

Investment Estimation in energy systems

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$$TotalCost[\$/year] = OPEX + CAPEX + Tax$$

$$OPEX = \sum_{p=1}^{n_p} \left(\sum_{r=1}^{n_r} \dot{m}_{r,p}^+ c_{r,p}^+ + \dot{E}_p^+ c_{e,p}^+ - \dot{E}_p^- c_{e,p}^- + \sum_{u=1}^{n_u} f_{u,p} c m_u \right) d_p$$

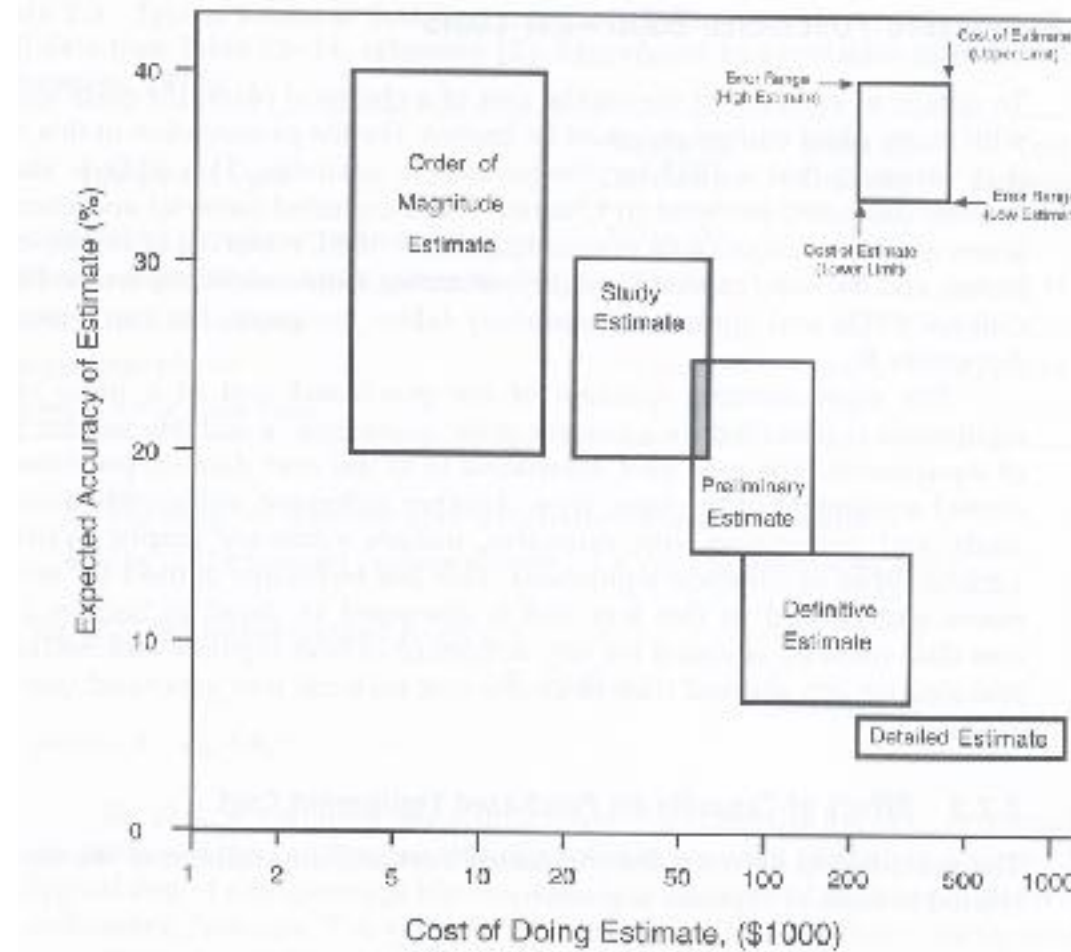
$$CAPEX = \sum_{u=1}^{n_u} \frac{1}{\tau(n_{y,u}, i)} (i_u \cdot \dot{Q}_{u,max})$$

$$Tax = \gamma^{CO_2^+} \cdot \left(\sum_{p=1}^{n_p} \left(\sum_{r=1}^{n_r} \dot{m}_{r,p}^+ \epsilon_r^{CO_2} + \dot{E}_p^+ \epsilon_{e,p}^{CO_2^+} - \dot{E}_p^- \epsilon_{e,p}^{CO_2^-} \right) d_p \right)$$

