Tutorial of Economic Analysis

Process development – CHE 459

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École polytechnique fédérale de Lausanne

Class and Error

Class 5: Order-of-magnitude estimate ✅
Normally, it requires only a block flow diagram.

Class 4: Study estimate ✅
Based on the process flow diagram. Costs from generalized charts.

Class 3: Preliminary estimate
Based on PFD. Includes vessel sketches for major equipment, preliminary plot plan, and elevation diagram.

Class 2: Definitive estimate
Final PFD, vessel sketches, plot plan, and elevation diagrams, utility balances, and a preliminary piping and instrumentation diagram (P&ID).

Class 1: Detailed estimate
Final PFD and P&ID, vessel sketches, utility balances, plot plan and elevation diagrams, and piping isometrics. All diagrams are required to complete the construction of the plant if it is built.

Class	Complete definition	Purpose of estimation	Methodology
5	0-2%	Screening or Feasibility	Stochastic or Judgment
4	1-15%	Concept Study or Feasibility	Primarily Stochastic
3	10-40%	Budget, authorization or Control	Mixed but Primarily Stochastic
2	30-70%	Control or Tender	Primarily Deterministic
1	50-100%	Check Estimate or Tender	Deterministic

Error of class 1: +6% ~ -4%
Error of class 4&5: +40% ~ -25%

Cost Estimation

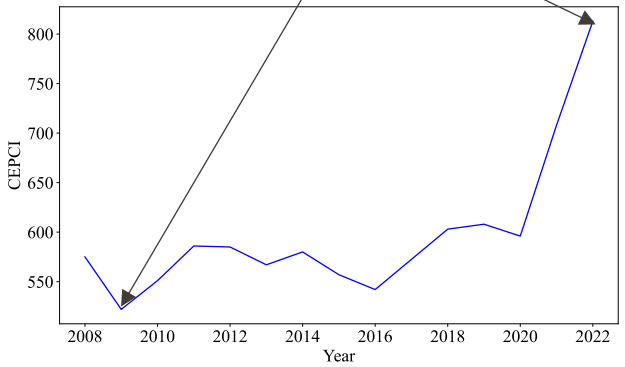
$$\log_{10} C_P^0 = K_1 + K_2 \log_{10} S_a + K_3 (\log_{10} S_a)^2$$ Equipment cost attribute (size)

Purchased cost at the year in the book (CEPCI=397, 2001)

$$\frac{C_{P\,a}^0}{C_{P\,ref}^0} = \left(\frac{S_a}{S_{ref}}\right)^n \frac{I_{2022}}{I_{2009}}$$

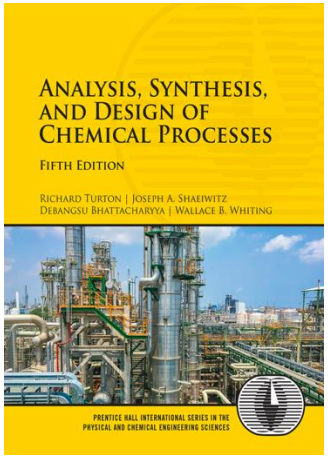
Size exponent, 0.6

Cost index - Chemical Engineering Plant Cost Index (CEPCI)



$$\frac{I_{2022}}{I_{2009}} = \frac{813}{522} = 1.56$$

When you spend money is important



Note:
The calculation equation of bare module cost will change according to different types of equipment.
You can find all the information in this book.

Bare module cost: $C_{BM} = C_P^0 F_{BM} = C_P^0 (B_1 + B_2 F_M F_P) = C_P^0 F_{\mathrm{BM}} F_{\mathrm{P}} F_{\mathrm{T}}$ → Temperature factor

Bare module cost factor | Material factor | Pressure factor

Case Study: Compressor

$$\log_{10} C_P^0 = K_1 + K_2 \log_{10} P + K_3 (\log_{10} P)^2$$

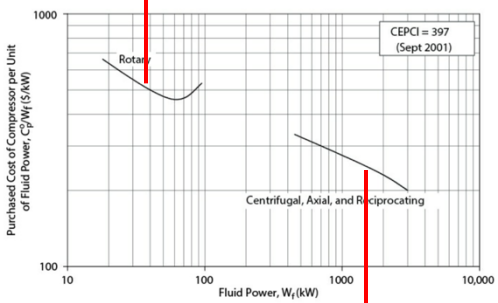
→ Equipment cost attribute, fluid power, kW
Achieved in ASPEN.

