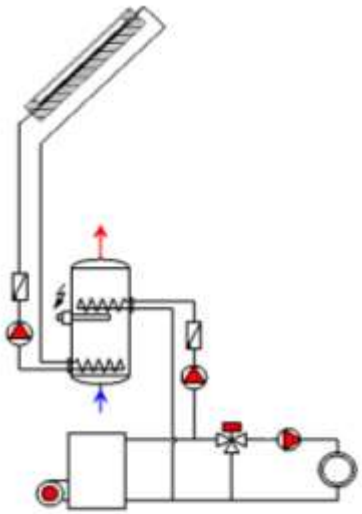
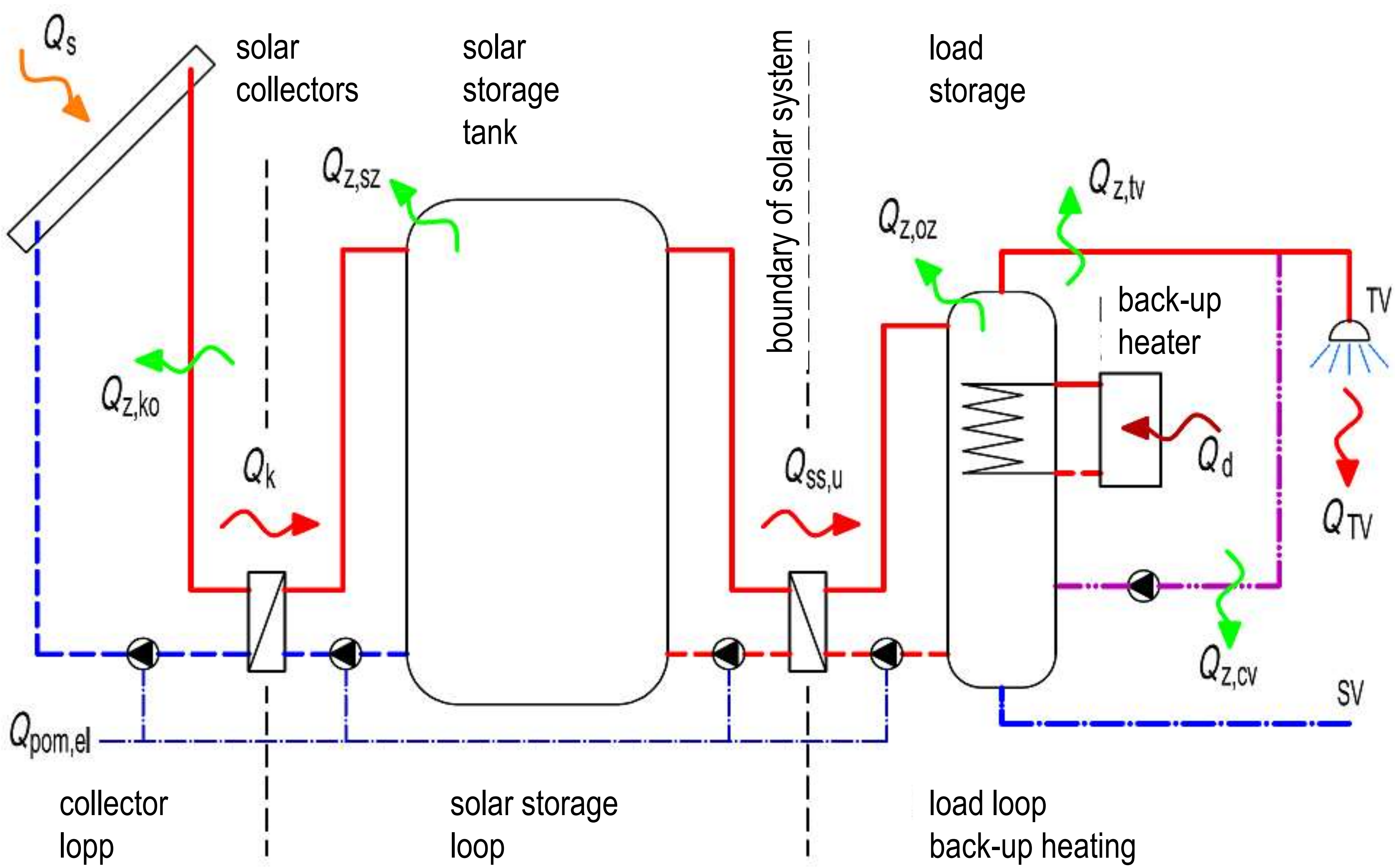
Solar systems design and evaluation

- designing & assessment
- nomograms
- balance method
- EN 15316-4-3 (f-chart)
- simulation tools



Balance of solar system



Solar system parameters

- **Annual heat gain, solar yield [kWh/a]**
  - supplied into storage Q_k
  - supplied to load – **used** solar system gain $\boldsymbol{Q}_{\mathbf{ss,u}}$
- **Annual energy savings $\boldsymbol{Q}_{\mathbf{u}}$ [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/(m².a)]**
  - referenced to aperture area of solar collectors A_a
  - specific annual energy savings
  - economic parameter: savings / m² vs. investment / m²