- Cost of doing a investment estimation

Offer call

Detailed design



EPFL Estimating purchased cost based on reference data

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- Purchased cost of unit u

$$C_{p,u} = C_{p_{ref},u} \cdot \left(\frac{A_u}{A_{u,ref}} \right)^{\gamma_u} \cdot \frac{Id_{year_{project}}}{Id_{year_{ref}}}$$

- $C_{p_{ref},u}$: purchased cost of a unit u for a reference size
- A_u Equipment sizing attribute of unit u => Size
- $A_{u_{ref}}$ Equipment sizing attribute of the reference unit u
- γ_u capacity exponent for unit u typical values are between 0.6 and 0.8 => is a function of equipment type
- $Id_{year_{ref}}$ cost index for the reference year where $C_{p_{ref},u}$ is given => year adaptation
- $Id_{year_{project}}$ cost index for the project year
- Ranges => Min and Max bounds (comparable equipment)
- Cost index :
 - Marshall & Swift Equipment Cost Index
 - CEPCI : Chemical Engineering Plant Cost Index
 - Chemical Engineering Journal

- Adapting the cost estimate from one year to another



$$C_{p,u} = C_{p_{ref},u} \cdot \left(\frac{A_u}{A_{u,ref}} \right)^{\gamma_u} \cdot \frac{I_{year_{project}}}{I_{year_{ref}}}$$

