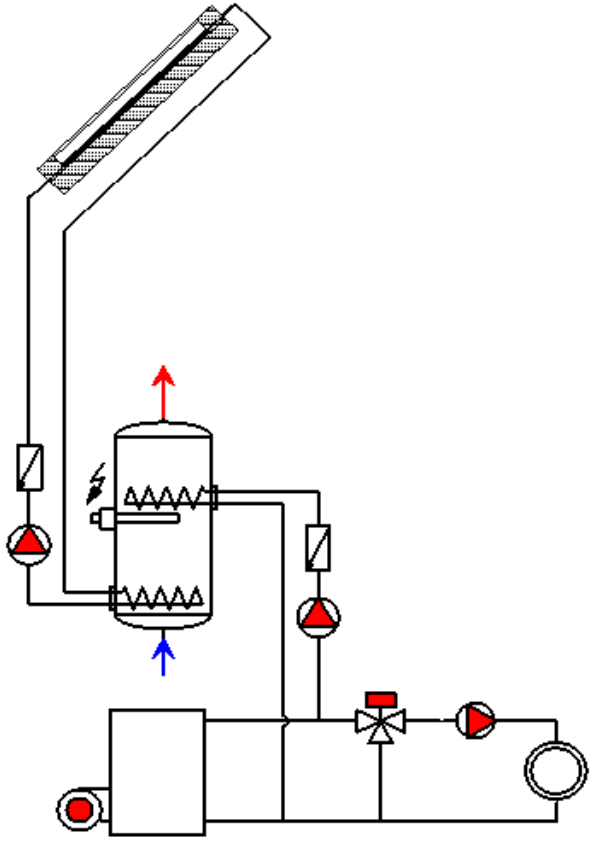
Solar systems

- evaluation of performance
- annual yields of solar systems
- typical values



Annual performance

Annual solar energy yields / savings by solar system installation

- simplified methods

  simple balance method (month)

  f-chart method

- simulation methods

  static – hour by hour calculation of main components

  dynamic simulation – for complex systems with high degree of detail

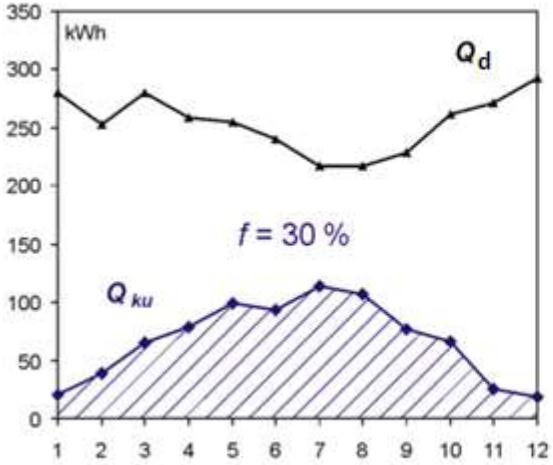
Simple balance method

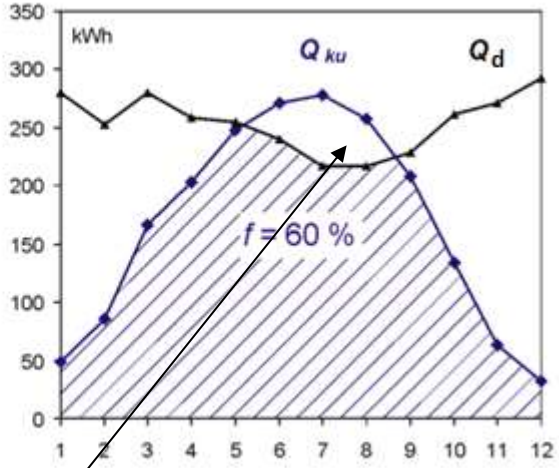
Balance of solar system

- for given collector area A_k
- for **all months** (reference design days, boundary conditions)

used solar system gain $Q_{ss,u}$

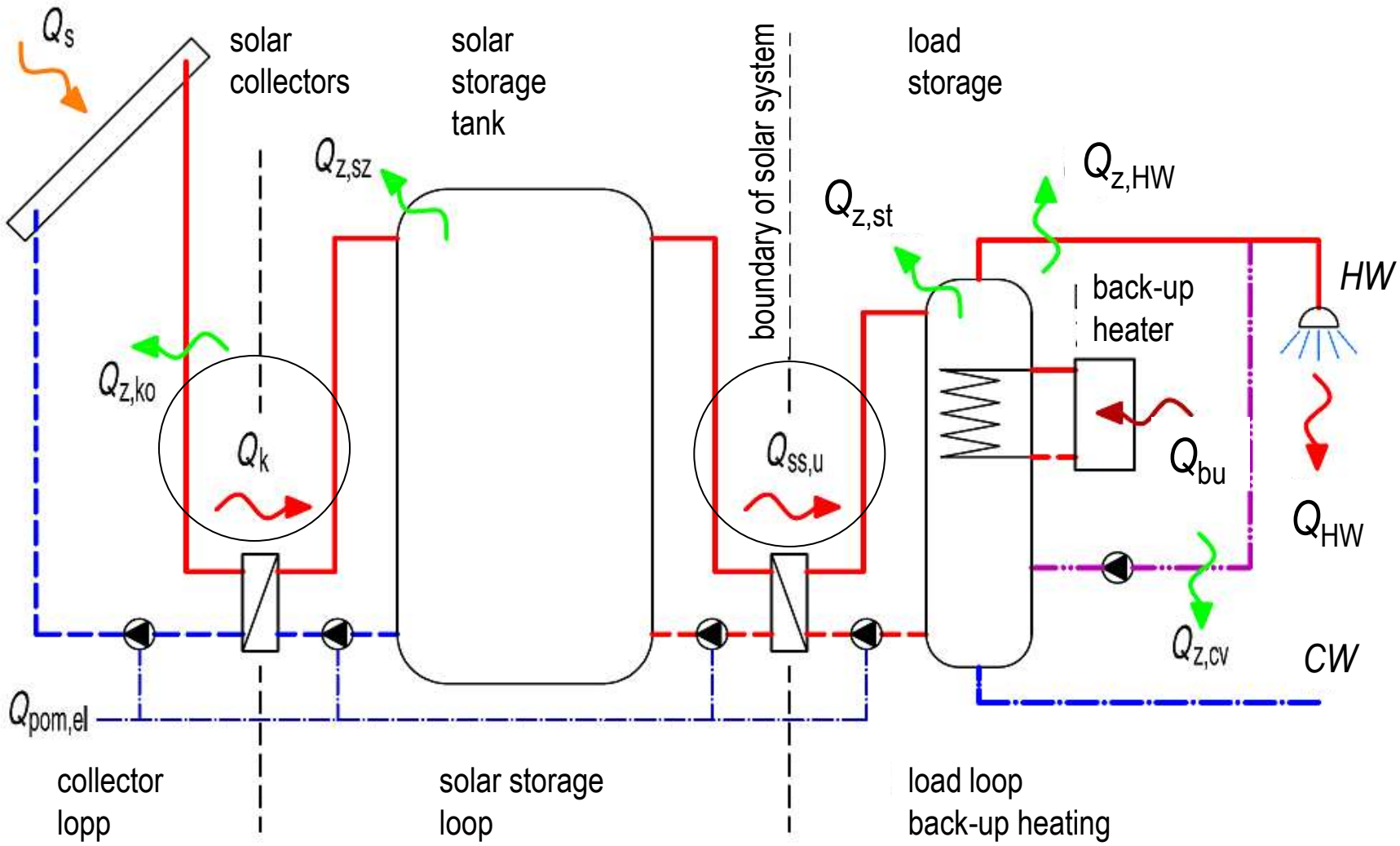
$$Q_{ss,u} = \min (Q_{k,u}; Q_d)$$





- usability of collector heat gains results from comparison with heat demand in individual months
- **excess heat gains can't be considered (!)**

Balance of solar system



supplied into storage Q_k **supplied to load $Q_{ss,u}$**

Solar system parameters

- **Annual heat gain,** (solar yield) **[kWh/a]**
  - supplied into storage Q_k
  - supplied to load – **used** solar system gain $Q_{ss,u}$

- **Annual energy savings Q_{sav} [kWh/a]**
  - influenced by **operational efficiency** of given heat source (boiler) η_{hs}
  - consumption of electricity for pumps in solar system
  - base for primary enegy savings, emission savings

Solar system parameters

- **Specific anual solar heat gain $q_{ss,u}$ [kWh/(m^2.a)]**
  - referenced to aperture area of solar collectors A_a
  - specific annual energy savings
  - economic parameter: savings / m^2 vs. investment / m^2

- **Solar coverage, solar fraction *f* [%]**

  f = 100 * used heat gain / heat demand (percentual coverage of demand)