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

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

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

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

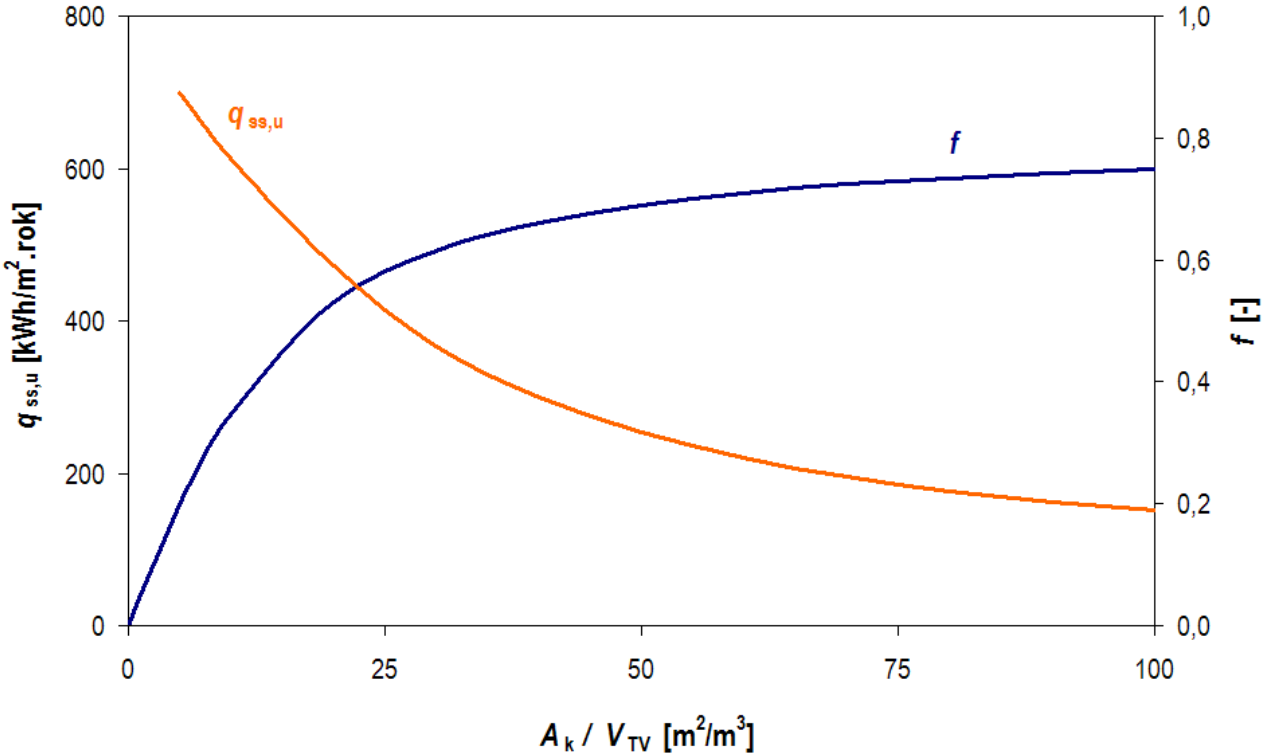
  usually < 1 % of gains

Calculations

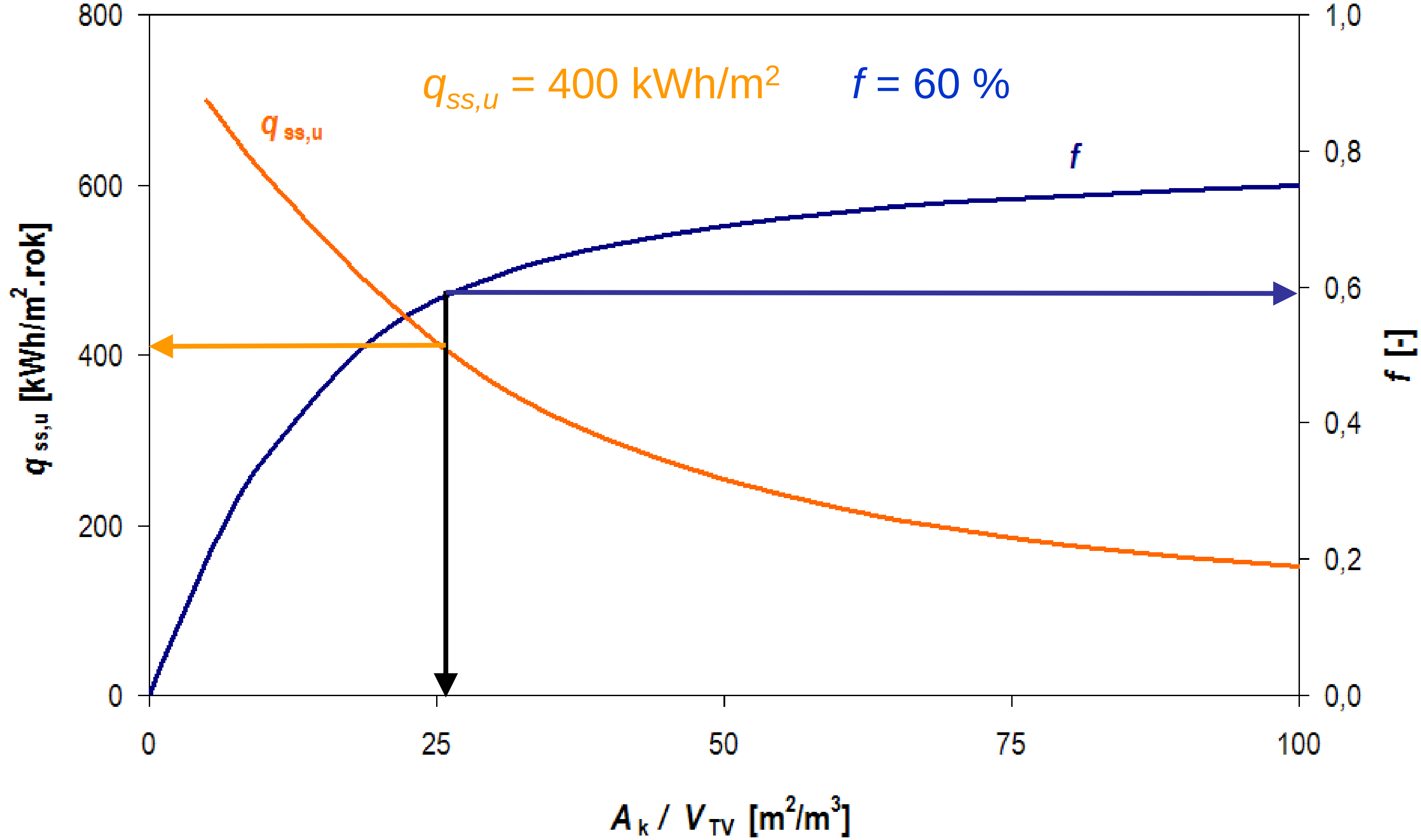
- **design**
  - daily heat demand in reference month
  - daily system yield for 1 m^2 of collector in reference month
  - **determination of collector area A_k**
- **assessment - annual balance (evaluation)**
  - monthly demands
  - monthly system energy yields for given collector area
  - balance, usability of yields
  - **used solar system energy yields Q_{ssu}, q_{ssu}**

Solar system parameters

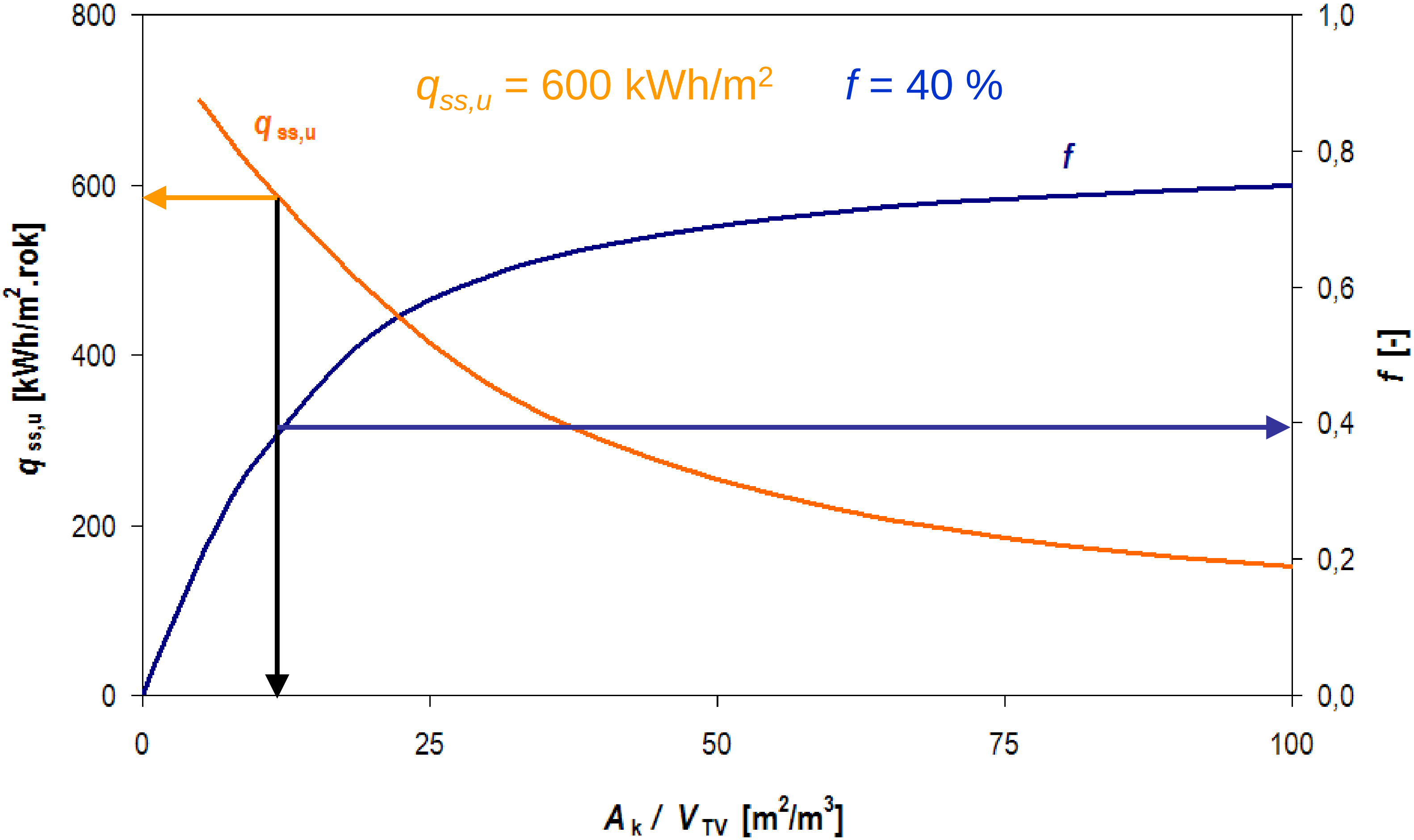
- **specific solar heat gain** $q_{ss,u}$ [kWh/m^2.a]
- **solar fraction** $$f = \frac{Q_{ss,u}}{Q_p} = 1 - \frac{Q_d}{Q_p} = \frac{Q_{ss,u}}{Q_{ss,u} + Q_d}$$ [-]