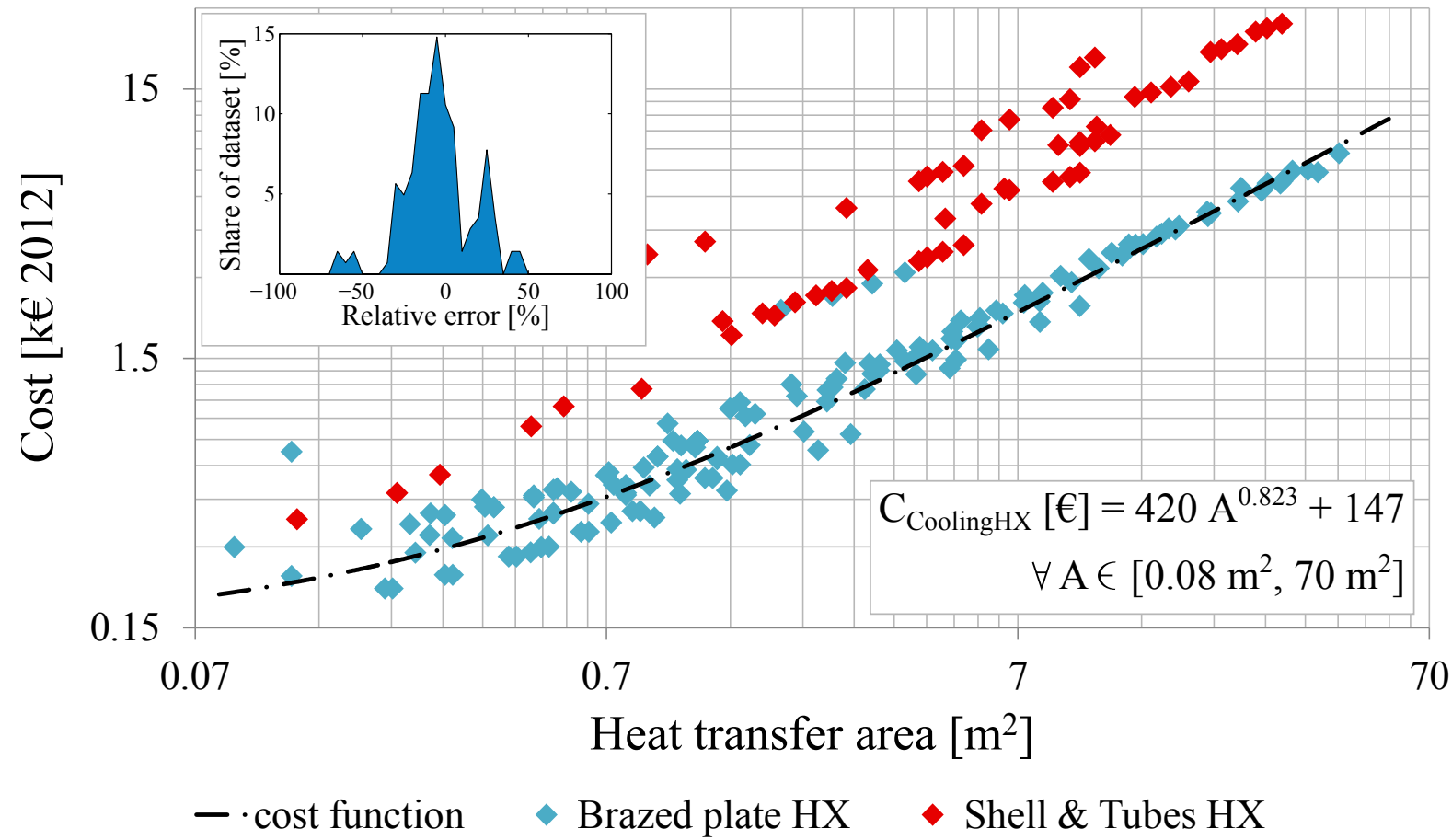
γ_u : year of the evaluation
 $I_{year_{ref}}$: year of the reference where the cost is known for a reference size

Equipment description	Capacity exponent γ	Relative base cost $C_{p,ref}$ (values from 1998)
Blowers and fans	0.68	9.5
Boilers, packaged unit	0.7	60
Boiler (industrial), 15psig	0.5	92
Boiler (industrial), 150psig	0.5	101.2
Boiler (industrial), 300psig	0.5	115
Boiler (industrial), 600psig	0.5	138
Column with trays	0.73	33.5
Column with packing	0.65	35.2
Compressor, air, 125psig	0.28	36.5
Compressor, process gas, 1000psig	0.82	85
Cooling tower facilities	0.6	9.9
Crushers, cone	0.85	12
Crushers, gyratory	1.2	3
Crushers, jaw	1.2	4.7
Crushers, pulverisers	0.35	23.4
Crystallisers, growth	0.65	385
Crystallisers, forced circulation	0.55	276.5
Crystallisers, batch	0.7	32.5
Dryers, drum	0.45	30
Dryers, pan	0.38	12.5
Dryers, rotary vacuum	0.45	43.4
Evaporators, forced circulation	0.7	270
Evaporators, vertical tube	0.53	37.2
Evaporators, horizontal tube	0.53	30.4
Evaporators, jacketted vessel	0.6	32
Filters, plate and frame	0.58	4.3
Filters, pressure leaf (wet)	0.58	5.3
Filters, pressure leaf (dry)	0.53	15.1
Filters, rotary drum	0.63	17.5
Filters, rotary disc	0.78	31
Furnace, process	0.85	135
Heat exchangers, cooler	0.66	6.8
Heat exchangers, kettle reboiler	0.65	8.8
Heat exchangers, shell and tube	0.65	6.5
Heat exchangers, U-tube	0.65	5.5
Heater, direct fired	0.85	103,5