- **Auxilliary energy consumption $Q_{aux,el}$ [kWh/a]**

  estimation: operation 2000 h x el. power for pumps, control, etc. [kW]

  usually < 1 % of gains

Solar system parameters

- **back up energy** (boiler)

$$Q_{bu} = Q_d - Q_{ss,u} \qquad [kWh/a]$$

Q_d heat demand - $Q_{ss,u}$ used solar system gain

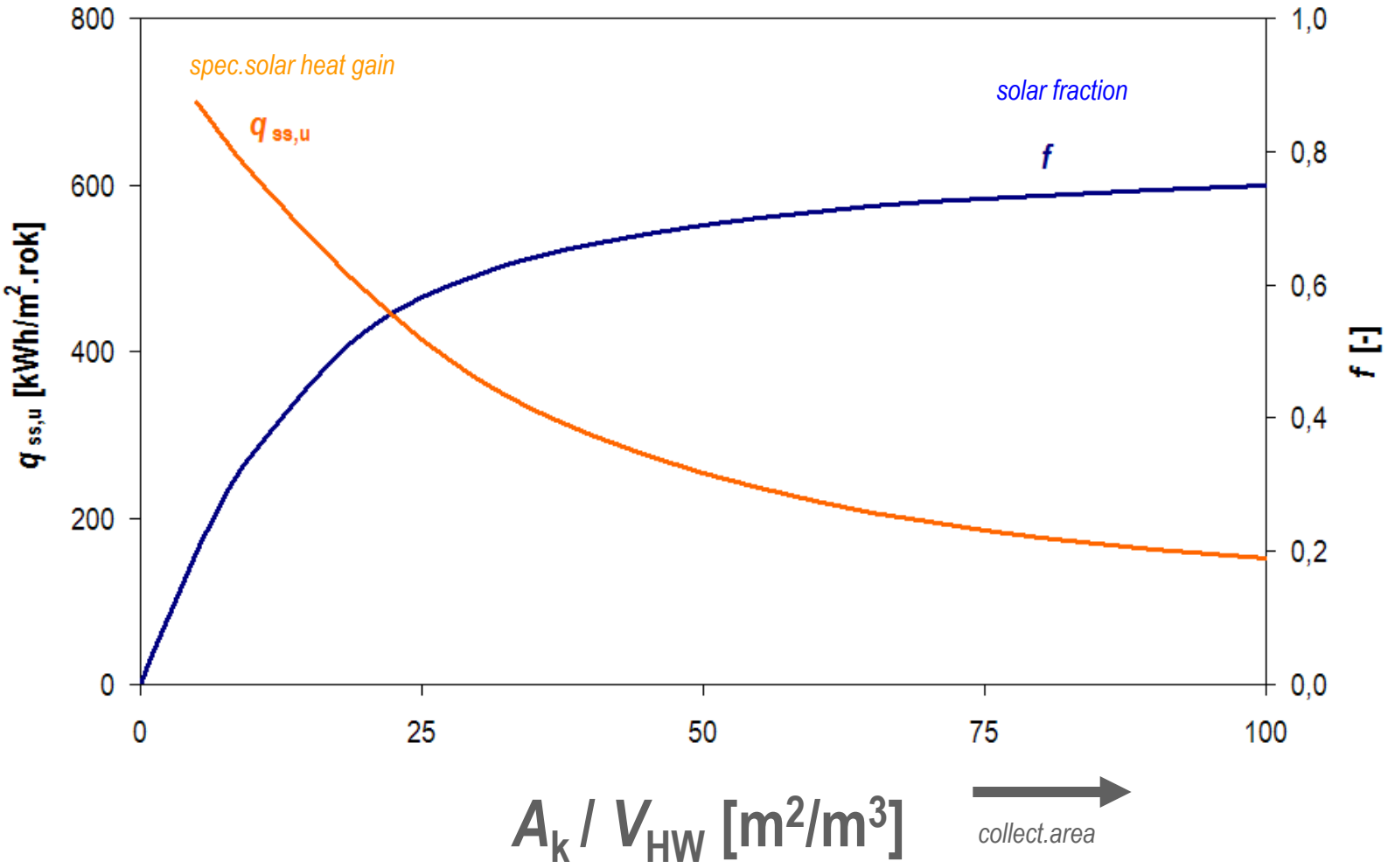
- **solar fraction**

$$f = \frac{Q_{ss,u}}{Q_d} = 1 - \frac{Q_{bu}}{Q_d} = \frac{Q_{ss,u}}{Q_{ss,u} + Q_{bu}} \qquad [-]$$

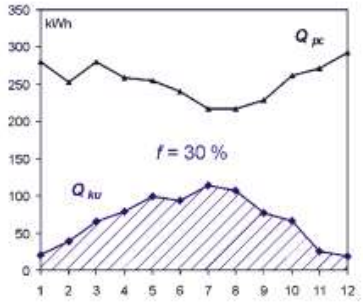
- **specific solar heat gain** $q_{ss,u}$ $[kWh/m^2.a]$

$$q_{ss,u} = \frac{\sum_{I}^{XII} Q_{ss,u}}{A_k}$$

Hot water example - balance



Hot water example - balance



$q_{ss,u}$ = 600 kWh/m^2 f = 40 %

$q_{ss,u}$

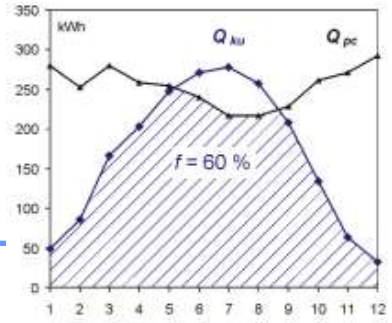
f

$q_{ss,u}$ [kWh/m^2.rok]

f [-]

A_k / V_{HW} [m^2/m^3]

Hot water example - balance



$q_{ss,u}$ = 400 kWh/m² f = 60 %

$q_{ss,u}$

f

$q_{ss,u}$ [kWh/m².rok]

f [-]

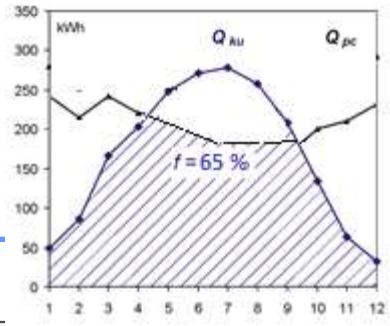
solar fraction

spec.solar heat gain

A_k / V_{HW} [m²/m³]

collect.area / DHW demand

Hot water example - balance



$q_{ss,u}$ = 300 kWh/m^2 f = 65 %

$q_{ss,u}$

f

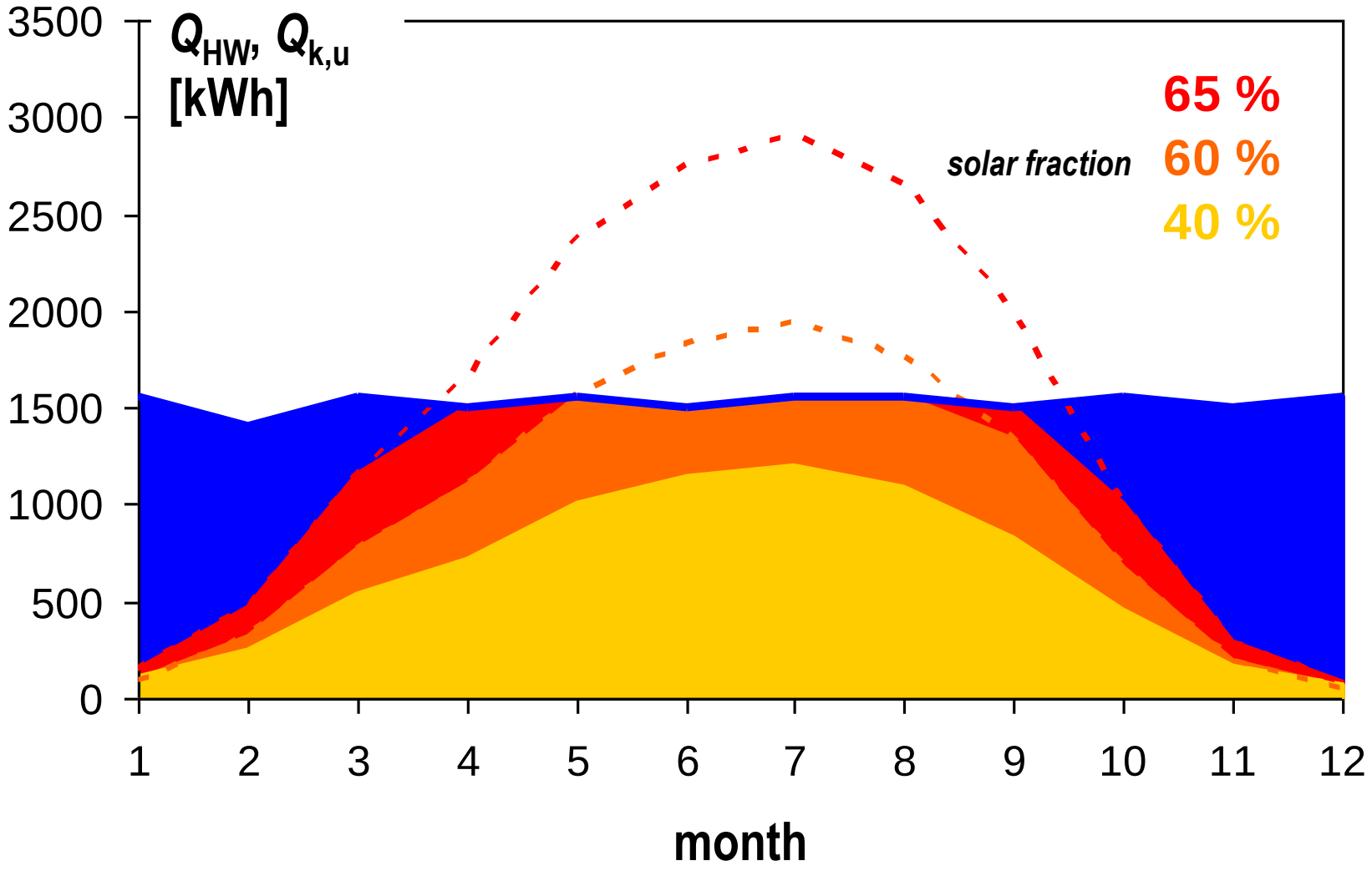
$q_{ss,u}$ [kWh/m^2.rok]