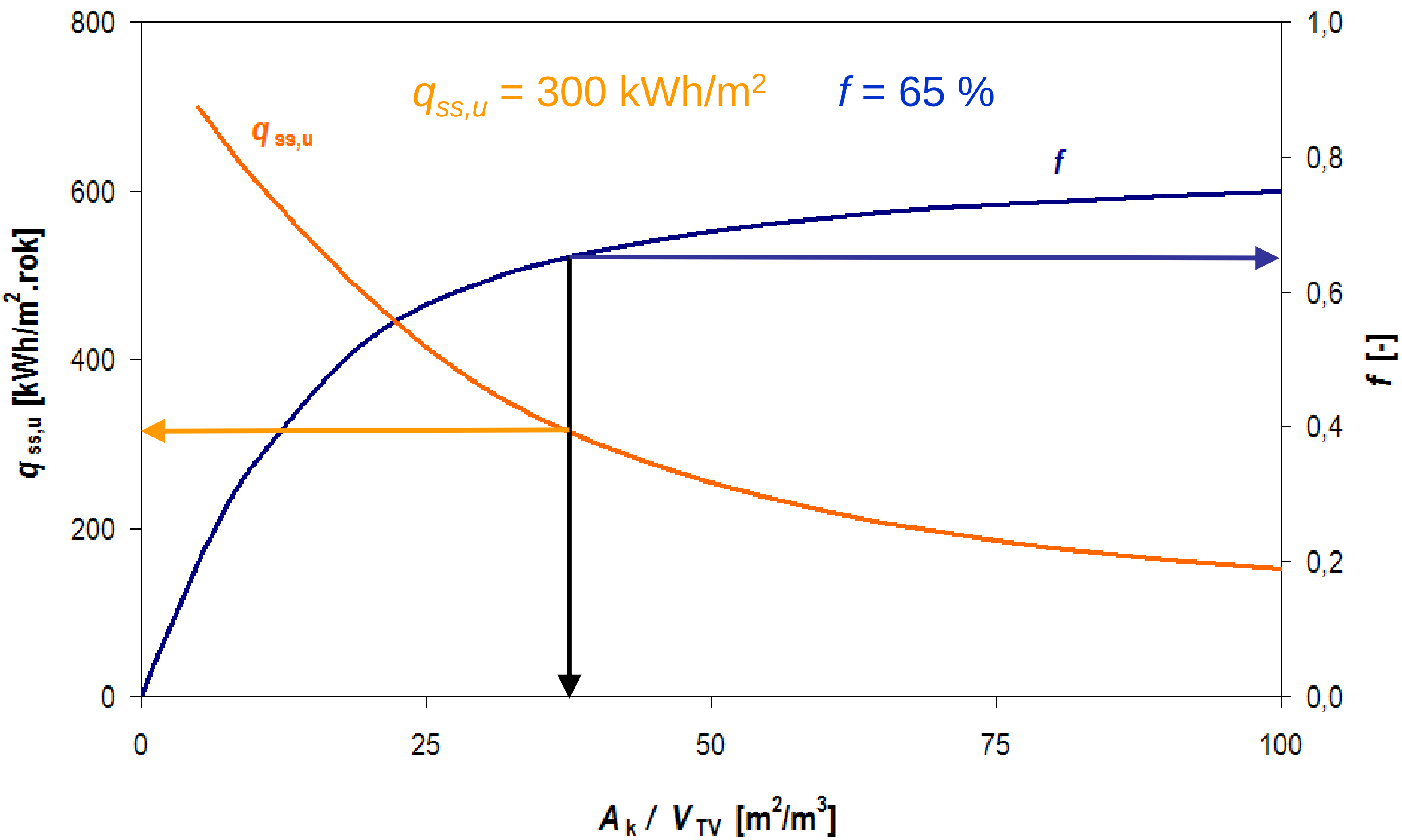
Hot water example - balance



Hot water example - balance

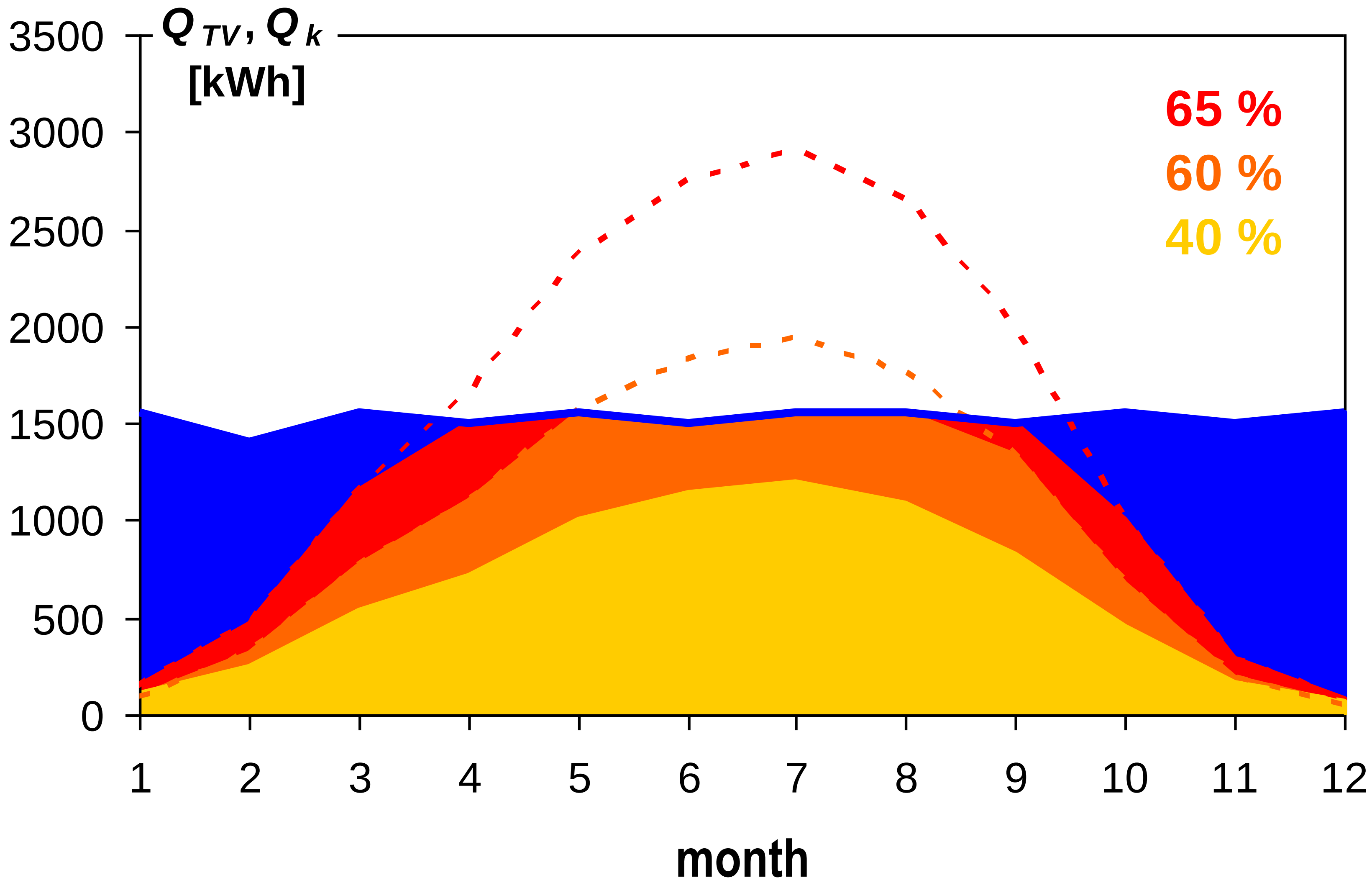


Hot water example - balance



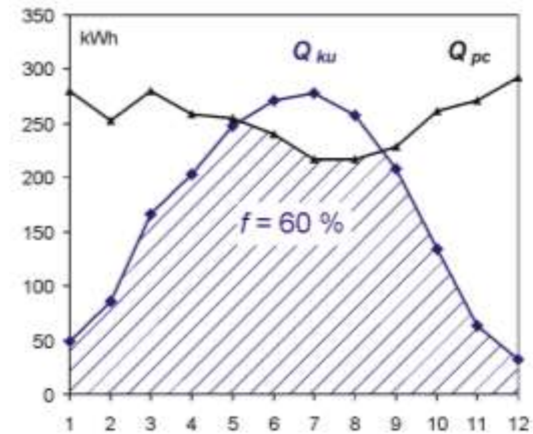
increase of solar fraction means decrease of specific heat gain

