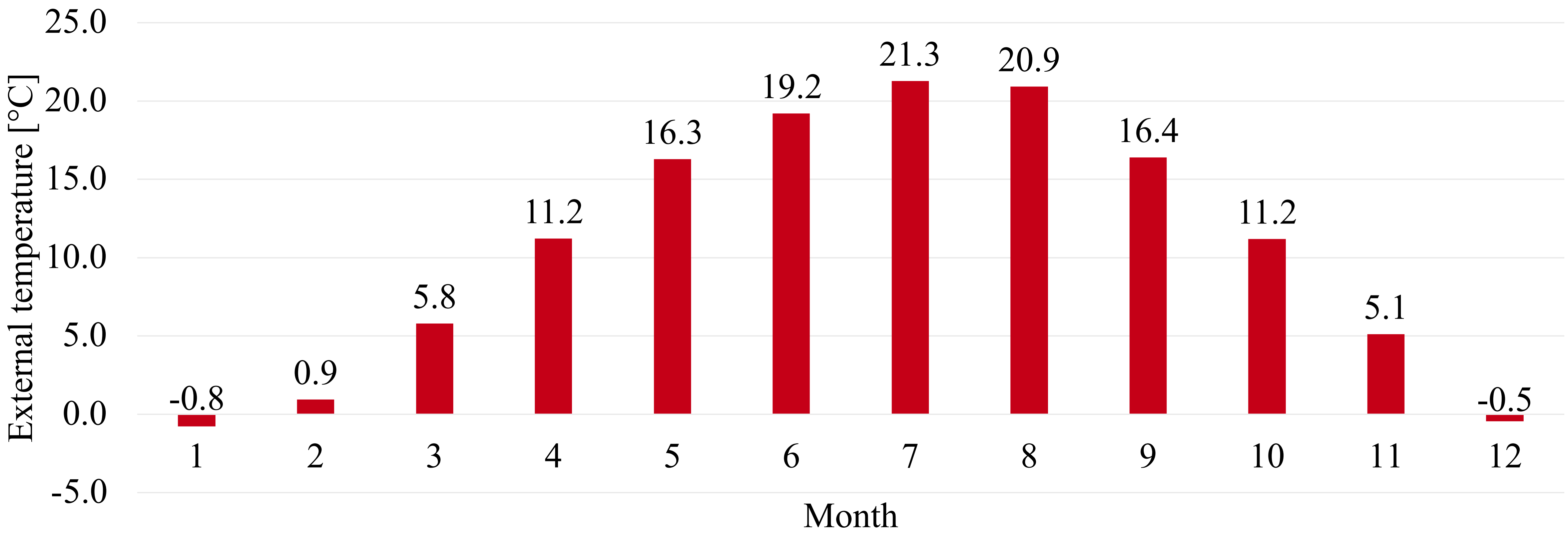
Available roof space, building characteristics

- Roof – orientation, tilt angle

Demand side

- DHW production
- Pool heating
- Space heating
- Other

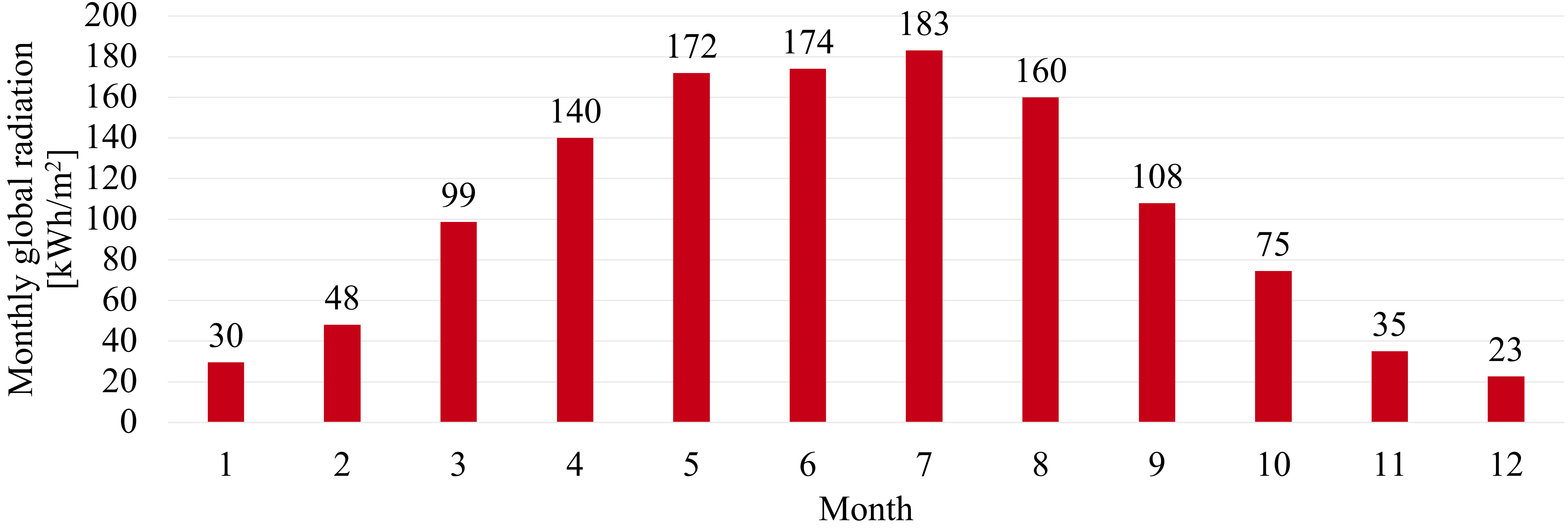
Meteorological data



HI-SMART

Erasmus+

Meteorological data



Solar collectors

Type

- Flat-plate collectors
- Vacuum tube collectors

Typical parameters (Solar Keymark database)