Importance of

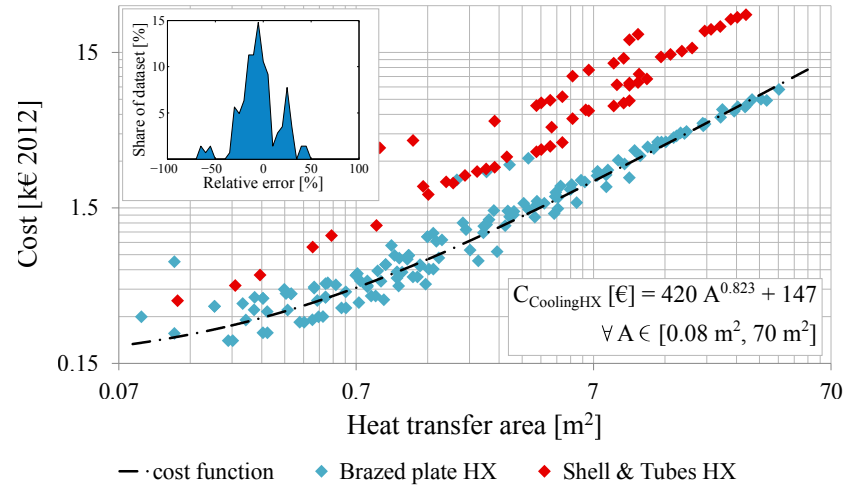
- Size range
- Type of materials
- Application area
- Domestic
- Industry
- Production
- Custom made