Design and evaluation in one step

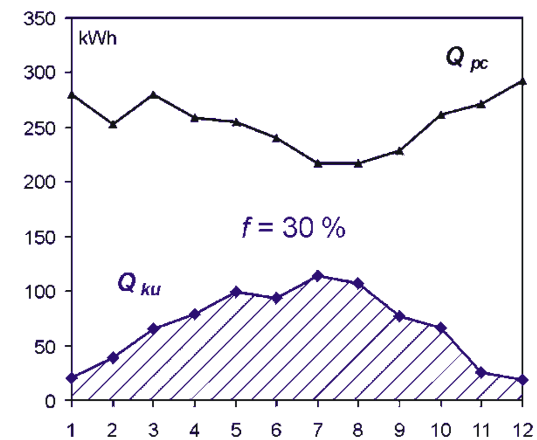


Solar hot water systems

- **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**

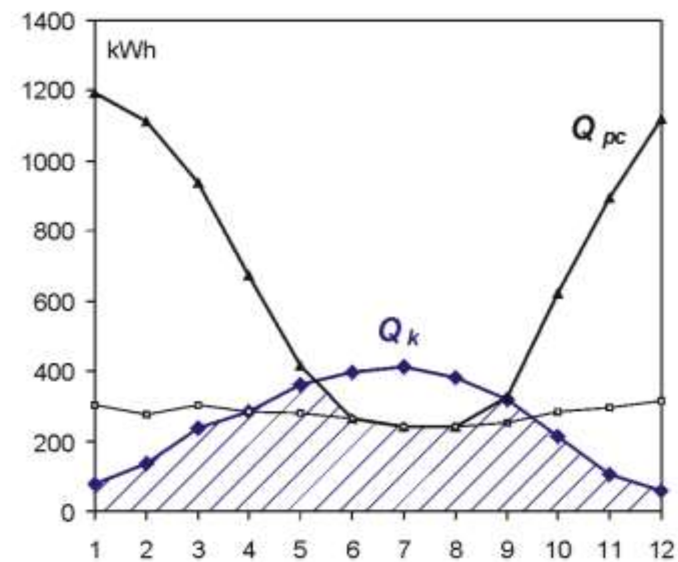


- **residential sector, hotels, ...**
  - (from 25 to 200 m^2; 1 to 8 m^3), solar fraction 40 to 50 %
  - solar yields **400 to 500 kWh/m^2.a**
- **hot water preheating**
  - solar fraction 20 to 40 %
  - solar yields **500 to 600 kWh/m^2.a**



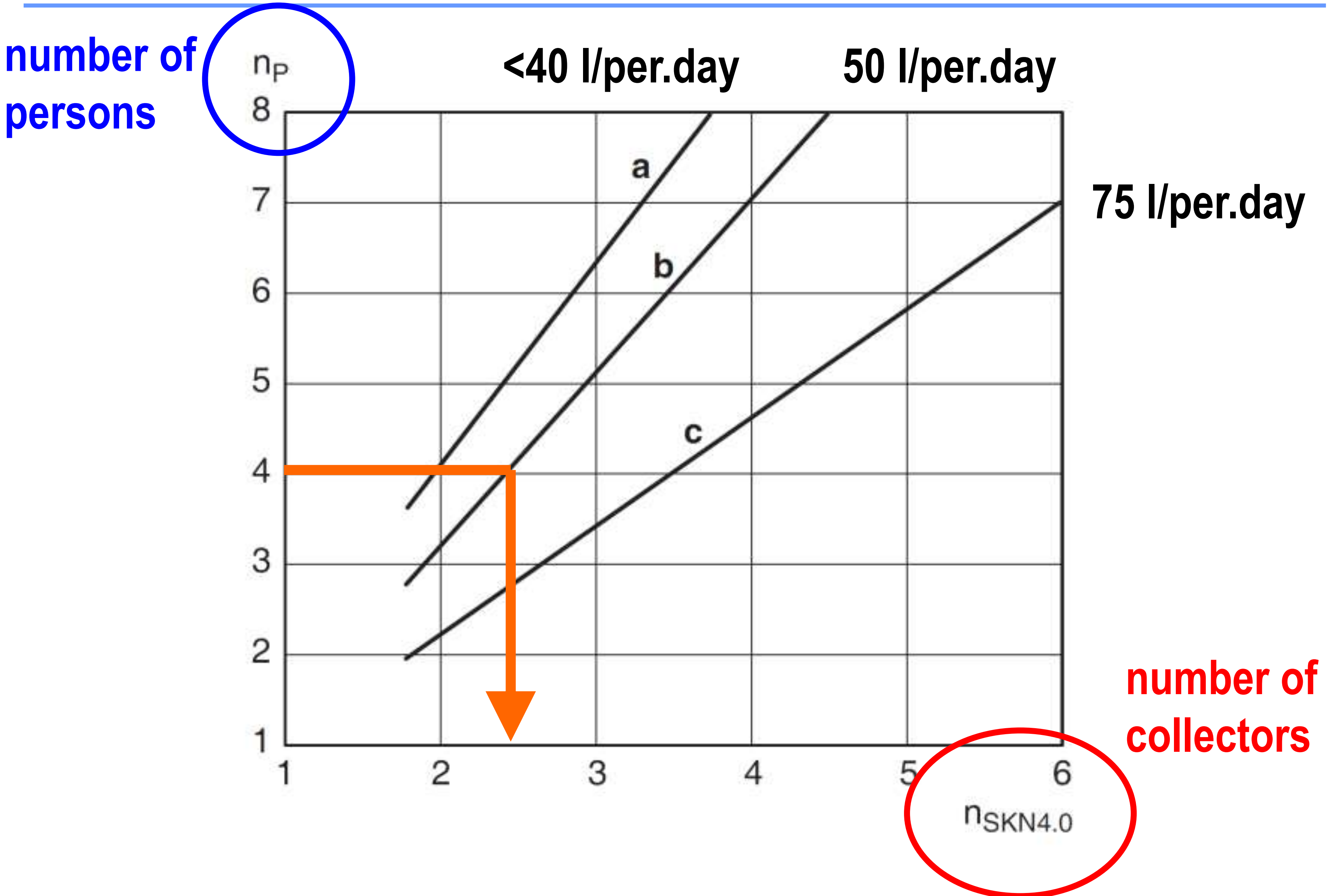
Solar combisystems

- **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**

Designing with nomograms ?