- Optic efficiency: η_0
- Temperature dependence coefficients: a_1, a_2
- Dependence on the incident angle of solar radiation: $K_{dir}(50°)$

Solar collector datasheet

TECHNICKÝ SKÚŠOBNÝ ÚSTAV PIEŠŤANY, š.p.

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Annex to Solar Keymark Certificate - Summary of EN ISO 9806:2013 Test Results		Licence Number	TSU 001-16/D
		Date issued	2016-10-03
		Issued by	TSU Piešťany, š.p.
Licence holder	ELVOSOLAR a.s.	Country	Slovak republic
Brand (optional)		Web	www.elvosolar.sk
Street, Number	Agátová 22, P.O.BOX 108	E-mail	ancic@elvosolar.sk
Postcode, City	SK-841 01 Bratislava	Tel	+421 905609462
Collector Type		Flat plate collector, glazed	

Collector name	Gross area (A_G)	Gross length	Gross width	Gross height	Power output per collector, Gb = 850 W/m²; Gd = 150 W/m², $\vartheta_m - \vartheta_a$: 0 K	10 K	30 K	50 K	70 K	90 K
	m²	mm	mm	mm	W	W	W	W	W	W
ELVOSOLAR TS300-2,03	2,03	2 009	1 009	75	1 445	1 379	1 234	1 074	899	708

Power output per m² gross area

Performance parameters test method

Performance parameters (related to AG)

Units

Test results

Data required for CDR (EU) No 812/2013 - Reference Area A_{sol}		
Zero-loss efficiency (η_0)	0,712	--
First-order coefficient (a_1)	3,18	W/(m²K)
Second-order coefficient (a_2)	0,010	W/(m²K²)
Incidence angle modifier IAM (50°)	0,95	--

Incidence angle modifier test method		Steady state - outdoor								
Bi-directional incidence angle modifiers	No									
Incidence angle modifier	Angle	10°	20°	30°	40°	50°	60°	70°	80°	90°
Transversal	$K_{\theta T,coll}$					0,95				0,00
Longitudinal	$K_{\theta L,coll}$					0,95				0,00

Heat transfer medium for testing	Water		
Flow rate for testing (per gross area, A_G)	dm/dt	0,010	kg/(sm²)
Maximum temperature difference for thermal performance calculations	$(\vartheta_m-\vartheta_a)_{max}$	90	K
Standard stagnation temperature (G = 1000 W/m²; ϑ_a = 30 °C)	ϑ_{stg}	196	°C
Effective thermal capacity, incl. fluid (per gross area, A_G)	C/m²	6,32	kJ/(Km²)
Maximum operating temperature	$\vartheta_{max\ op}$	100	°C
Maximum operating pressure	$p_{max\ op}$	600	kPa

Testing laboratory	Technický skúšobný ústav Piešťany, š.p	http://www.tsu.sk	
Test report(s)	120700004/1/P(D5) 110700001/1/PQ(D5)	Dated	4.3.2016 4.3.2016

Comments of testing laboratory — Datasheet version: 5.01, 2016-03-01

Performance parameters - complete re-evaluation of the test data of the previous test (according to EN 12975-2:2006) taking into account gross area.

TECHNICKÝ SKÚŠOBNÝ ÚSTAV PIEŠŤANY, š.p. Krajinská cesta 2929/9 921 01 PIEŠŤANY -318/3-

Technický skúšobný ústav Piešťany, š.p.
Address: Krajinská cesta 2929/9, 92101 Piešťany, Slovak Republic
Phone: +421 33 79 57 111, Fax: +421 33 77 23 716, E-mail: sv@tsu.sk, web: www.tsu.eu

TECHNICKÝ SKÚŠOBNÝ ÚSTAV PIEŠŤANY, š.p.