f [-]

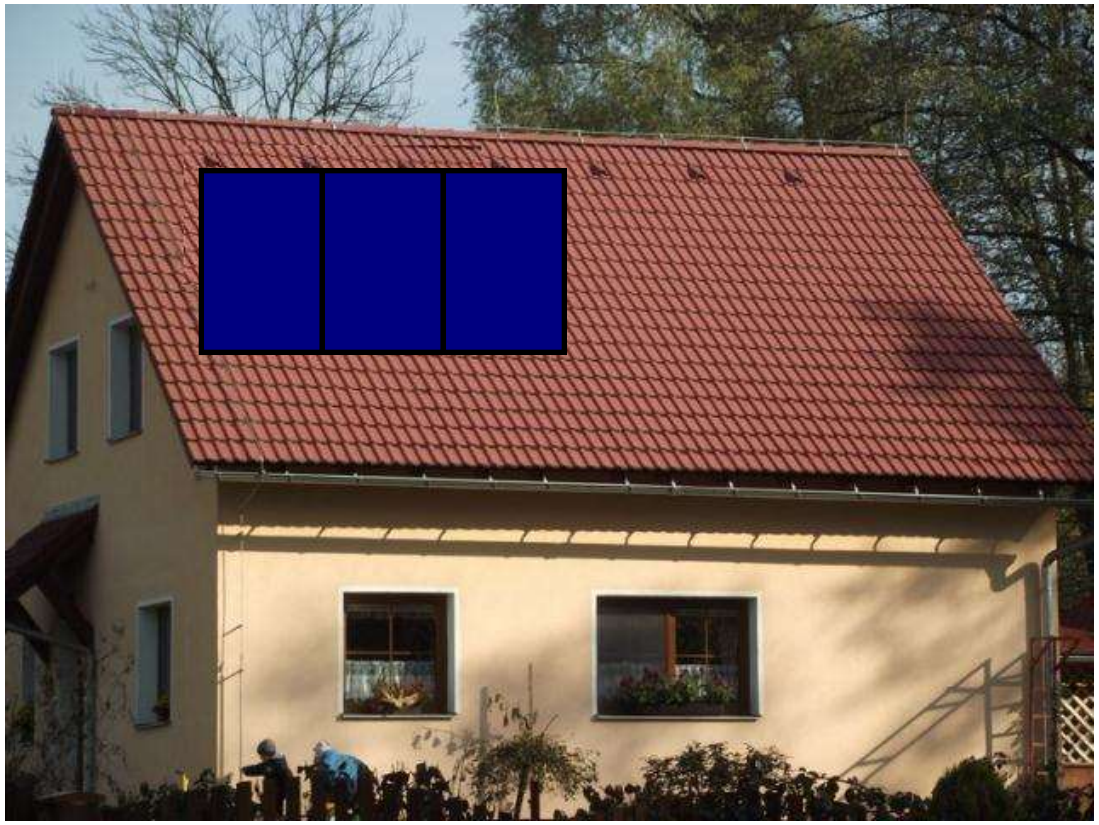
A_k / V_{HW} [m^2/m^3]

increase of solar fraction means decrease of specific heat gain

Hot water example - balance



Example 3 – solar DHW for family house



2 or 3 collectors?

Example 3 – solar DHW system

- **monthly heat demand $Q_{d,HW}$ for DHW**
  - daily demand **8.4 kWh/day** x number of days

- **monthly available solar system gain $Q_{k,u}$**
  - calculation of collector efficiency for given climate condition η_k
  - calculation of monthly irradiation $H_{T,month}$

- **balance of demand x gain**

$$Q_{ss,u,month} = \min\left[0{,}9 \cdot \eta_k \cdot H_{T,month} \cdot A_k \cdot (1-p)\,;\, Q_{d,HW}\right]$$

Example 3 – solar collector

- **solar collector: flat-plate**
  - $\eta_0 = 0.78$
  - $a_1 = 3.5\ W/m^2K$
  - $a_2 = 0.015\ W/m^2K^2$
  - $A_{k1} = 2.0\ m^2$ (aperture)

Example 3 – solar DHW system

month	t_{es}	G_m	η_k	$H_{T,month}$
	°C	W/m^2	–	kWh/m^2
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

Example 3 – solar DHW system

month	t_{es}	G_m	η_k	$H_{T,month}$
	°C	W/m^2	–	kWh/m^2
1	2,2	418		
2	3,4	489		
3	6,5	535		
4	12,1	527		
5	16,6	521		
6	20,6	517		
7	22,5	512		
8	22,6	515		
9	19,4	516		
10	13,8	488		
11	7,3	427		
12	3,5	387		

Example 3 – solar DHW system

month	t_{es}	G_m	η_k	$H_{T,month}$
	°C	W/m^2	–	kWh/m^2
1	2,2	418	0,41	
2	3,4	489	0,48	
3	6,5	535	0,53	
4	12,1	527	0,57	
5	16,6	521	0,61	
6	20,6	517	0,64	
7	22,5	512	0,65	
8	22,6	515	0,65	
9	19,4	516	0,63	
10	13,8	488	0,57	
11	7,3	427	0,47	
12	3,5	387	0,40	

Example 3 – solar DHW system

month	t_{es}	G_m	η_k	$H_{T,month}$
	°C	W/m^2	–	kWh/m^2
1	2,2	418	0,41	34,2
2	3,4	489	0,48	55,3
3	6,5	535	0,53	99,2
4	12,1	527	0,57	118,8
5	16,6	521	0,61	150,1
6	20,6	517	0,64	158,6
7	22,5	512	0,65	160,7
8	22,6	515	0,65	145,9
9	19,4	516	0,63	118,4
10	13,8	488	0,57	74,5
11	7,3	427	0,47	36,4
12	3,5	387	0,40	24,0

Example 3 – solar DHW system

	2 collectors	3 collectors		2 collectors	3 collectors
month	$Q_{ku,month}$	$Q_{ku,month}$	$Q_{d,HW}$	$Q_{ss,u}$	$Q_{ss,u}$
	kWh	kWh	kWh	kWh	kWh
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

Example 3 – solar DHW system

	2 collectors	3 collectors		2 collectors	3 collectors
month	$Q_{ku,month}$	$Q_{ku,month}$	$Q_{d,HW}$	$Q_{ss,u}$	$Q_{ss,u}$
	kWh	kWh	kWh	kWh	kWh
1	41	61			
2	76	114			
3	151	227			
4	196	294			
5	263	394			
6	291	437			
7	302	452			
8	274	412			
9	214	321			
10	123	184			
11	50	75			
12	28	41			