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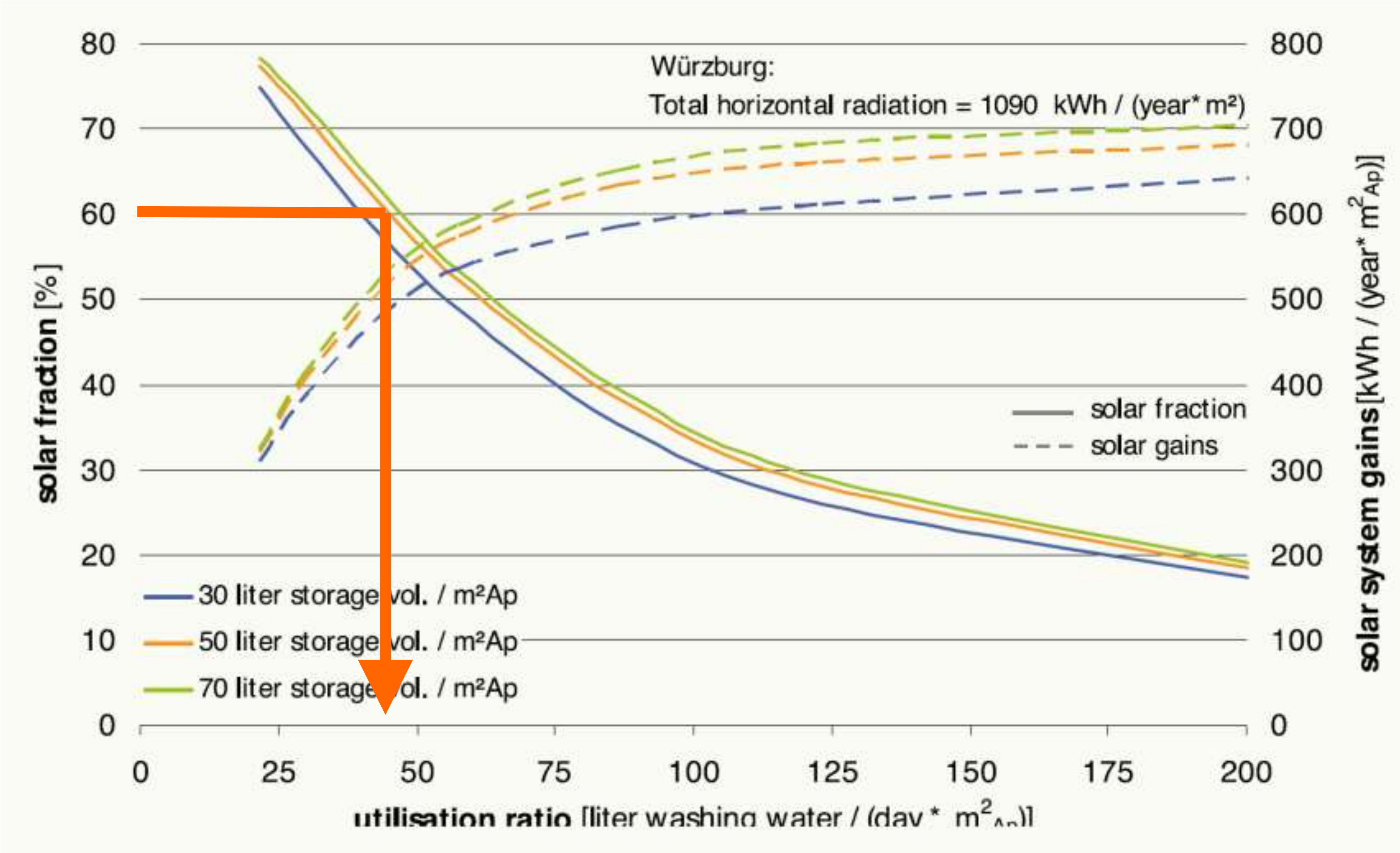
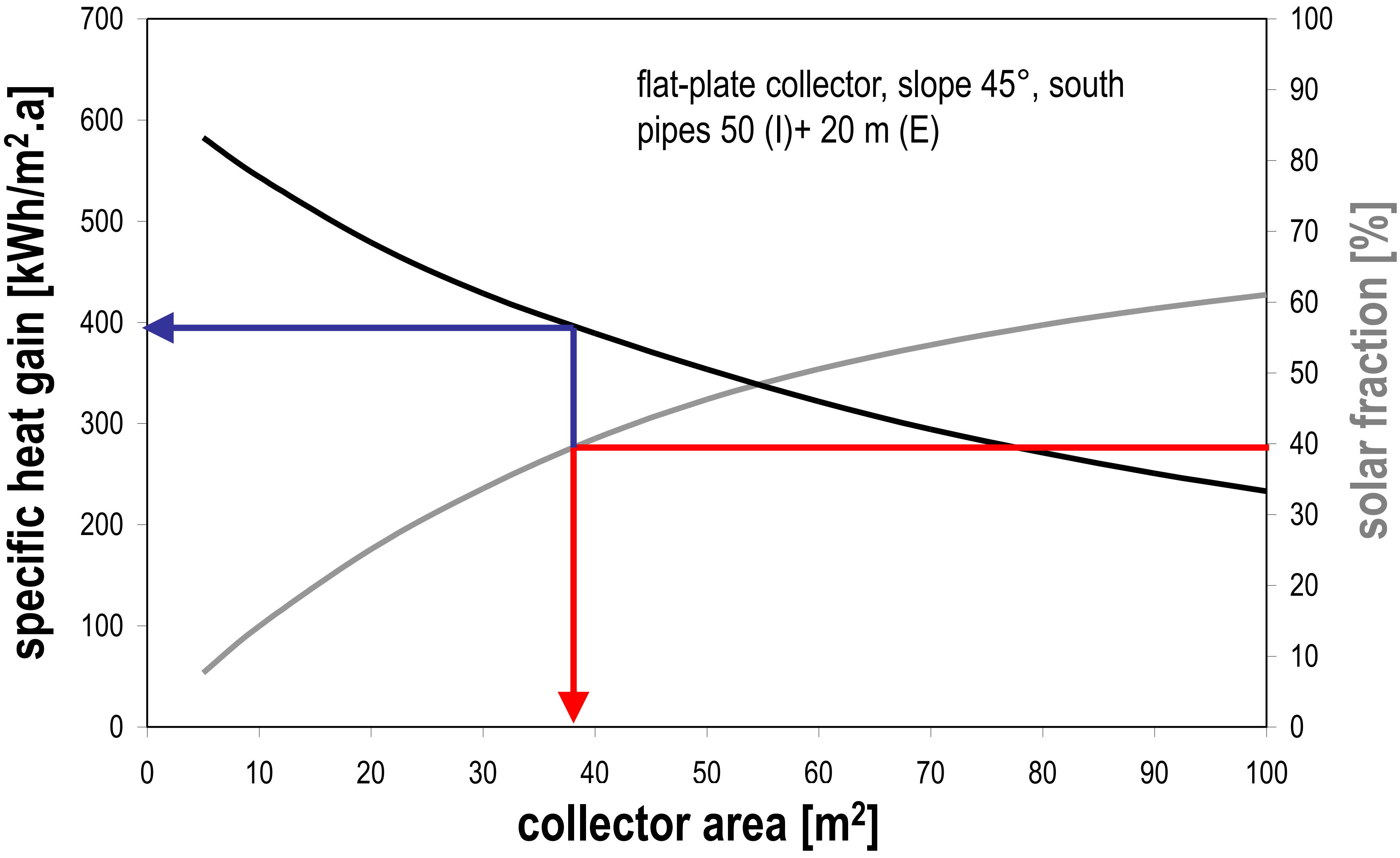


40 l/day.m^2

200 l/day / 40 = 5 m^2

Designing with nomograms ?



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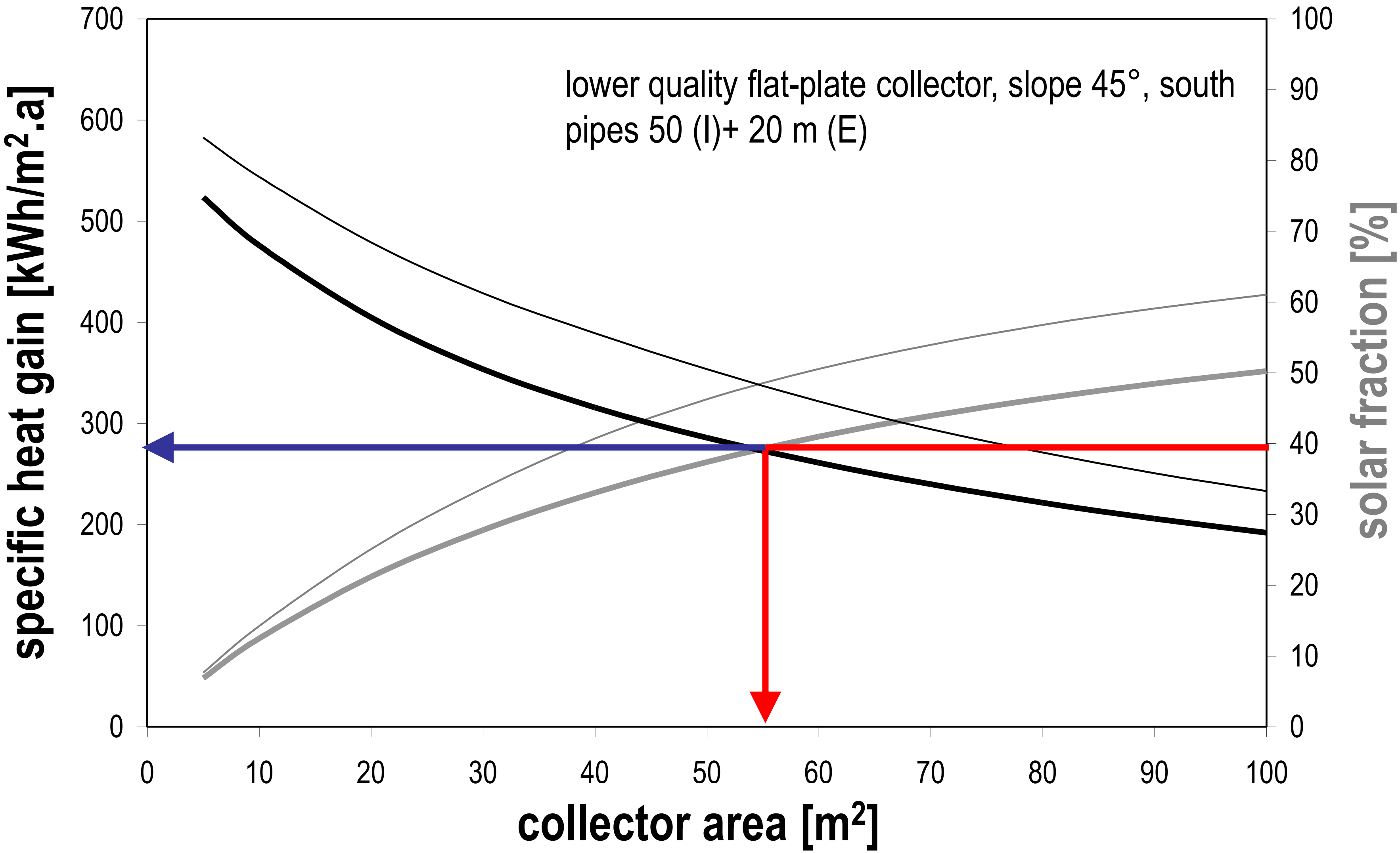