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Annex to Solar Keymark Certificate Supplementary Information	Licence Number	TSU 001-16/D
	Issued	2016-10-03

Annual collector output in kWh/collector at mean fluid temperature ϑ_m, based on ISO 9806:2013 test results

Standard Locations	Athens			Davos			Stockholm			Würzburg		
Collector name / ϑ_m	25°C	50°C	75°C	25°C	50°C	75°C	25°C	50°C	75°C	25°C	50°C	75°C
ELVOSOLAR TS300-2.03	2 335	1 707	1 164	1 793	1 277	843	1 319	888	563	1 432	961	599
Annual output per m² gross area	1 150	841	573	883	629	415	650	437	277	705	474	295
Fixed or tracking collector	Fixed (slope = latitude - 15°; rounded to nearest 5°)											
Annual irradiation on collector plane	1765 kWh/m²			1714 kWh/m²			1166 kWh/m²			1244 kWh/m²		
Mean annual ambient air temperature	18,5°C			3,2°C			7,5°C			9,0°C		
Collector orientation or tracking mode	South, 25°			South, 30°			South, 45°			South, 35°		

…mperatures). The calculation of the annual collector …ocalc Ver. 5.01 (March 2016). A detailed description

…n

	Water-Glycole	
	No	
	No	
…ollowing conditions:		
	C	--
	1000	Pa
	1000	Pa
		m

Energy Labelling Information

	Reference Area, A_{sol} (m²)	Data required for CDR (EU) No 811/2013 - Reference Area A_{sol}		
ELVOSOLAR TS300-2.03	2,03	Collector efficiency (η_{col})	57	%

Remark: Collector efficiency (η_{col}) is defined in CDR (EU) No 811/2013 as collector efficiency of the solar collector at a temperature difference between the solar collector and the surrounding air of 40 K and a global solar irradiance of 1000 W/m², expressed in % and rounded to the nearest integer. Deviating from the regulation η_{col} is based on reference area (A_{sol}) which is aperture area for values according to EN 12975-2 or gross area for ISO 9806:2013.

Data required for CDR (EU) No 812/2013 - Reference Area A_{sol}		
Zero-loss efficiency (η_0)	0,712	--
First-order coefficient (a_1)	3,18	W/(m²K)
Second-order coefficient (a_2)	0,010	W/(m²K²)
Incidence angle modifier IAM (50°)	0,95	--

Remark: The data given in this section are related to collector reference area (A_{sol}) which is aperture area for values according to EN 12975-2 or gross area for ISO 9806. Consistent data sets for either aperture or gross area can be used in calculations like in the regulation 811 and 812 and simulation programs.