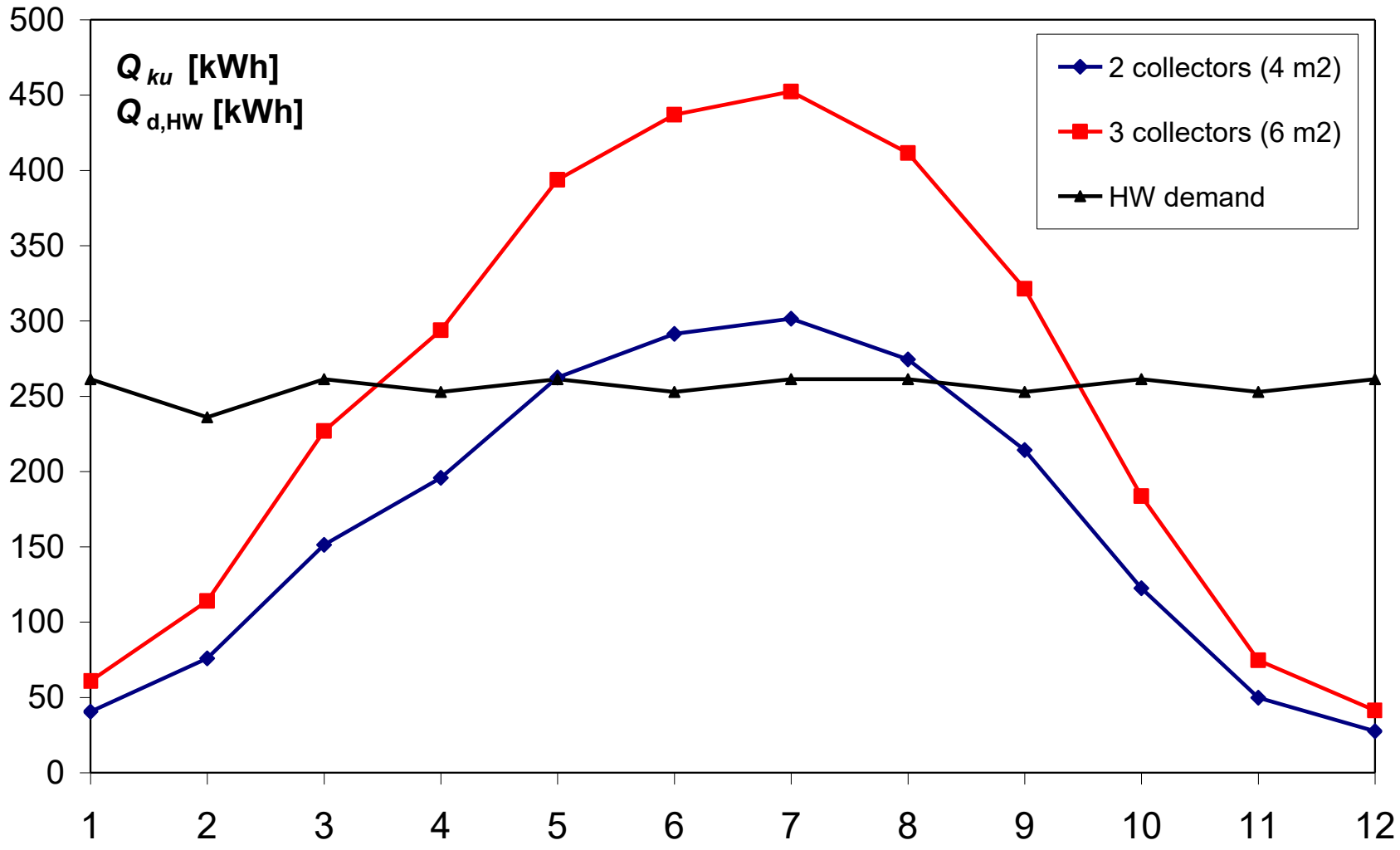
Example 3 – solar DHW system

	2 collectors	3 collectors		2 collectors	3 collectors
month	$Q_{ku,month}$	$Q_{ku,month}$	$Q_{d,HW}$	$Q_{ss,u}$	$Q_{ss,u}$
	kWh	kWh	kWh	kWh	kWh
1	41	61	261		
2	76	114	236		
3	151	227	261		
4	196	294	253		
5	263	394	261		
6	291	437	253		
7	302	452	261		
8	274	412	261		
9	214	321	253		
10	123	184	261		
11	50	75	253		
12	28	41	261		

Example 3 – solar DHW system

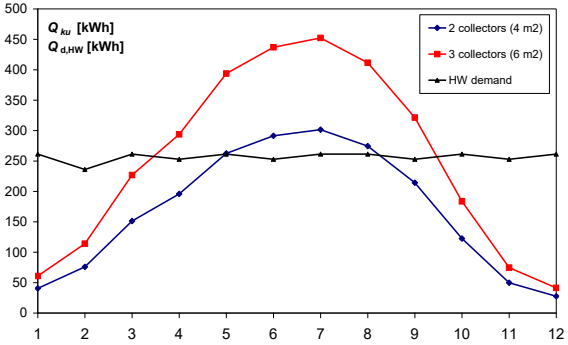
	2 collectors	3 collectors		2 collectors	3 collectors
month	$Q_{ku,month}$	$Q_{ku,month}$	$Q_{d,HW}$	$Q_{ss,u}$	$Q_{ss,u}$
	kWh	kWh	kWh	kWh	kWh
1	41	61	261	41	61
2	76	114	236	76	114
3	151	227	261	151	227
4	196	294	253	196	253
5	263	394	261	261	261
6	291	437	253	253	253
7	302	452	261	261	261
8	274	412	261	261	261
9	214	321	253	214	253
10	123	184	261	123	184
11	50	75	253	50	75
12	28	41	261	28	41

Example 3 – results



Example 3 – results

- **total heat demand $Q_{d,HW}$**
  - **3076 kWh/a**
- **total solar system usable gain $Q_{ss,u}$**
  - 2 collectors **1914 kWh/a**
  - 3 collectors **2243 kWh/a**