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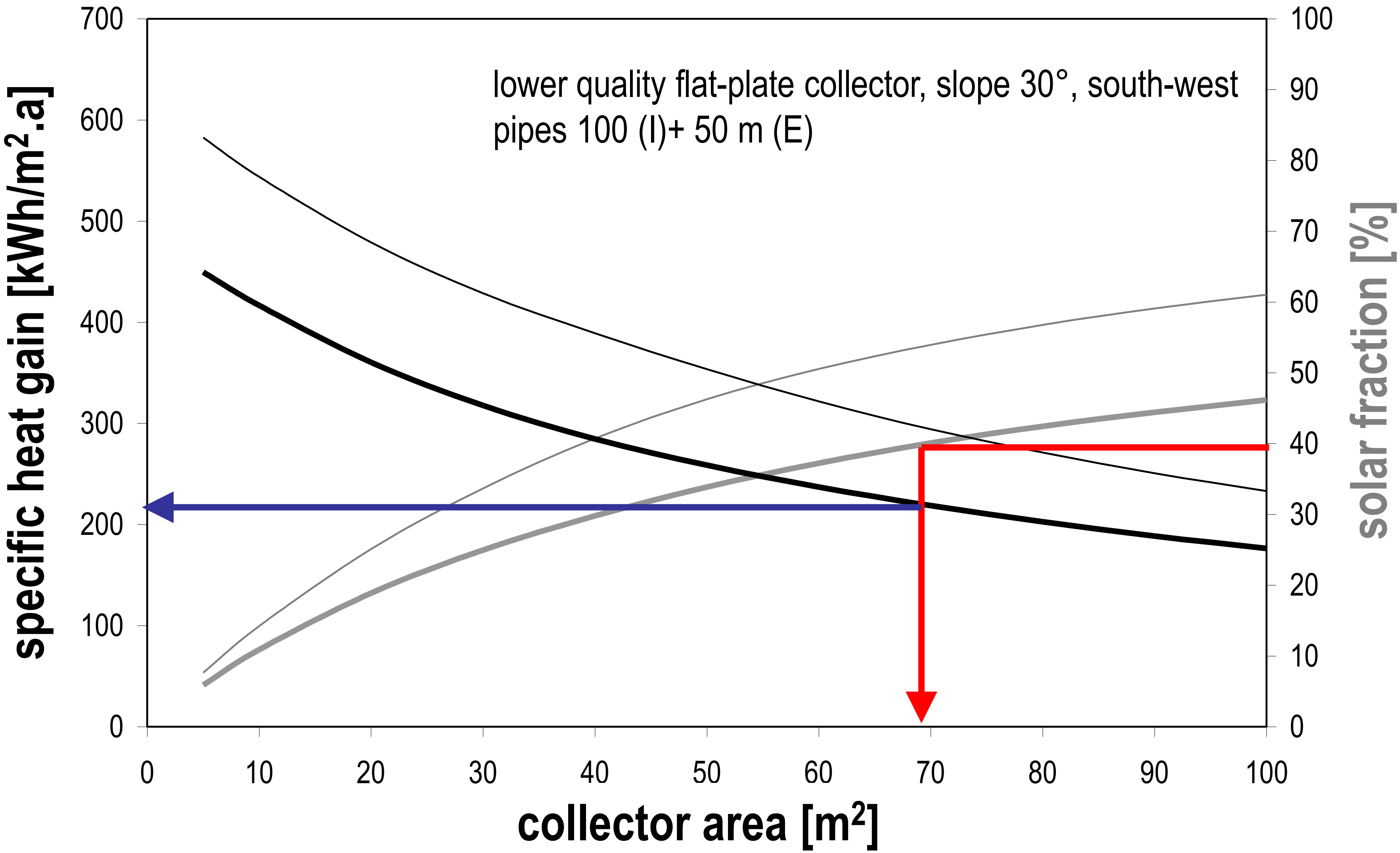

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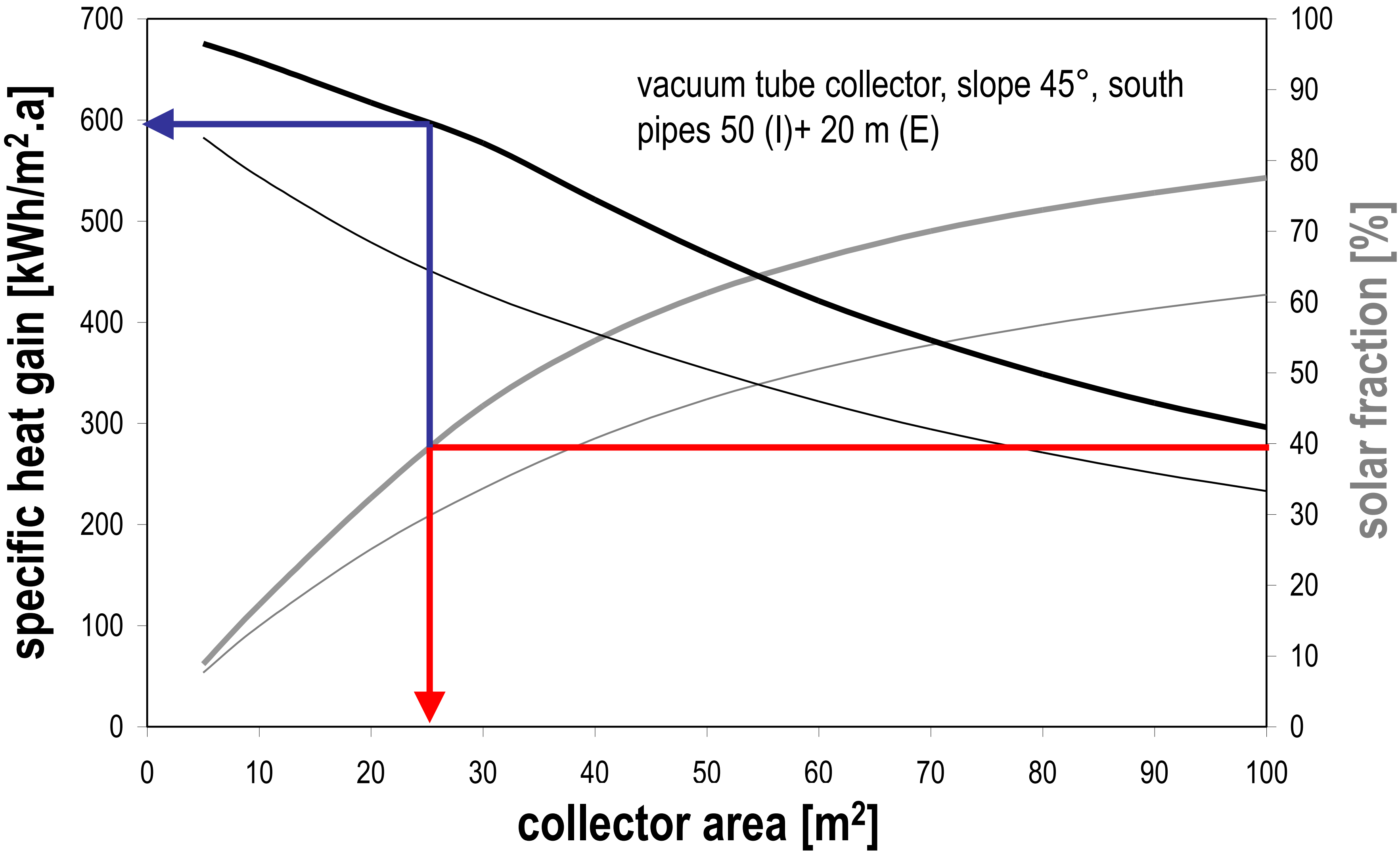
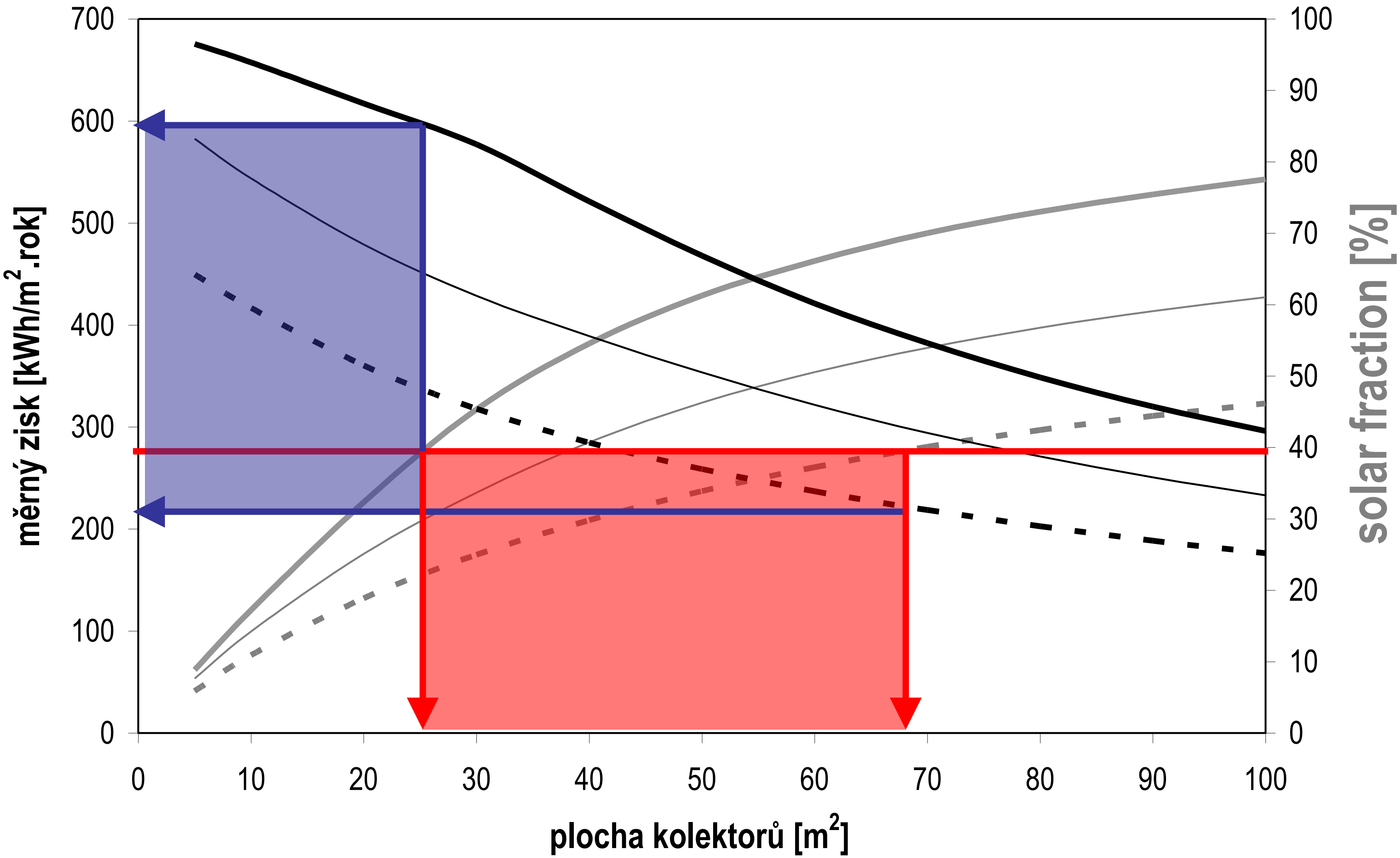