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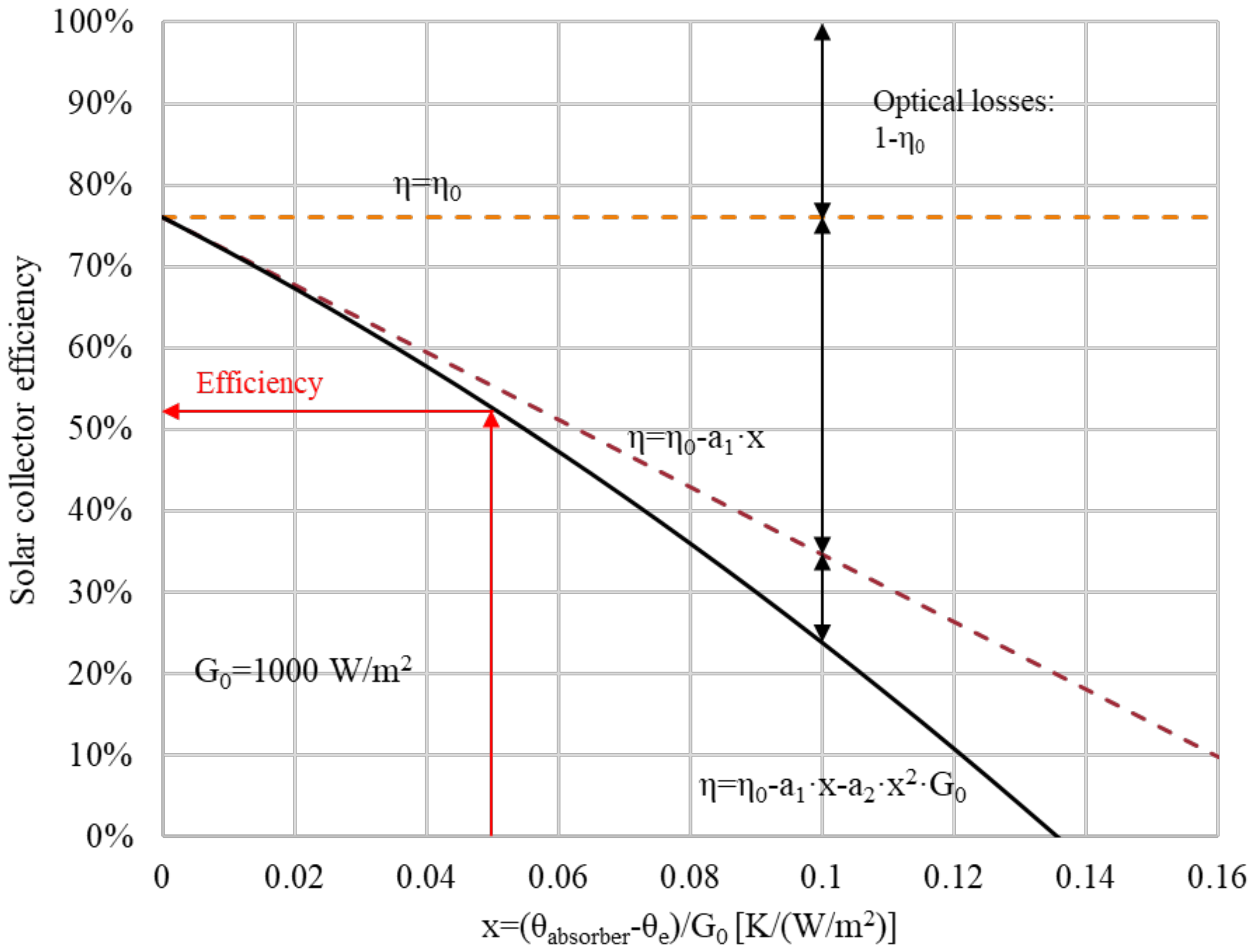
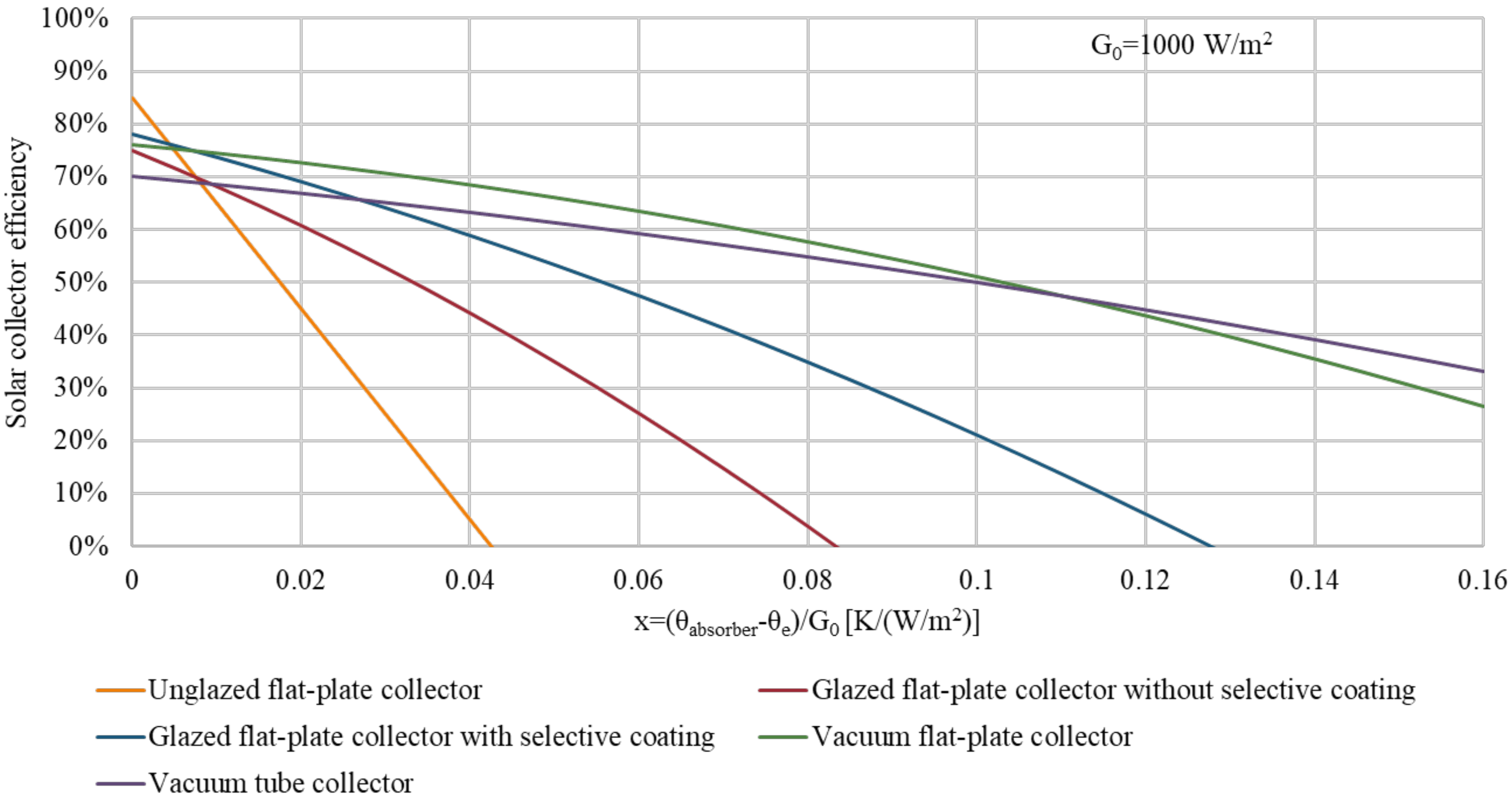
Solar collector efficiency



Solar collector efficiency



Demand side

DHW production

- Net DHW demand (usually yearly)
- Distribution and storage losses (usually yearly)