- **solar fraction**
  - 2 collectors **62 %**
  - 3 collectors **73 %**

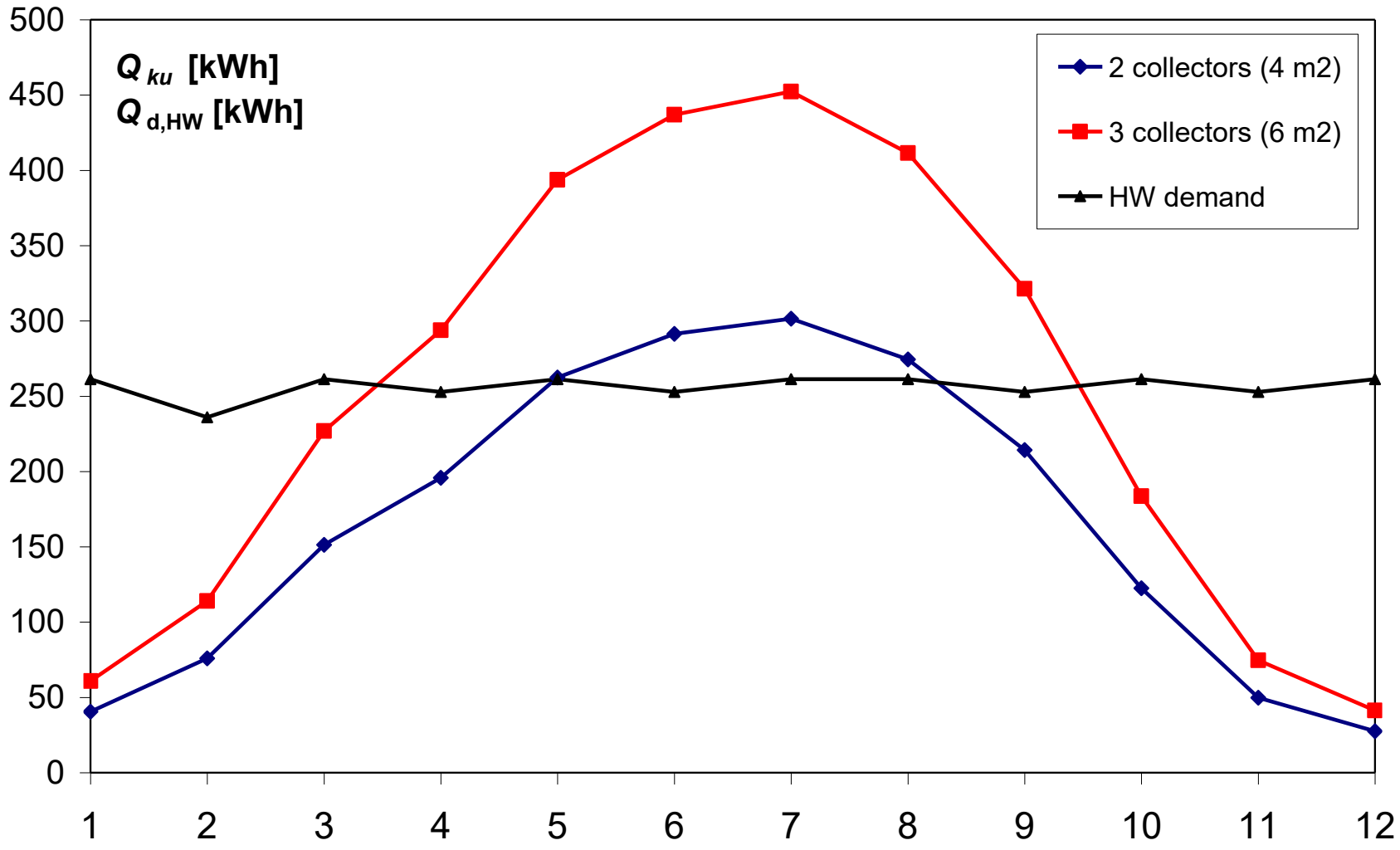
specific heat gains

479 kWh/m².a **economic**

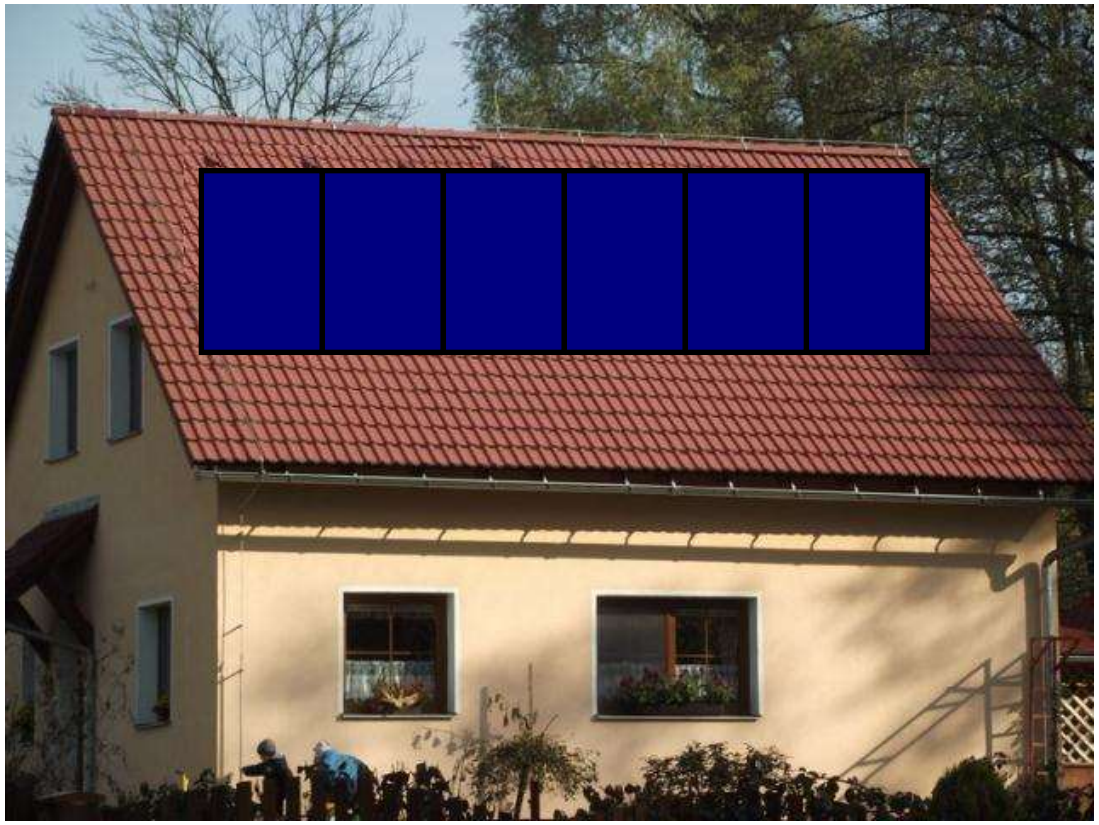
374 kWh/m².a **ecologic**

what is better?

Example 3 – results



Example 4 – solar combisystem



5 or 6 collectors ?

Example 4 – solar combisystem

měsíc	t_{es}	G_m	η_k	$H_{T,month}$
	°C	W/m^2	–	kWh/m^2
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

Example 4 – solar combisystem

month	t_{es}	G_m	η_k	$H_{T,month}$
	°C	W/m^2	–	kWh/m^2
1	2,2	418		
2	3,4	489		
3	6,5	535		
4	12,1	527		
5	16,6	521		
6	20,6	517		
7	22,5	512		
8	22,6	515		
9	19,4	516		
10	13,8	488		
11	7,3	427		
12	3,5	387		

Example 4 – solar combisystem

měsíc	t_{es}	G_m	η_k	$H_{T,month}$
	°C	W/m^2	–	kWh/m^2
1	2,2	418	0,30	
2	3,4	489	0,38	
3	6,5	535	0,44	
4	12,1	527	0,49	
5	16,6	521	0,52	
6	20,6	517	0,56	
7	22,5	512	0,57	
8	22,6	515	0,57	
9	19,4	516	0,55	
10	13,8	488	0,48	
11	7,3	427	0,37	
12	3,5	387	0,28	

Example 4 – solar combisystem

měsíc	t_{es}	G_m	η_k	$H_{T,month}$
	°C	W/m^2	–	kWh/m^2
1	2,2	418	0,30	34,2
2	3,4	489	0,38	55,3
3	6,5	535	0,44	99,2
4	12,1	527	0,49	118,8
5	16,6	521	0,52	150,1
6	20,6	517	0,56	158,6
7	22,5	512	0,57	160,7
8	22,6	515	0,57	145,9
9	19,4	516	0,55	118,4
10	13,8	488	0,48	74,5
11	7,3	427	0,37	36,4
12	3,5	387	0,28	24,0

Example 4 – solar combisystem

	5 collectors	6 collectors		5 collectors	6 collectors
měsíc	$Q_{ku,month}$	$Q_{ku,month}$	$Q_{d,HW+SH}$	$Q_{ss,u}$	$Q_{ss,u}$
	kWh	kWh	kWh	kWh	kWh
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

Example 4 – solar combisystem

	5 collectors	6 collectors		5 collectors	6 collectors
měsíc	$Q_{ku,month}$	$Q_{ku,month}$	$Q_{d,HW+SH}$	$Q_{ss,u}$	$Q_{ss,u}$
	kWh	kWh	kWh	kWh	kWh
1	73	88			
2	151	181			
3	316	379			
4	417	500			
5	566	679			
6	635	762			
7	659	791			
8	601	721			
9	465	558			
10	257	309			
11	96	115			
12	48	57			