↓ Purchase cost of the equipment, at ambient operating pressure and using carbon steel construction.

Table A.1 Equipment Cost Data to Be Used with Equation (A.1)

Equipment Type	Equipment Description	K_1	K_2	K_3	Capacity, Units	Min Size	Max Size
Compressors	Centrifugal, axial, and reciprocating	2.2897	1.3604	−0.1027	Fluid power, kW	450	3000
	Rotary	5.0355	−1.8002	0.8253	Fluid power, kW	18	950

Rotary



Centrifugal axial

Be careful with the range and unit

Turton R, Bailie RC, Whiting WB, Analysis SJA. synthesis, and design of chemical processes. 3rd ed. Pearson Education; Appendix A.

Impact of Pressure

Pressure factor ← $\log_{10}F_P = C_1 + C_2\log_{10}P + C_3(log_{10}P)^2$

Table A.2 Pressure Factors for Process Equipment

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Equipment Type	Equipment Description	C_1	C_2	C_3	Pressure Range (barg)
Compressors	Centrifugal, axial, rotary,	0	0	0	–
Pumps	Reciprocating	0	0	0	P<10
		−0.245382	0.259016	−0.01363	10<P<100
	Positive displacement	0	0	0	P<10
		−0.245382	0.259016	−0.01363	10<P<100
	Centrifugal	0	0	0	P<10
		−0.3935	0.3957	−0.00226	10<P<100

Note:
The pressure factor of compressors is 1;
For other equipment, such as pumps, be careful with the pressure range.

Turton R, Bailie RC, Whiting WB, Analysis SJA. synthesis, and design of chemical processes. 3rd ed. Pearson Education; Appendix A.

Calculation Method

$$C_{BM} = C_P^0 F_{BM} = C_P^0 (B_1 + B_2 F_M F_P)$$

Equations depend on the type of equipment

Table A.4 Constants for Bare Module Factor to Be Used in Equation (A.4)

Equipment Type	Equipment Description	B_1	B_2
Heat exchangers	Double pipe, multiple pipe, scraped wall, and spiral tube	1.74	1.55
	Fixed tube sheet, floating head, U-tube, bayonet, kettle reboiler, and Teflon tube	1.63	1.66
	Air cooler, spiral plate, and flat plate	0.96	1.21
Process vessels	Horizontal	1.49	1.52
	Vertical (including towers)	2.25	1.82
Pumps	Reciprocating	1.89	1.35
	Positive displacement	1.89	1.35

Table A.5 Equations for Bare Module Cost for Equipment Not Covered by Tables A.3 and A.4

Equipment Type	Equation for Bare Module Cost
Compressors and blowers without drives	$C_{BM} = C_p^o F_{BM}$
Drives for compressors and blowers	$C_{BM} = C_p^o F_{BM}$
Evaporators and vaporizers	$C_{BM} = C_p^o F_{BM} F_p$
Fans with electric drives	$C_{BM} = C_p^o F_{BM} F_p$
Fired heaters and furnaces	$C_{BM} = C_p^o F_{BM} F_p F_T$

Turton R, Bailie RC, Whiting WB, Analysis SJA. synthesis, and design of chemical processes. 3rd ed. Pearson Education; Appendix A.