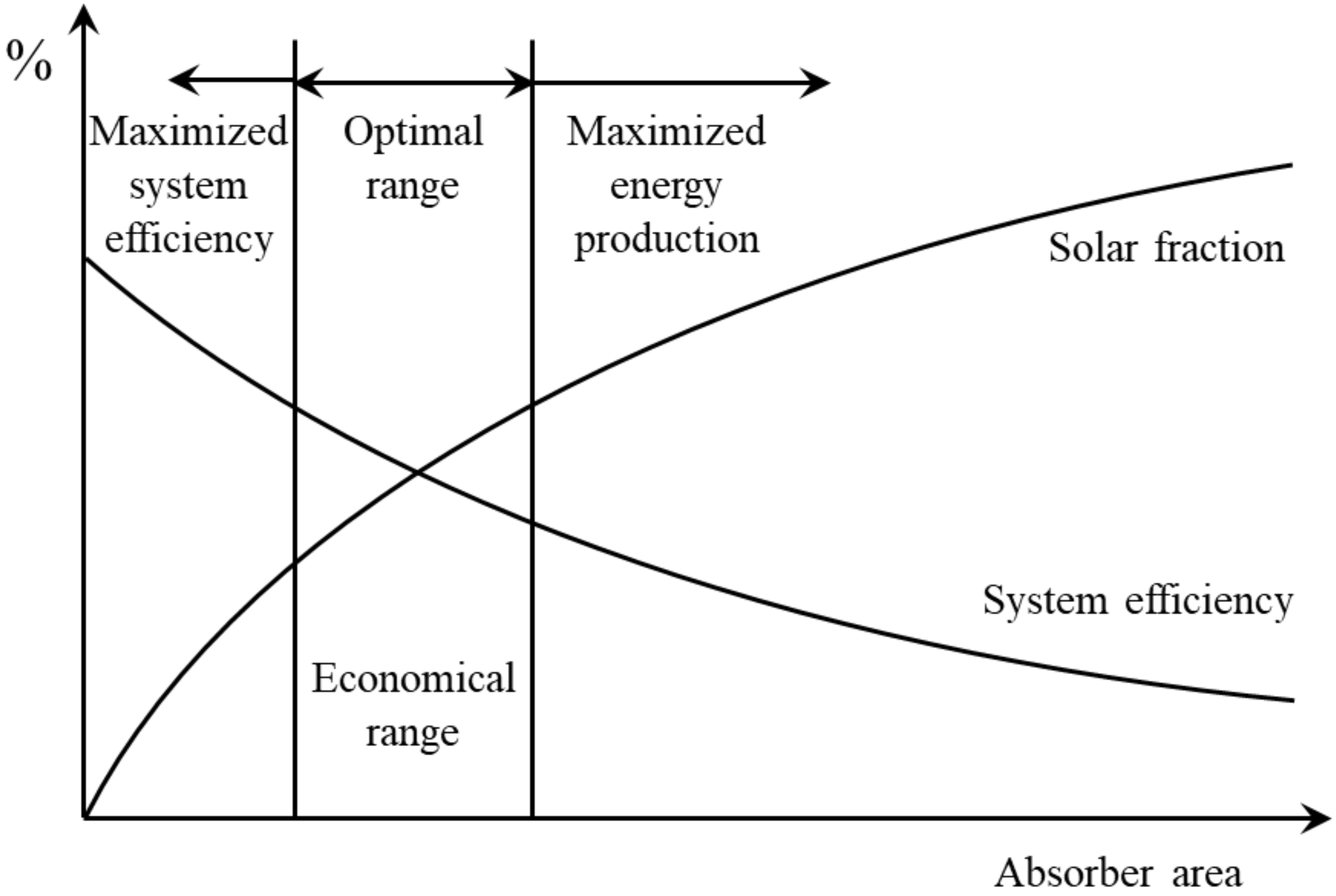
Space heating

- Net heating demand (seasonal)
- Distribution and storage losses (seasonal)

Pool heating

Other

System size



%
Maximized system efficiency
Optimal range
Maximized energy production
Solar fraction
System efficiency
Economical range
Absorber area