Cost of heat exchangers

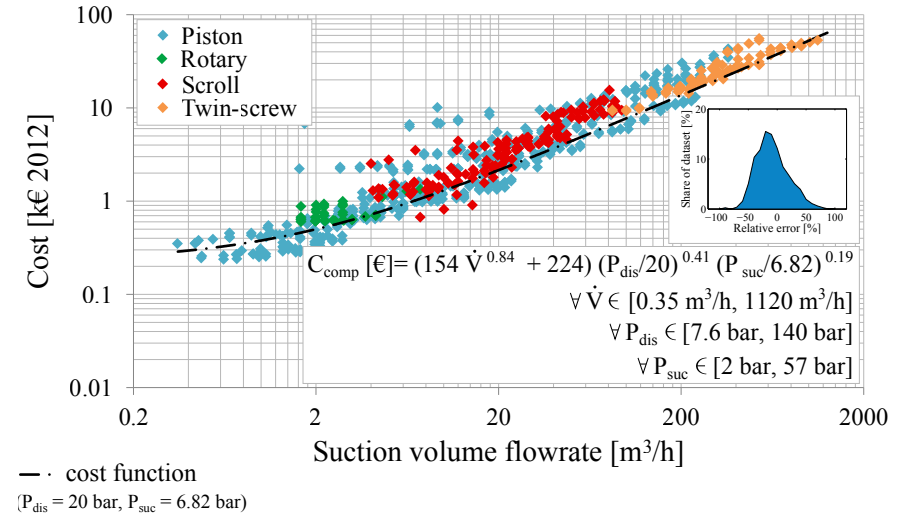


Validity for the different types of technologies

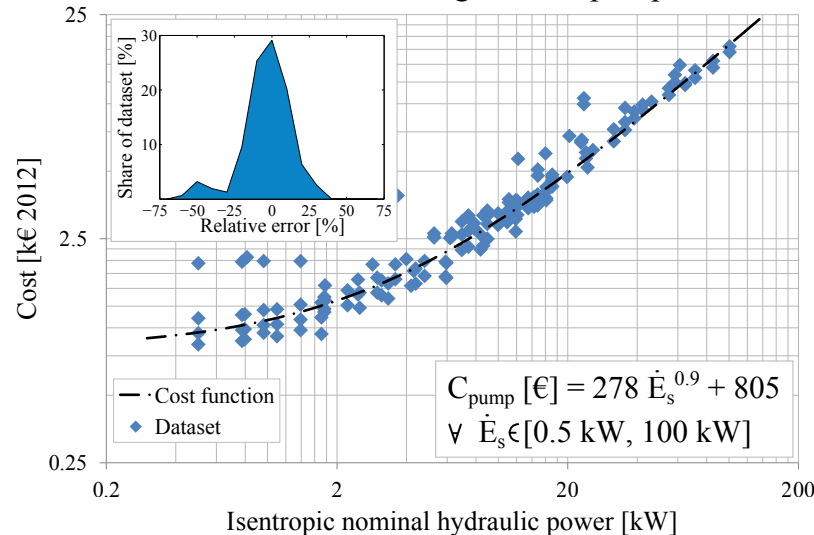
Cost of heat exchangers



Cost of compressors



Cost of centrifugal water pumps



- Purchased costs of an equipment : statistical analysis (log/log) of the equipment market

$$C_{p,u} = \frac{Id_{year_{project}}}{Id_{year_{ref}}} \cdot 10^{(k_{1,u} + k_{2,u} \log(A_u) + k_{3,u} (\log(A_u))^2)}$$

- k_i empirical constants derived from the cost database

- Note that : if $k_{3,u} = 0$
$$C_{p,u} = \frac{I_{year_{project}}}{I_{year_{ref}}} \cdot 10^{k_{1,u}} \cdot (A)^{k_{2,u}}$$

Reference year = year of the data publication :

e.g. Turton, R., Whiting, W., and Shaeiwitz, J. (1998).

Analysis, Synthesis and Design of chemical processes, ,
(ISBN:130647926),

Installed cost proportional to purchased cost

Accounts for

- Piping, contingencies, control, etc...
- Materials
- Pressure

$$C_{BM,u} \quad [CHF_{installed}] = F_{BM,u} \cdot C_{p,u}$$

$F_{BM,u}$: Order of magnitude

Fluids : 4.74

Solids : 3.1

Solids- fluids : 3.63

$$i_{u\dot{Q}_{u,max}} \quad [CHF/kW] = \frac{C_{BM,u}}{\dot{Q}_{u,max}}$$

Update the statistics by further statistics

$$F_{BM} = B_1 + B_2 \cdot F_m \cdot F_p$$

B_i constants computed on the base of existing equipment cost databases

F_m material factor, describes the effect of material change on the bare-module cost. If there is no material change $F_m = 1$

F_p pressure factor, describes the effect of operating pressure change on the bare-module cost.

$$F_p = 10^{c_1 + c_2 \cdot \log \tilde{P} + c_3 \cdot (\log \tilde{P})^2}$$

c_i empirical constant derived from the existing plant cost database

$\tilde{P}$ pressure difference from atmospheric pressure e.g. pressure expressed in bar gauge (barg)

Data in : Turton, R., Whiting, W., and Shaeiwitz, J. (1998).