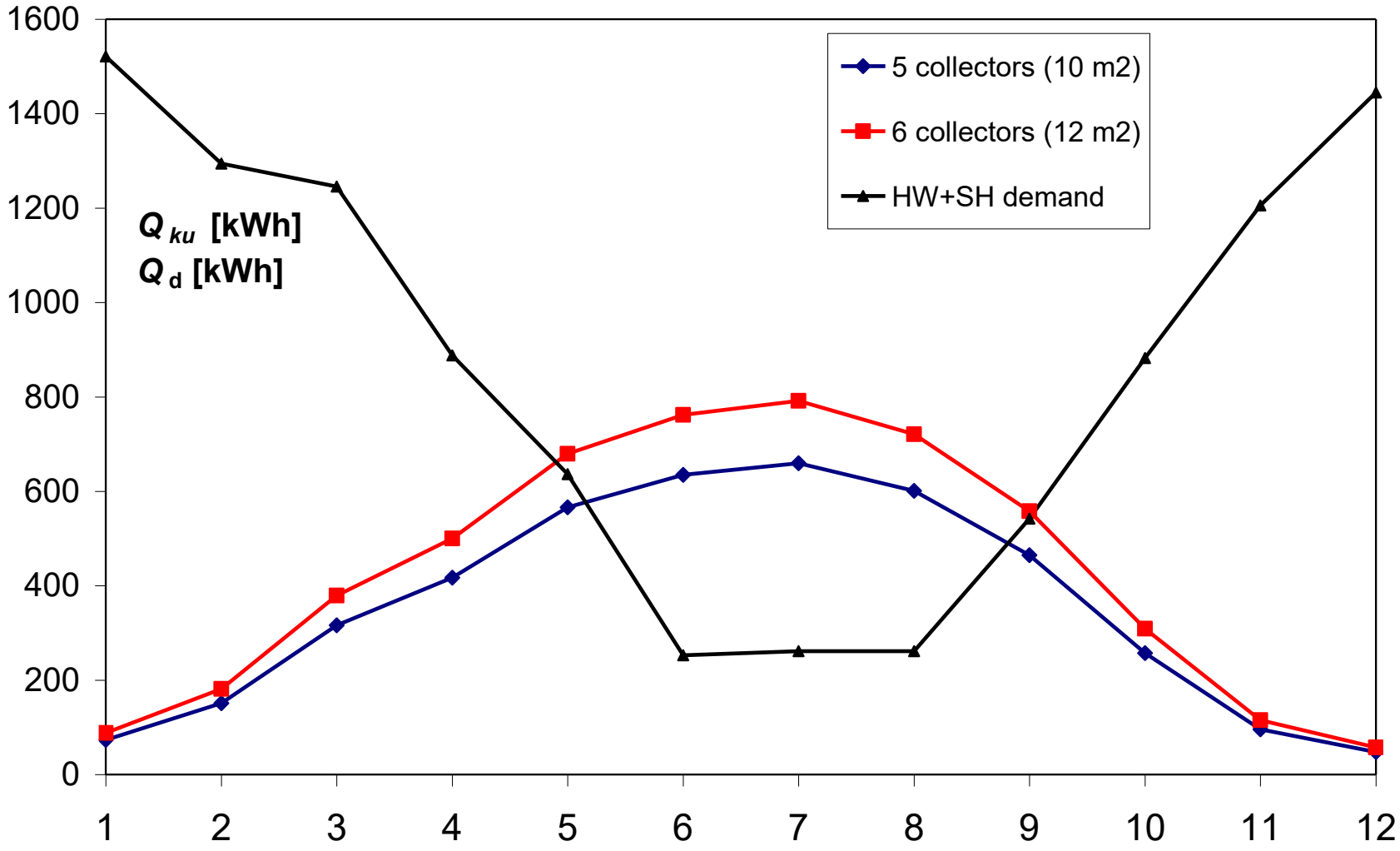
Example 4 – solar combisystem

	5 collectors	6 collectors		5 collectors	6 collectors
měsíc	$Q_{ku,month}$	$Q_{ku,month}$	$Q_{d,HW+SH}$	$Q_{ss,u}$	$Q_{ss,u}$
	kWh	kWh	kWh	kWh	kWh
1	73	88	1521		
2	151	181	1294		
3	316	379	1246		
4	417	500	888		
5	566	679	636		
6	635	762	253		
7	659	791	261		
8	601	721	261		
9	465	558	542		
10	257	309	882		
11	96	115	1205		
12	48	57	1445		

Example 4 – solar combisystem

	5 collectors	6 collectors		5 collectors	6 collectors
měsíc	$Q_{ku,month}$	$Q_{ku,month}$	$Q_{d,HW+SH}$	$Q_{ss,u}$	$Q_{ss,u}$
	kWh	kWh	kWh	kWh	kWh
1	73	88	1521	73	88
2	151	181	1294	151	181
3	316	379	1246	316	379
4	417	500	888	417	500
5	566	679	636	566	636
6	635	762	253	253	253
7	659	791	261	261	261
8	601	721	261	261	261
9	465	558	542	465	542
10	257	309	882	257	309
11	96	115	1205	96	115
12	48	57	1445	48	57

Example 4 – solar combisystem



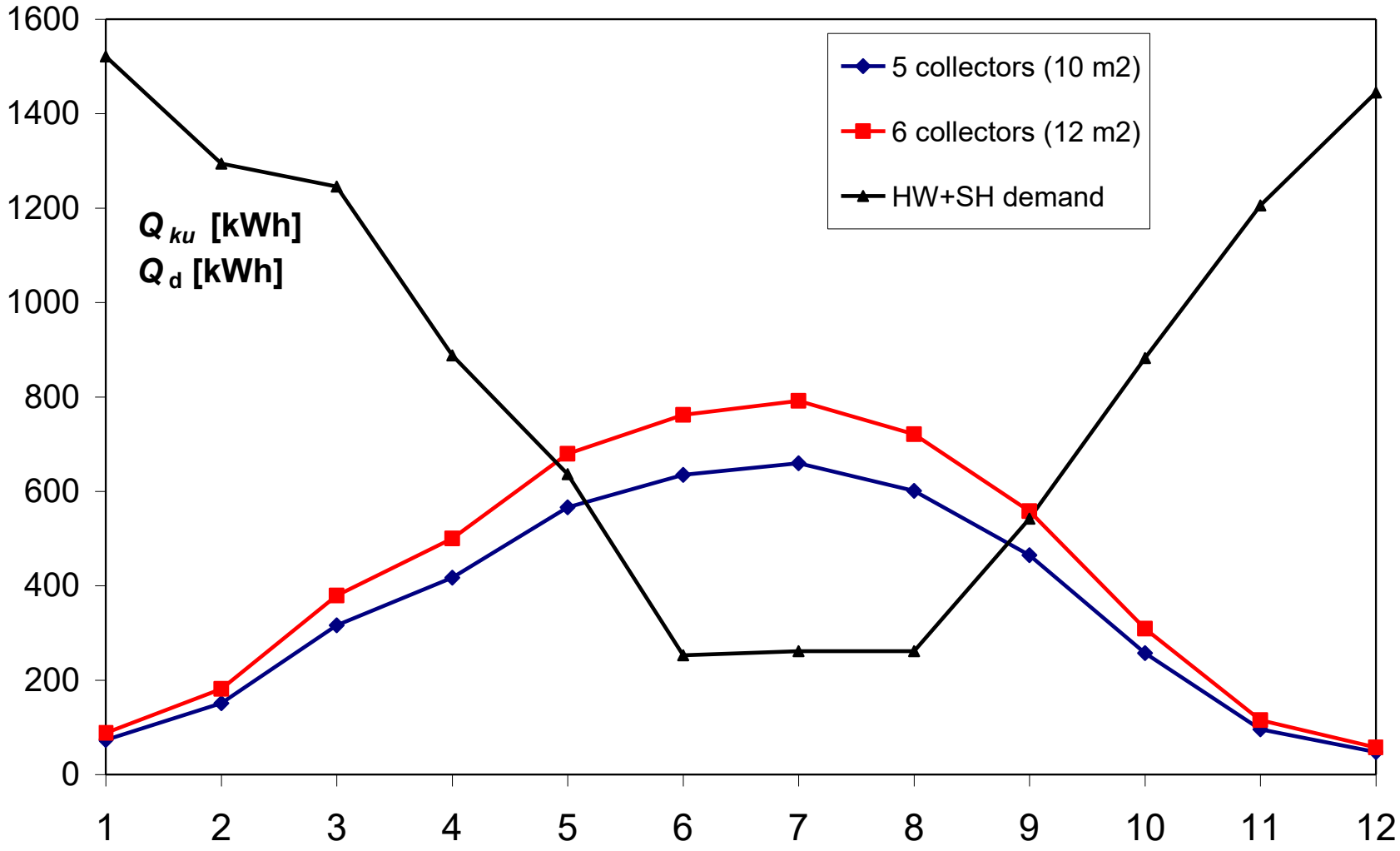
Example 4 – solar combisystem

- **total heat demand Q_d**
  - **10434 kWh/a**
- **total solar system usable gain $Q_{ss,u}$**
  - 5 collectors **3164 kWh/a**
  - 6 collectors **3583 kWh/a**

solar fraction		**specific heat gains**
5 collectors	**30 %**	**316 kWh/m^2.a**
6 collectors	**34 %**	**299 kWh/m^2.a**

what is better?

Example 4 – solar combisystem

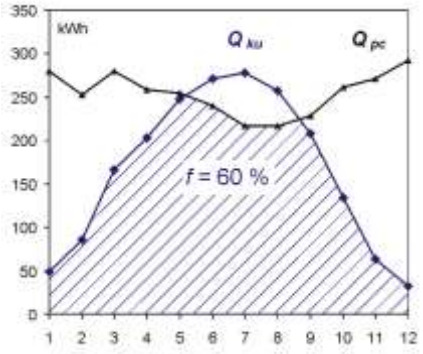


Performance of solar systems

- hot water
- combisystems
- pool water

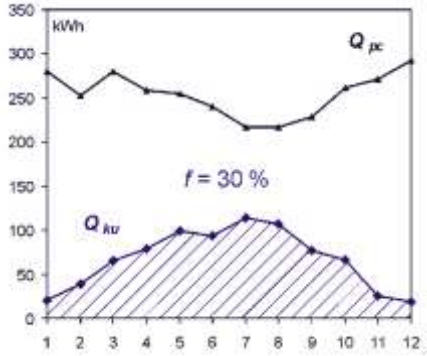
Solar hot water systems

- **family houses**
  - (3 to 6 m^2; 250 to 400 l), solar fraction 50 to 70 %
  - solar yields **300 to 400 kWh/m^2.a**



- **residential sector, hotels, ...**
  - (from 25 to 200 m^2; 1 to 8 m^3), solar fraction 40 to 50 %
  - solar yields **400 to 500 kWh/m^2.a**

- **hot water preheating**
  - solar fraction 20 to 40 %
  - solar yields **500 to 600 kWh/m^2.a**