Solar collector production: monthly method

Input parameters

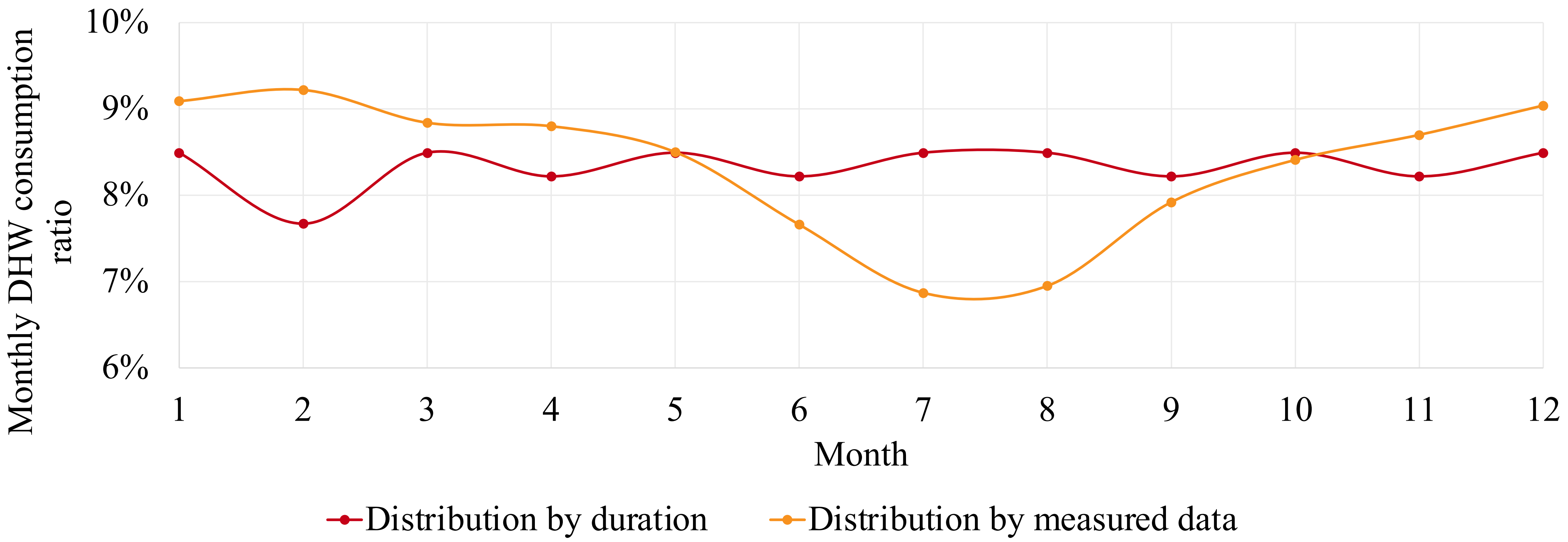
- Collector parameters, η_0, a_1, a_2, $K_{dir}(50°)$, *area*

- Monthly incoming radiation, $Q_{s,i}$
- Monthly DHW system energy demand, $Q_{demand,i}$

- Monthly outdoor temperature, $t_{e,i}$
- Reference temperature for the solar collector, t_{ref}
- DHW temperature, t_{DHW}
- Cold water temperature, t_{CW}

- Solar collector heat removal factor, *FR*
- Solar collector flow rate, *FR'/FR*
- DHW storage tank size, V_t

Monthly DHW demand



Solar collector production: monthly method

$$\frac{\boldsymbol{X_{c1}}}{\boldsymbol{X}} = \frac{11{,}6 + 1{,}18 \cdot t_{HMV} + 3{,}86 \cdot t_{víz} - 2{,}32 \cdot t_{e,i}}{t_{ref} - t_{e,i}}$$

$$\frac{\boldsymbol{X_{c2}}}{\boldsymbol{X}} = \left(\frac{V_{t,a}}{V_{t,opt}}\right)^{-0{,}25} = \left(\frac{0{,}7 \cdot V_t}{0{,}075 \cdot A_{koll}}\right)^{-0{,}25}$$

$$\boldsymbol{X} = \left(FR \cdot a_1 + FR \cdot a_2 \cdot \left(t_{HMV} - t_{e,i}\right)\right) \cdot \frac{FR'}{FR} \cdot \left(t_{ref} - t_{e,i}\right) \cdot \tau_m \cdot \frac{A_{koll}}{Q_{igény,i}} \cdot \frac{1}{1000}$$

Solar collector production: monthly method

$$\boldsymbol{X_c} = X \cdot \frac{X_{c1}}{X} \cdot \frac{X_{c2}}{X}$$

$$\boldsymbol{Y} = \eta_0 \cdot Q_{s,i} \cdot \frac{FR'}{FR} \cdot K_{dir}(50°) \cdot \frac{A_{koll}}{Q_{igény,i}}$$

$$\boldsymbol{f_i} = min(1{,}029 \cdot Y - 0{,}065 \cdot X_c - 0{,}245 \cdot Y^2 + 0{,}0018 \cdot X_c^2 + 0{,}0215 \cdot Y^3; 1)$$

$$\boldsymbol{Q_{koll,i}} = f_i \cdot Q_{HMV,tot,i}$$

Monthly method – single family house

Final energy demand of DHW system:

$$Q_{DHW} = q_{DHW} \cdot \left(1 + \frac{q_{DHW,d}}{100} + \frac{q_{DHW,s}}{100}\right) \cdot C_k \cdot \alpha_k \cdot A_N$$

Net DHW demand (A_N=133 m^2)

Above 80 m^2: 15 kWh/m^2year

Building type	Net DHW demand q_{DHW} [$kWh/m^2/year$]
Residential	30
Office	9
Education	7

$$q_{DHW} = \frac{(80 \cdot 30 + 53 \cdot 15)}{133} = \mathbf{24.0\ kWh/(m^2 year)}$$