Designing with nomograms ?



Designing with nomograms ?

- **nomograms valid only for specific conditions**
  - individual solar collector (brand)
  - geometry, location, etc.)
  - application – operation conditions, insulation, piping length
- **if we change parameters ...**
  - collector type, application, etc
  - **... results will not change (but should change)**

not recommended ...

Simplified balance method

- **Czech standard / monthly method**
  - heat demand Q_p
  - collector average efficiency (daily = monthly) from η_0, a_1, a_2
  - collector heat gain Q_k
  - percentual heat loss (tables)
  - available (usable) solar system heat gain $Q_{k,u}$
  - utilizability
  - **used solar system yield** $Q_{ss,u} = \min(Q_{k,u}; Q_p)$

for details see Alternative energy sources AES-L3

Usable heat gain of collector

- usable heat gain $Q_{k,u}$ [kWh/m²] of solar collectors in given period (day, month)

$$Q_{k,u} = 0{,}9 \cdot \eta_k \cdot H_{T,day} \cdot A_k \cdot (1 - p) \qquad \text{kWh/day}$$

  - efficiency of solar collector for given conditions η_k
  - solar irradiation of given plane of solar collector $H_{T,day}$
    - *climate data from tables*
  - heat loss of solar system
    - reduction factors p
    - *according to type and size of the solar system, data from tables*

Solar collector efficiency

- average daily collector efficiency η_k

$$\eta_\mathrm{k} = \eta_0 - a_1 \cdot \frac{t_\mathrm{k,m} - t_\mathrm{e,s}}{G_\mathrm{T,m}} - a_2 \cdot \frac{(t_\mathrm{k,m} - t_\mathrm{e,s})^2}{G_\mathrm{T,m}}$$

  - mean fluid temperature $t_{k,m}$ in collector during the day
    - *according to type and size of solar system*
  - for mean ambient temperature in time of sunshine $t_{e,s}$
    - *climate data from tables*
  - mean daily solar irradiance $G_{T,m}$ for given plane (slope, orientation)
    - *climate data from tables*

Solar collector efficiency

- mean daily fluid temperature in collector $t_{k,m}$

Application	$t_{k,m}$ [°C]
Water preheating, solar fraction < 35 %	35
Hot water preparation, 35 % < solar fraction < 70 %	40
Hot water preparation, solar fraction > 70 %	50
How water and space heating, solar fraction < 25 %	50
How water and space heating, solar fraction > 25 %	60

Heat losses – relative figures

- **reduction factor** $Q_{k,u} = 0{,}9 \cdot \eta_k \cdot H_{T,day} \cdot A_k \cdot (1 - p)$

Application	*p*
Hot water preparation, up to 10 m^2	0,20
Hot water preparation, from 10 to 50 m^2	0,10
Hot water preparation, from 50 to 200 m^2	0,05
Hot water preparation, above 200 m^2	0,03
Hot water and space heating, up to 10 m^2	0,30
Hot water and space heating, from 10 to 50 m^2	0,20
Hot water and space heating, from 50 to 200 m^2	0,10
Hot water and space heating, above 200 m^2	0,06

Determination of required collector area

Collector area design A_k

- for given **design day** in **typical** design month
  - climate and operation conditions
- to provide coverage of considered heat demand
  - according to application, local conditions

$$Q_{k,u} = 0{,}9 \cdot \eta_k \cdot H_{T,day} \cdot A_k \cdot (1 - p) = Q_p$$

Example for calculation

- block of flats

Example

- block of flats
- given number of flats, given number of occupants
- consider hot water demand **40 l/per.day**
- cold water 10 °C, hot water 55 °C
- losses 30 %
- calculate daily heat demand $\boldsymbol{Q}_{\mathbf{p,HW}}$ for hot water preparation
- for the heat demand design the collector area for conditions of July
  = no excess heat gains, high usability of solar energy for hot water

Example - inputs

- **solar collector: flat-plate**
- $\eta_0 = 0.78$
- $a_1 = 5.1$ W/m^{2}K
- $a_2 = 0.014$ W/m^{2}K^2
- $A_c = 1.87$ m^2 (aperture)
- $IAM_{50} = 0.95$

Example

- design for block of flats = design day in summer (July)
- **daily balance**

$$Q_{k,u} = 0{,}9 \cdot \eta_k \cdot H_{T,day} \cdot A_k \cdot (1 - p) = Q_p$$

$$0{,}9 \cdot \eta_k \cdot H_{T,day} \cdot A_k \cdot (1 - 0.1) = Q_p$$

Example

- daily total solar irradiation for July, Prague
- slope 45°, south
- theoretical $H_{\mathrm{T,day,th}}$ =
- diffuse $H_{\mathrm{T,day,dif}}$ =
- relative period of sunshine τ_{r} =

$$H_{\mathrm{T,day}} = H_{\mathrm{T,day,th}} \cdot \tau_{\mathrm{r}} + H_{\mathrm{T,day,dif}} \left(1 - \tau_r\right) =$$

Example

- average daily solar collector efficiency
- fluid temperature $t_{k,m}$ = 40 °C
- ambient temprature in period of sunshine $t_{e,s}$ =
- mean daily irradiance $G_{T,m}$ =

$$\eta_k = \eta_0 - a_1 \cdot \frac{t_{k,m} - t_{e,s}}{G_{T,m}} - a_2 \cdot \frac{\left(t_{k,m} - t_{e,s}\right)^2}{G_{T,m}} =$$

Example

- **required solar collector area**

$$A_k = \frac{Q_p}{0{,}9 \cdot \eta_k \cdot H_{T,day} \cdot (1-p)}$$

final number of collectors will respect the connection to rows with 4 or 5 collectors (multiples of 4 or 5 pcs)

EN 15316-4-3 (f-chart method)

- **monthly method**
  - heat demand Q_p [kWh/month]
  - loss parameter X
  - gain parameter Y
  - solar fraction f
  - **used solar system energy yield $Q_{ss,u}$ [kWh/month]**

$$Q_{ss,u} = f \cdot Q_p$$

EN 15316-4-3 (f-chart method)

- **loss parameter *X***

$$X = U_{loop} \times \eta_{loop} \times (t_{ref} - \bar{t}_e) \times \Delta\tau \times \frac{A_c}{1000 \cdot Q_p} \times \left(\frac{V_{ref}}{V_{st}}\right)^{0,25}$$