Solar system in Meziboří – DHW

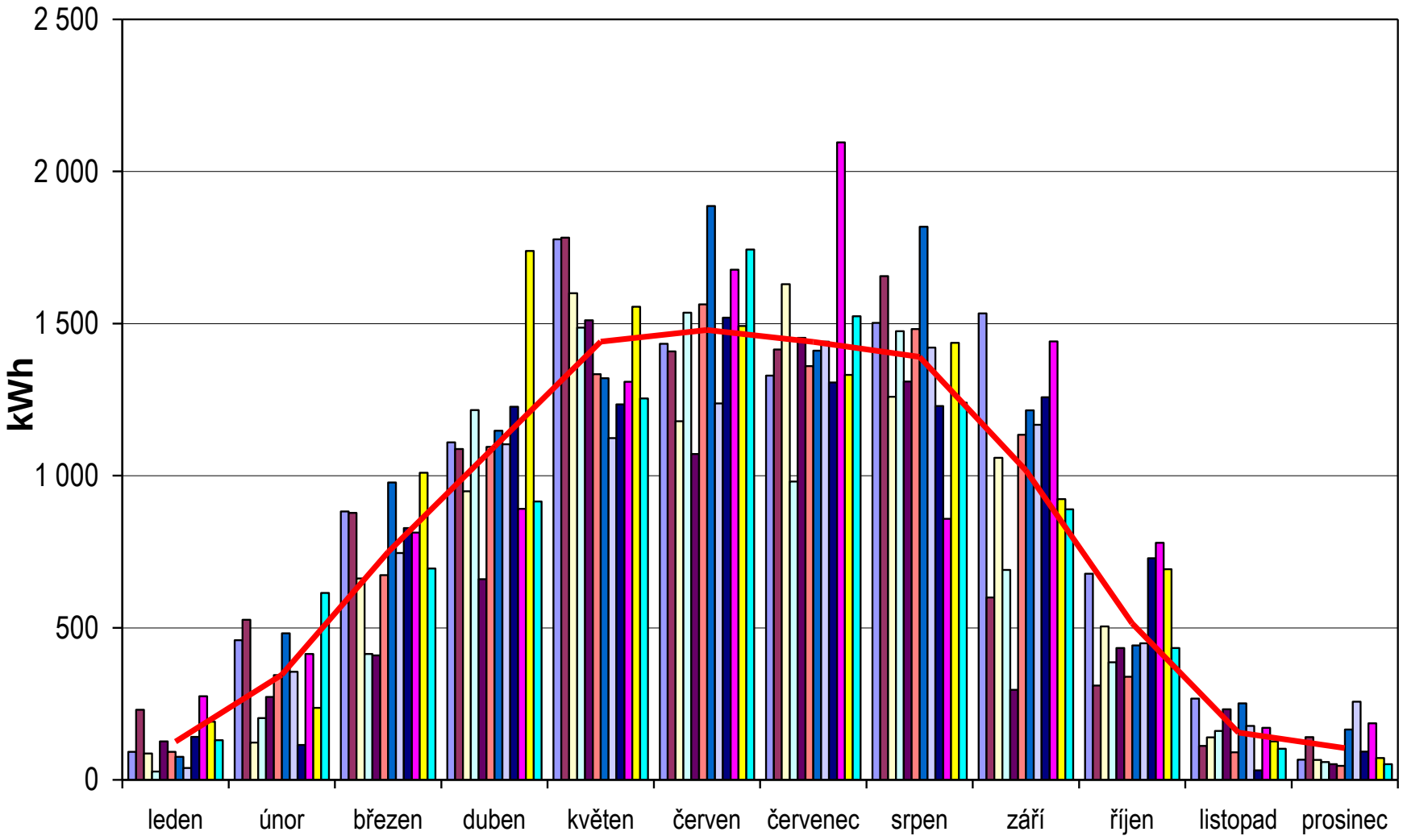
company Doterm Servis
administration building

installation 1996
offices
workshop
accommodation

measurement for more than12 years

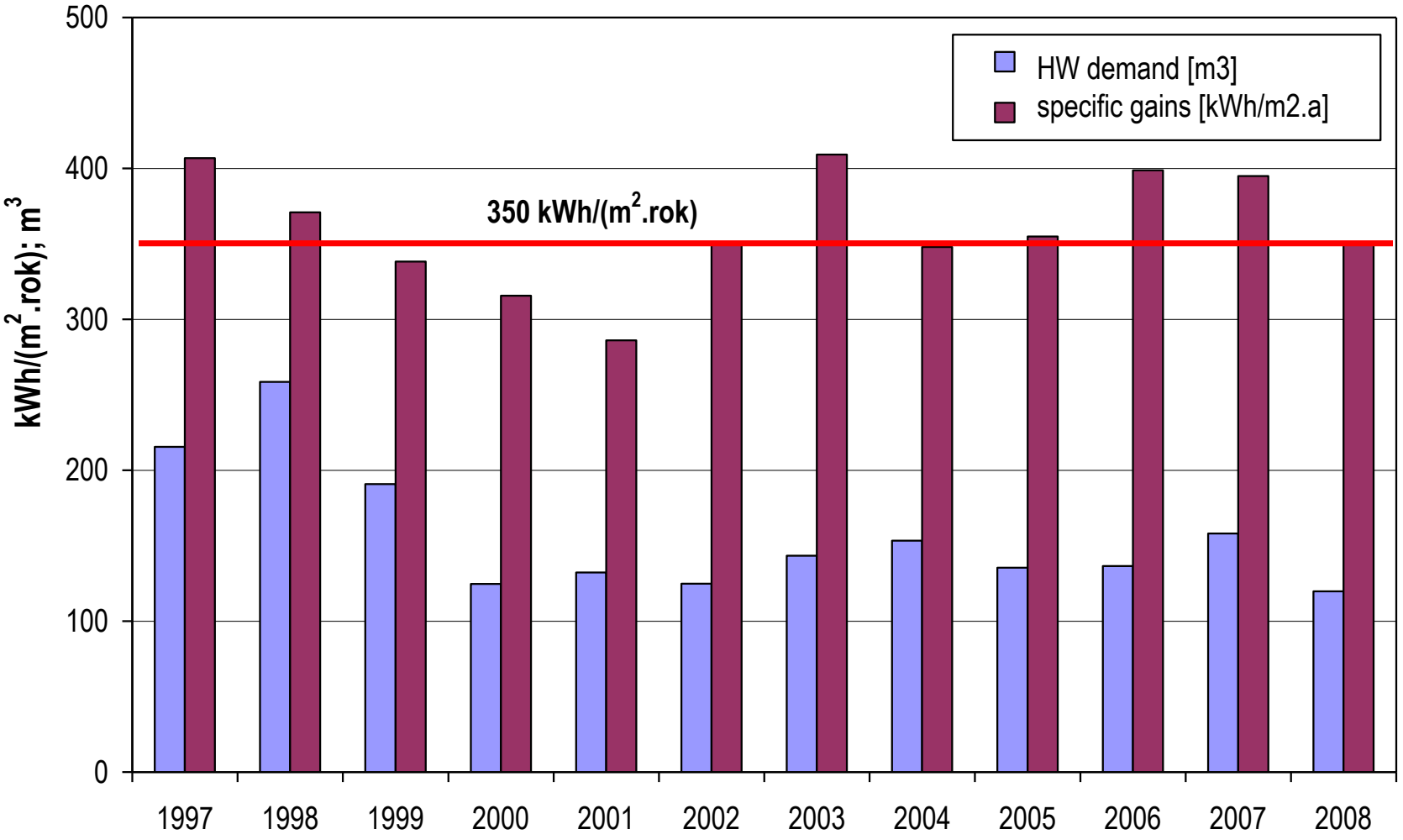
15 pcs flat-plate solar collectors Heliostar = 27 m^2

Solar system in Meziboří – DHW



Solar system in Meziboří – DHW

HW demand: 130 to 250 m^3 (high share of heat losses)

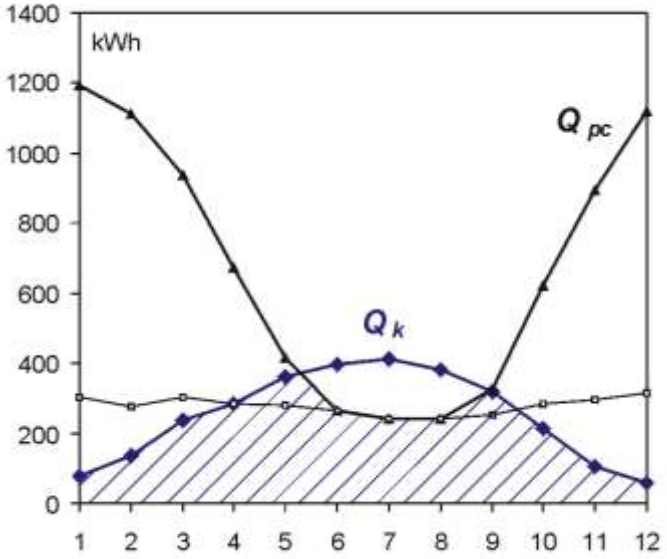


Solar combisystems

Solar combisystems

- **family houses**
  - (6 to 12 m^2; 1000 to 4 000 l)
  - solar fraction: standard houses 10 to 20 %
    low energy, passive houses 20 to 40 %
  - solar yields **250 to 350 kWh/m^2.a**