DHW system

Condensing boiler: $C_k = 1.16$

Distribution losses: $q_{DHW,d} = 13\%$

Storage losses: $q_{SHW,s} = 23.4\%$

Solar collector system

- orientation, tilt angle: South, 30°

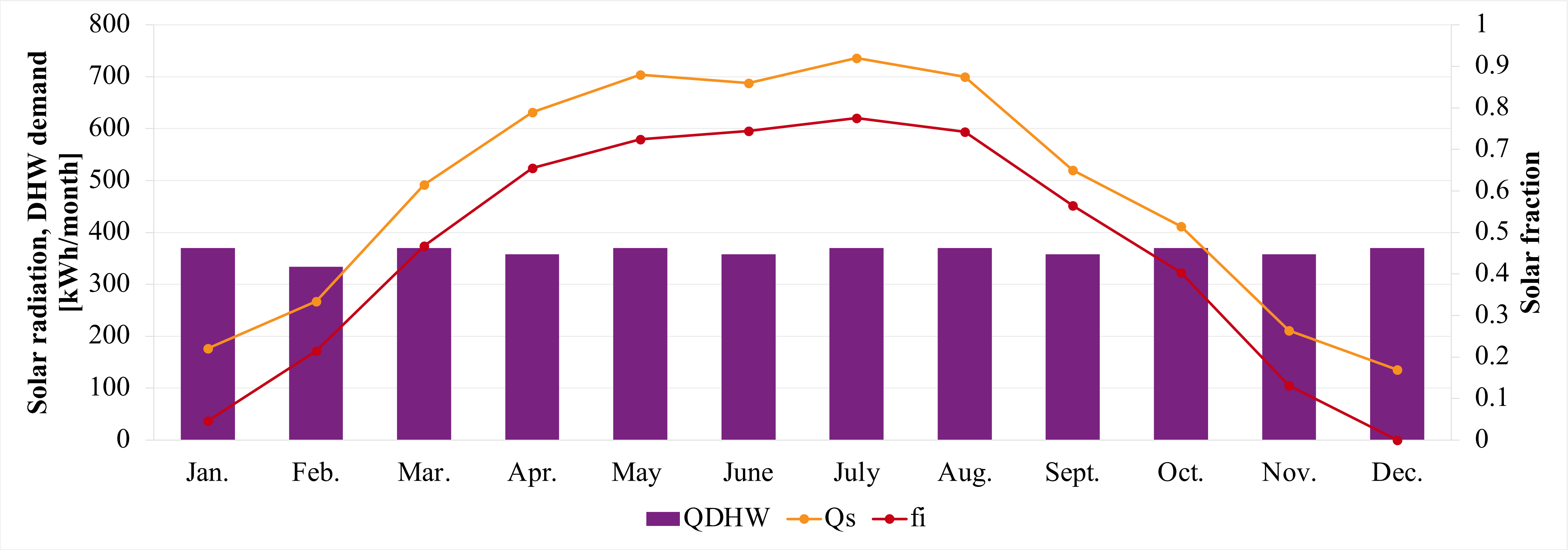
η_0	a_1	a_2	$K_{dir(50°)}$	FR	FR'/FR	t_{ref}	t_h	t_{HMV}	A_{koll}	V_t
0.79	3.79	0.01	0.92	0.95	0.8	100	10.6	50	4	0.2
[1]	$[W/(m^2K)]$	$[W/(m^2K^2)]$	[1]	[1]	[1]	[°C]	[°C]	[°C]	$[m^2]$	$[m^3]$

DHW system

Delivered energy demand

$$Q_{DHW} = q_{DHW} \cdot \left(1 + \frac{q_{DHW,d}}{100} + \frac{q_{DHW,s}}{100}\right) \cdot A_N = 24.0 \cdot \left(1 + \frac{13}{100} + \frac{23.4}{100}\right) \cdot 133 = 4354\ \frac{\text{kWh}}{\text{year}}$$

Solar collector output



Yearly solar fraction: 45.7%; Yearly DHW production: 1991 kWh

Simplified seasonal method

Limitations for application:

- Only residential DHW demand is covered by the solar collector system.
- The storage is at least 50 l/m^2 per solar collector area.

Simplified method

Determination of maximal collector production:

- Solar collector type (flat-plate/vacuum tube collector)
- Gross solar collector area
- Reference system area
- Storage and distribution

Reduction factor

Calculation of the solar fraction

DHW system

Condensing boiler: $C_k = 1.16$

Distribution losses: $q_{DHW,d} = 13\%$

Storage losses: $q_{DHW,s} = 23.4\%$

Solar collector system

- Flat-plate collector
- 4 m^2 gross collector area
- orientation, tilt angle: South, 30°

Maximal collector performance – Flat-plate collector

$\left[\frac{kWh}{year}\right]$	Reference system area [m²]														
Gross collector area [m²]	40	50	60	70	80	90	100	110	120	130	140	150	200	250	300
1,5	725	779	817	845	867	884	898	908	917	924	930	936	957	971	980
2	844	944	1006	1053	1089	1119	1142	1160	1175	1187	1198	1207	1245	1268	1284
2,5	911	1054	1159	1230	1283	1326	1362	1388	1411	1430	1446	1461	1517	1553	1578
3	963	1123	1265	1373	1451	1510	1558	1595	1626	1653	1676	1696	1775	1826	1861
4	1036	1224	1395	1547	1687	1796	1888	1948	1999	2043	2081	2115	2250	2337	2397
5	1089	1295	1485	1661	1822	1971	2109	2206	2296	2367	2423	2472	2672	2803	2893
6	1138	1349	1554	1745	1925	2093	2247	2377	2499	2599	2686	2765	3046	3227	3352
7	1184	1398	1608	1813	2005	2187	2361	2502	2634	2758	2875	2979	3374	3610	3775
8	1231	1445	1658	1868	2072	2264	2448	2605	2750	2883	3008	3126	3645	3956	4165
10	1291	1539	1752	1968	2178	2387	2590	2762	2924	3077	3223	3360	4014	4518	4848