Impact of Material

$$C_{BM} = C_P^0 F_{BM} = C_P^0 (B_1 + B_2 F_M F_P)$$

Equations depend on the type of equipment

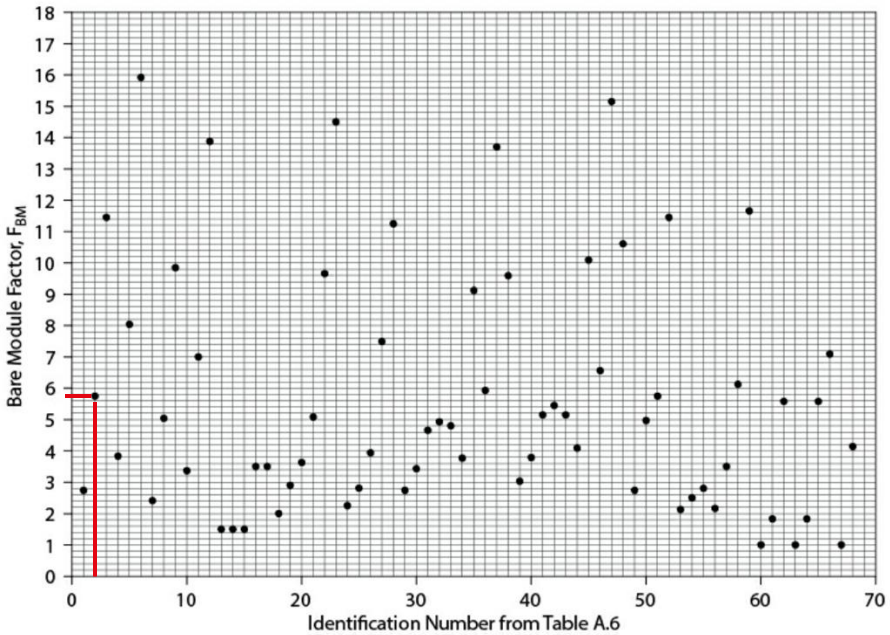


Figure A.19 Bare Module Factors for Equipment in Table

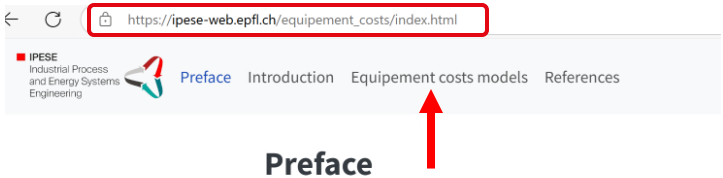
Table A.6 Identification of Material Factors for Equipment Listed in Table A.5 to Be Used with Figure A.19

Identification Number	Equipment Type	Equipment Description	Material of Construction
1	Compressors/blowers	Centrifugal compressor or blower	CS
2		Centrifugal compressor or blower	SS
3		Centrifugal compressor or blower	Ni alloy
4		Axial compressor or blower	CS
5		Axial	SS

F_{BM}=5.75

Turton R, Bailie RC, Whiting WB, Analysis SJA. synthesis, and design of chemical processes. 3rd ed. Pearson Education; Appendix A.

Website - Overview



Get access to the website: https://ipese-web.epfl.ch/equipement_costs/index.html.

Preface

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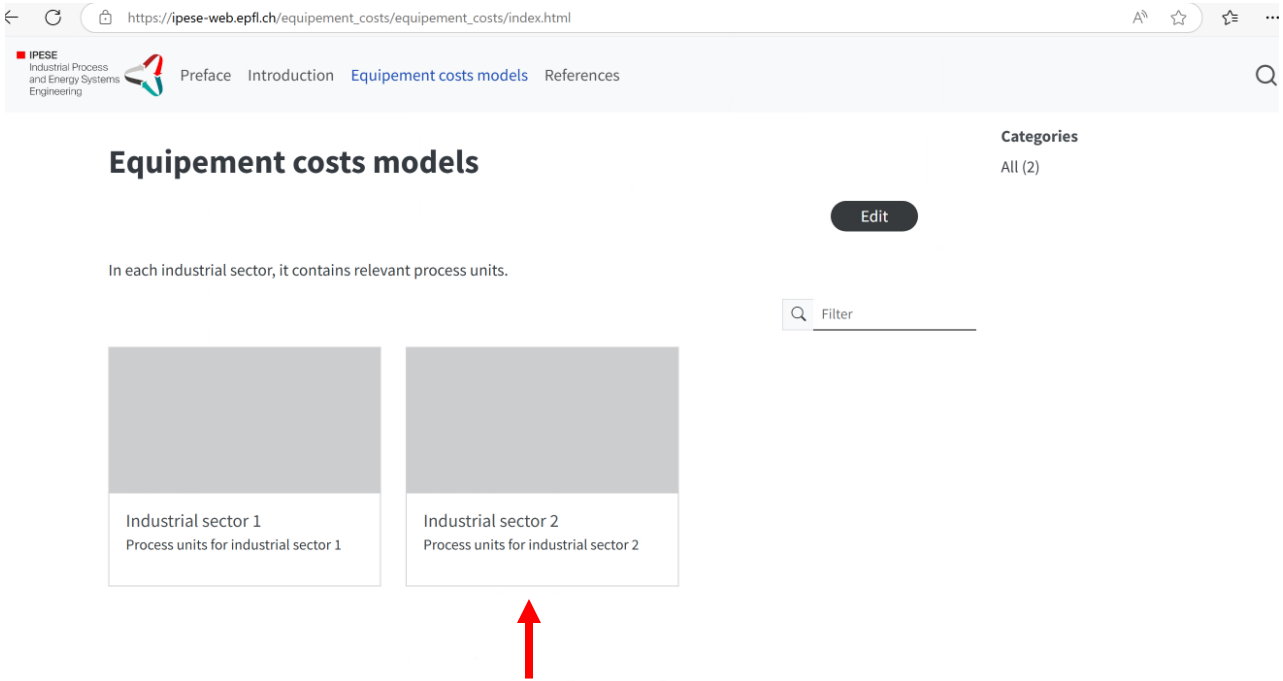
Edit

This Quarto book will give an introduction of how we connect all resources in FM's lab.