- **block of flats**
  - (40 to 200 m^2; 4 to 16 m^3)
  - solar fraction 10 to 20 %
  - solar yields **350 to 450 kWh/m^2.a**

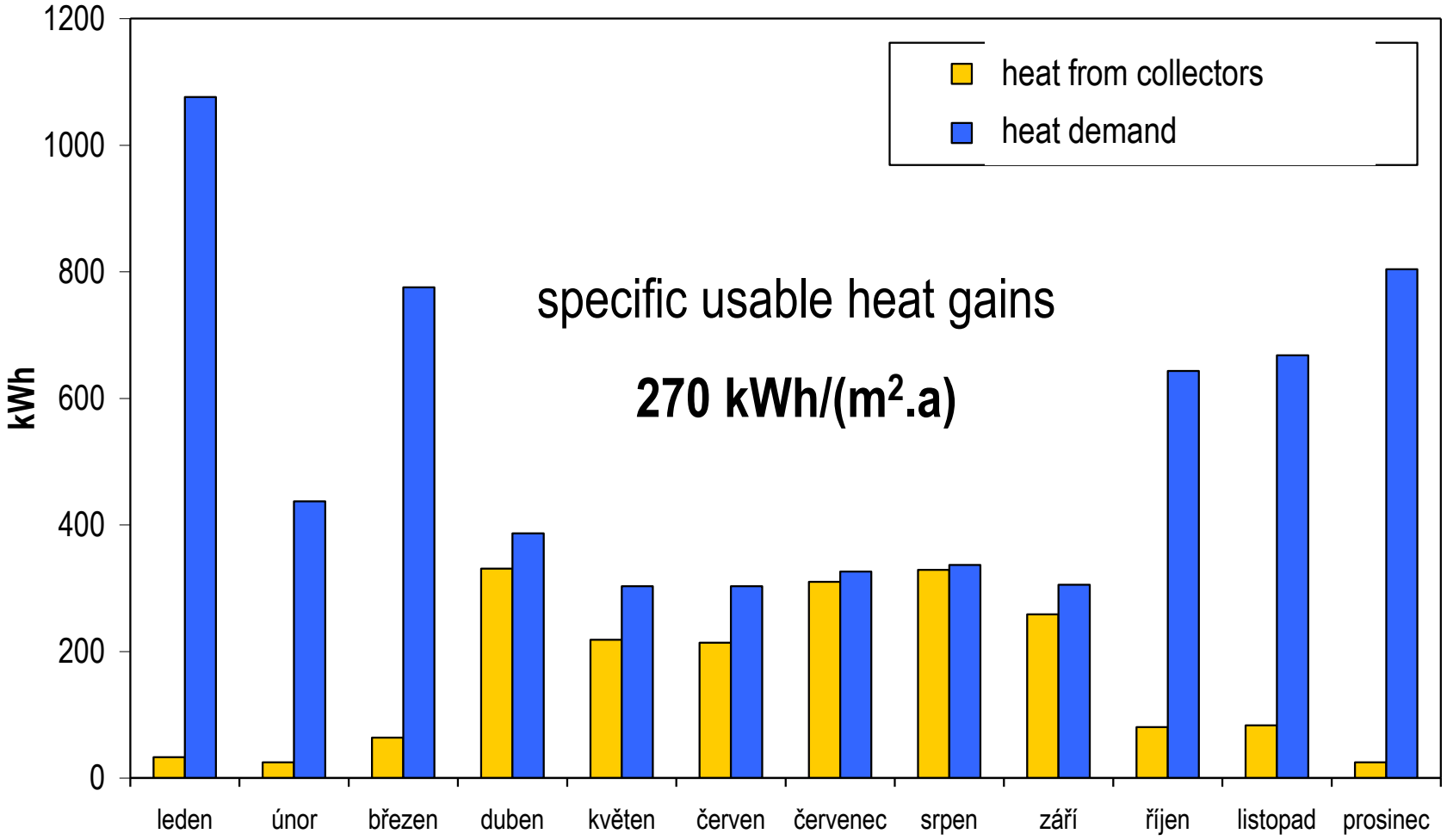


Solar system in Mnichovice (HW+SH)

family house, 4 persons, heat loss 5,2 kW

solar collector area 7,3 m^2, slope 60°

Solar system in Mnichovice (HW+SH)



Swimming pool heating

Swimming pool heating

- whole year – covered pools
- seasonal use – open, outdoor pools
- covering the heat losses from pool water surface, heating of fresh cold water
- pool is the storage

- specific energy yields above 500 kWh/m^2.a

  (if whole year operation)

Outdoor pool Rusava

installation 1984-1985

557 m^2 solar collectors SP 80/08

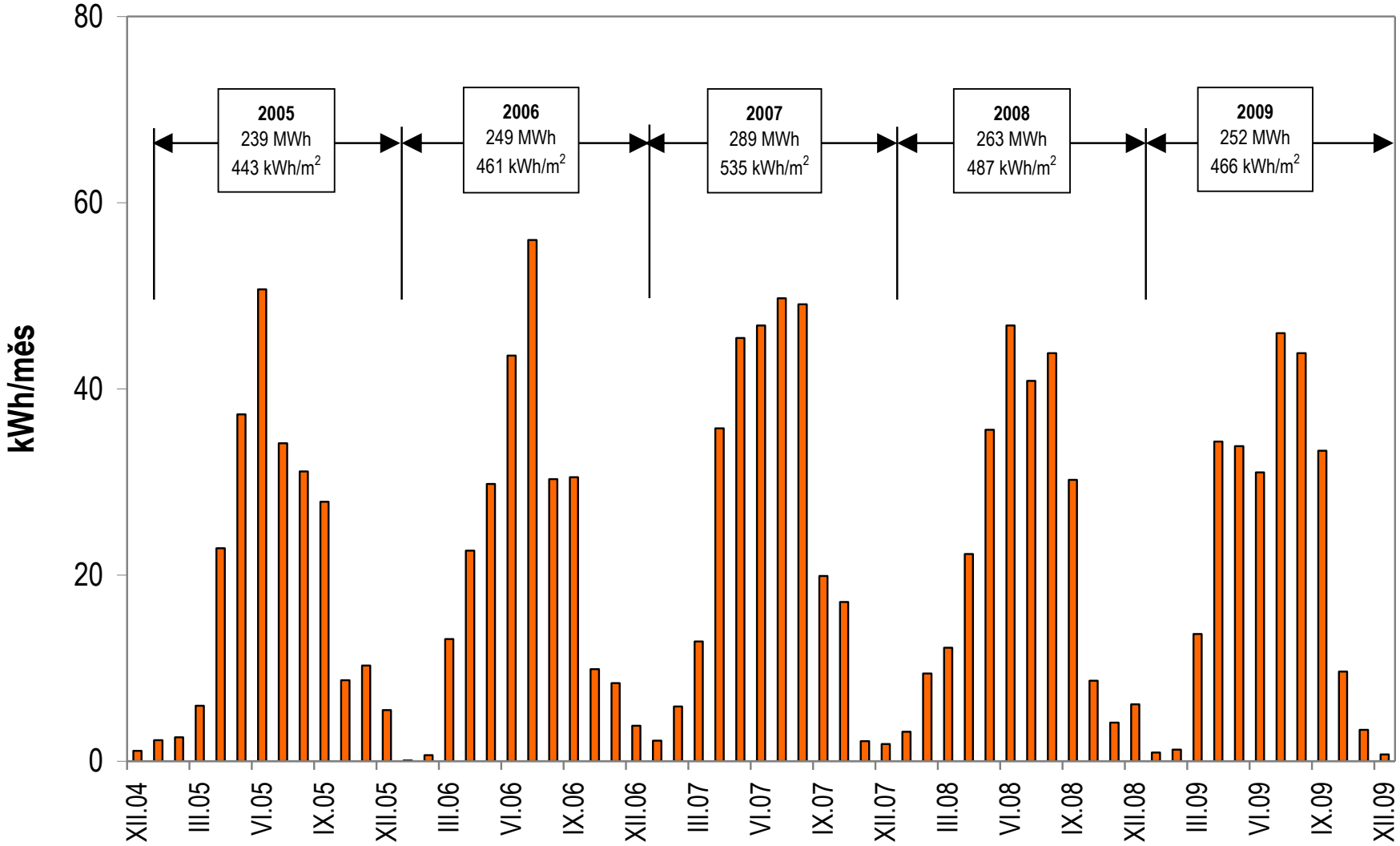
retrofit 2002

540 m^2 solar collectors Ekostart

Solar system in Rusava

Solar system in Rusava

Annual yields 450 to 540 kWh/m^2



Operation 1.5. – 30.9. 350 to 400 kWh/m²