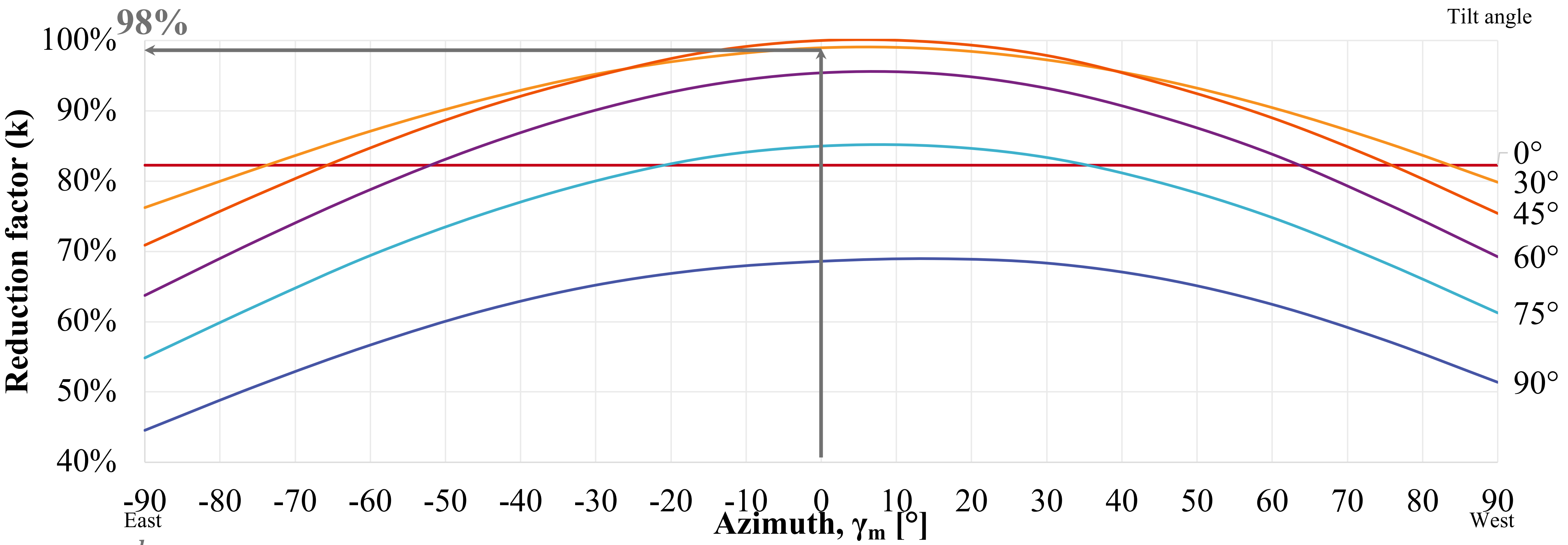
Net DHW demand (A_N=133 m^2)

Above 80 m^2: 15 kWh/m^2year

Building type	**Net DHW demand q_{DHW} [$kWh/m^2/year$]**
Residential	30
Office	9
Education	7

$$q_{DHW} = \frac{(80 \cdot 30 + 53 \cdot 15)}{133} = \mathbf{24.0}\ \boldsymbol{kWh/(m^2 year)}$$

Reduction factor for solar collectors



$$k = (9.88 \cdot 10^{-9} \cdot \alpha_m{}^2 - 1.18 \cdot 10^{-6} \cdot \alpha_m) \cdot \gamma_m{}^2 + (-4.99 \cdot 10^{-8} \cdot \alpha_m{}^2 + 9.25 \cdot 10^{-6} \cdot \alpha_m) \cdot \gamma_m + (-1.17 \cdot 10^{-4} \cdot \alpha_m{}^2 + 9.11 \cdot 10^{-3} \cdot \alpha_m + 0.821)$$

Solar fraction

$$q_{coll} = \frac{Q_{coll,max} \cdot k}{A_N} = \frac{2043 \cdot 0.98}{133} = \mathbf{15.05\ kWh/(m^2 year)}$$

$$\alpha_{coll} = \frac{q_{coll}}{q_{DHW} \cdot \left(1 + \frac{q_{DHW,d}}{100} + \frac{q_{DHW,s}}{100}\right)} =$$

$$\frac{15.05}{24.0 \cdot \left(1 + \frac{13}{100} + \frac{23.4}{100}\right)} = 0.460$$

Thank you very much for your attention!

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