Analysis, Synthesis and Design of chemical processes, , (ISBN:130647926),

Types of equipment

Table A.1 Correlation Coefficients for Heat Exchangers

Ranges

Exchanger Type	K_1	K_2	K_3	C_1	C_2	C_3	B_1	B_2	A_{min} (m ²)	A_{max} (m ²)	P_{max} (barg)
Double Pipe	3.0238	0.0603	0	6.4945 ¹	-6.6786	1.7442	0.74	1.21	0.2	10	300
Multiple Pipe	2.1138	0.9658	0	6.4945 ¹	-6.6786	1.7442	0.74	1.21	10	75	300
Fixed Tube Sheet or U-Tube	3.2138	0.2688	0.07961	-0.06499 ²	0.05025	0.01474	1.80	1.50	4	900	140
Floating Head	3.4338	0.1445	0.10790	-0.06499 ²	0.05025	0.01474	1.80	1.50	10	900	140
Bayonet	3.5238	0.1916	0.09474	-0.06499 ²	0.05025	0.01474	1.80	1.50	10	900	140
Kettle Reboiler	3.5638	0.1906	0.11070	-0.06499 ²	0.05025	0.01474	1.80	1.50	10	100	140
Scraped Wall	3.7438	0.9270	0	6.4945 ¹	-6.6786	1.7442	0.74	1.21	2	20	300
Teflon Tube	3.5738	0.4548	0	0	0	0	1.80	1.50	7	75	15
Air Cooler	3.6418	0.4053	0	-0.06154	0.0473	0	1.53	1.27	3.5	20,000	250
Spiral Tube	3.4088	0.6000	0.09944	-0.4045 ³	0.1859	0	0.74	1.21	1	45	400
Spiral Plate	3.6788	0.4412	0	0	0	0	1.53	1.27	2	200	19
Flat Plate	3.8528	0.4242	0	0	0	0	1.53	1.27	15	1,500	19

¹ Pressure factors given are for 100 < P < 300 barg, for 40 < P < 100 use C₁ = 0.6209, C₂ = -0.9274, C₃ = 0.3369, for P < 40 C₁ = C₂ = C₃ = 0

² Pressure factors given are for when shell or both shell and tube are > 10 barg, when tubes only > 10 barg use C₁ = -0.04139, C₂ = 0.04139, C₃ = 0

³ Pressure factors given are for when shell or both shell and tube are > 10 barg, when tubes only > 10 barg use C₁ = -0.27150, C₂ = 0.09717, C₃ = 0

CEPCI : 382, Turton, R., Whiting, W., and Shaeiwitz, J. (1998).
 Analysis, Synthesis and Design of chemical processes, ,
 (ISBN:130647926),

Table A.2 Material Factors for Heat Exchangers

Exchanger Type	Material Factor, F_M								
	Shell—CS Tube—CS	CS Cu	Cu Cu	CS SS	SS SS	CS Ni	Ni Ni	CS Ti	Ti Ti
Double Pipe	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Multiple Pipe	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Fixed Tube Sheet or U-Tube	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Floating Head	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Bayonet	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Kettle Reboiler	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Scraped Wall	1.00	1.25	1.60	1.70	3.00	2.80	3.80	7.20	12.00
Spiral Tube	1.00	1.25	1.60	2.30	3.00	2.80	3.80	7.20	12.00
Teflon Tube Exchanger		Flat and Spiral Plate				Air Cooler			
Shell Material		F_M		Material in Contact with Process Fluid		F_M		Tube Material	
CS		1.00		CS		1.00		CS	
Cu		1.20		Cu		1.20		Al	
SS		1.30		SS		2.30		SS	
Ni		1.40		Ni		2.80		—	
Ti		3.30		Ti		7.20		—	

CEPCI : 382, Turton, R., Whiting, W., and Shaeiwitz, J. (1998).

Analysis, Synthesis and Design of chemical processes, , (ISBN:130647926),

- Estimation of an investment when equipment **type** and **size [kW or m2]** is known

$$i_{u\dot{Q}_{u,ref}} \text{ [CHF/kW]} = \frac{\sum_{e_u=1}^{n_{e,u}} C_{BM,e_u}}{\dot{Q}_{u,ref}}$$

- e_u : equipment e of the $N_{e,u}$ equipment needed to construct the unit u
- 20% precision
- Similar equipment or correlations
 - Check validity range

- Note the year of the data and use index update $\frac{Id_{year_{project}}}{Id_{year_{ref}}}$

- Scaling factor (default =0.8)
- Installed cost = (3 to 4) * Purchased cost
- Factors for Materials + Pressure

- Cost estimation
 - Comparing sizes => scaling factor
 - Statistical values from data base (log/log) => precision ???
 - Index for the year of the reference data update
 - Heuristics
 - Installation Factor
 - Materials/Pressure Factor