- U_{loop} [W/m²K] — total heat loss coefficient of solar collector loop
- η_{loop} [-] — efficiency of collector loop
- t_{ref} [°C] — reference solar system temperature
- t_e [°C] — ambient average temperature
- $\Delta\tau$ [h] — time period [month]
- A_c [m²] — collector field area
- Q_p [kWh] — heat demand

EN 15316-4-3 (f-chart method)

- ***U*loop**

$$U_{\text{loop}} = a_1 + a_2 \cdot 40 + \frac{(U \cdot L)_{\text{loop,p}}}{A_{\text{c}}}$$

  - *U* [W/mK] heat loss coefficient of pipes in solar collector loop
  - *L* [m] length of pipes

  - typically

    $$(U \cdot L)_{\text{loop,p}} = 5 + 0.5 \cdot A_c$$

EN 15316-4-3 (f-chart method)

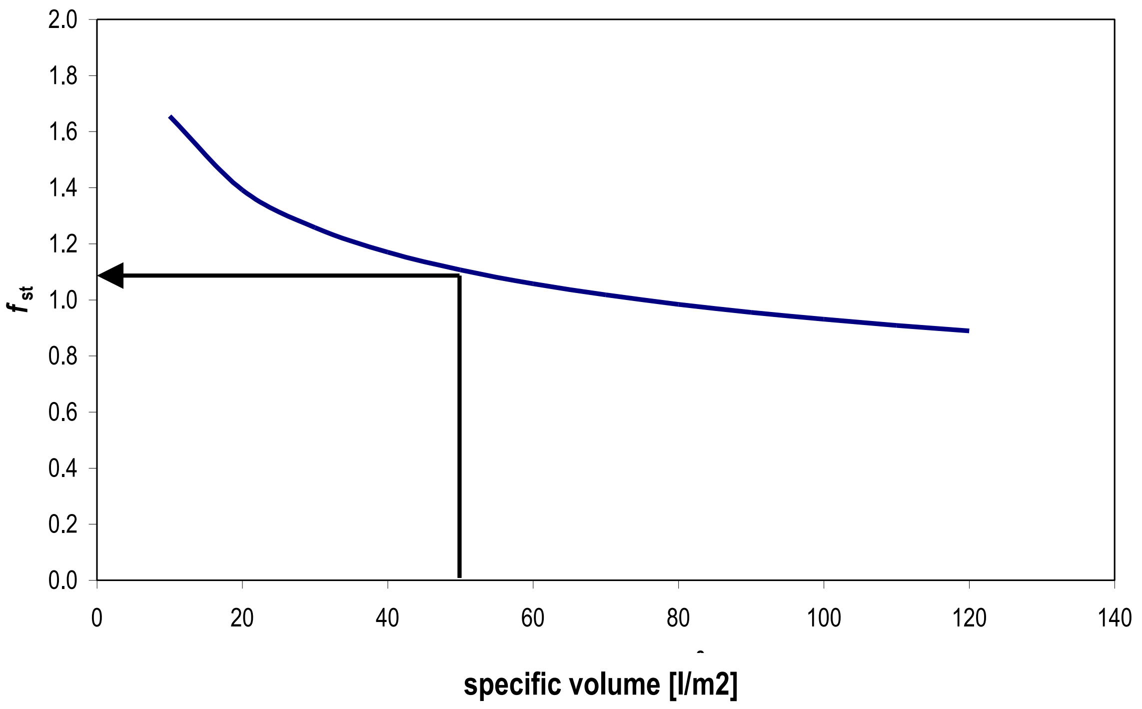
- η_{loop}

$$\eta_{loop} = 1 - \frac{\eta_0 \cdot A_c \cdot a_1}{(UA)_{hx}}$$

  - $(UA)_{hx}$ [W/K] specific heat power of heat exchanger
  - influence of heat exchanger
  - typically η_{loop} = 0.9

EN 15316-4-3 (f-chart method)

- **storage influence**
  - $V_{ref} = 75\ l/m^2$
  - V_{st} real volume of solar part of the storage (50 l/m^2)



EN 15316-4-3 (f-chart method)

- **reference temperature of solar system**
  - **hot water**
  - $t_{ref} = 11.6 + 1.18\ t_{hw} + 3.86\ t_{cw} - 1.32\ t_e$ 70 to 120 °C
  - t_{hw} hot water temperature 40 °C
  - t_{cw} cold water temperature 10 °C
  - t_e ambient average temperature
  - **space heating**
  - $t_{ref} = 100$ °C

EN 15316-4-3 (f-chart method)

- **gain parameter *Y*** **$H_{T,month}$ [Wh/m²]**

$$Y = \eta_0 \times \eta_{loop} \times IAM \times \overline{G}_T \cdot \Delta\tau \times \frac{A_c}{1000 \cdot Q_p}$$

- η_0 [-] — zero-loss efficiency of collector
- η_{loop} [-] — efficiency of collector loop
- *IAM* — average incidence angle modifier (*IAM* for 50°)
- G_T [W/m²] — mean solar irradiance (average per 24h!)
- $\Delta\tau$ [h] — time period [month]
- A_c [m²] — collector field area
- Q_p [kWh] — heat demand

EN 15316-4-3 (f-chart method)

- **solar fraction (monthly)**

$$f = 1{,}029 \cdot Y - 0{,}065 \cdot X - 0{,}245 \cdot Y^2 + 0{,}0018 \cdot X^2 + 0{,}0215 \cdot Y^3$$

$$Q_{\mathrm{ss,u}} = f \cdot Q_{\mathrm{p}}$$

Simulation tools

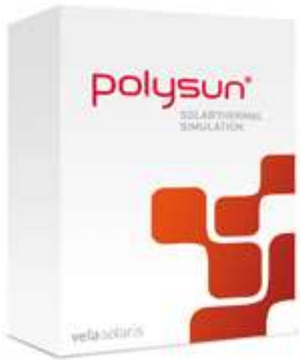
- simulation with hourly step, dynamic models fo components (storage, collector), hourly climatic data
- demanding input data (details on components, materials, etc.)
- experience need
- price of tools thousands of EUR

- **Polysun (Professional, Designer)**
- **T-Sol (Professional, Expert)**
- **TRNSYS (research & development) – not suitable for designer (!)**

Polysun (SPF Rapperswil, CH)

Polysun Light

Intuitive use, templates for hydraulics

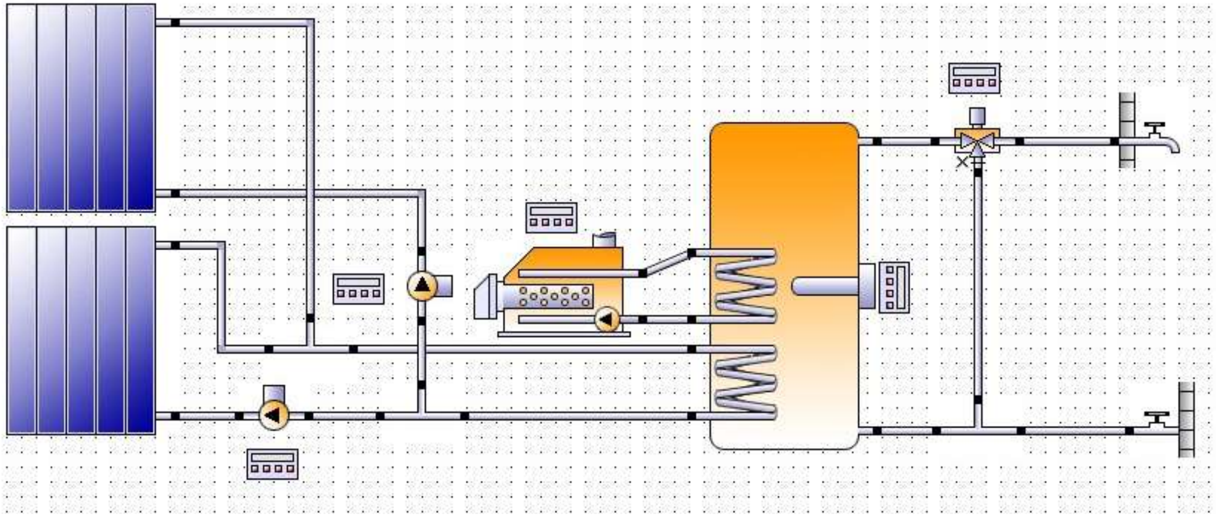


Polysun Professional

Definition of own components, more templates

Polysun Designer

Flexibility and modularity for design of complex hydraulic system



T*SOL (Valentin Software, DE)

T*SOL Pro (advanced)
80 pre-defined configurations for hot water, space heating and pools

T*SOL Expert (premium)
experts, development and optimization of systems, complex solutions with other sources (district heating, **industry**, etc)