All relevant information of each process unit will be put in one folder with the name of the unit being the name of the folder, such as:

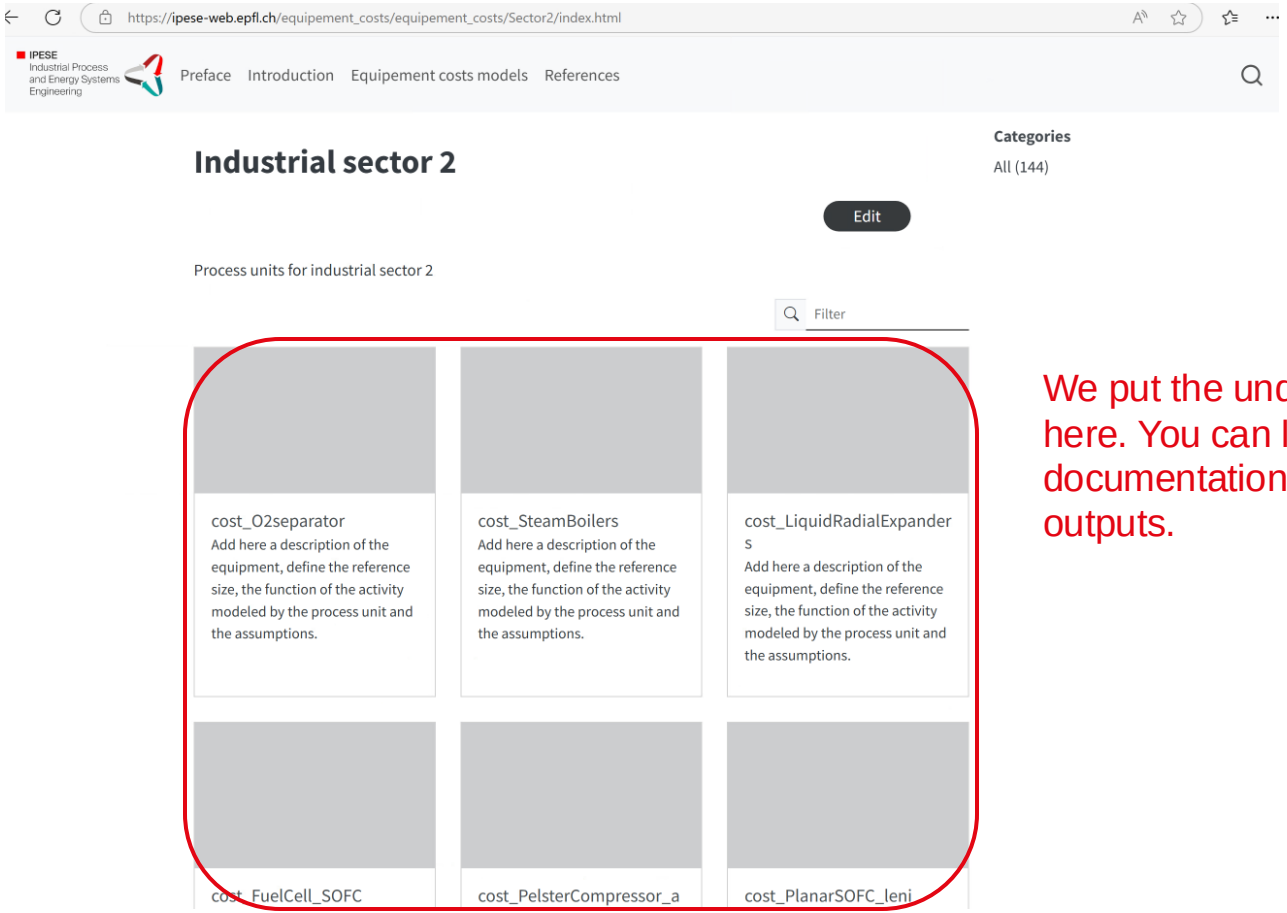
- **index.qmd**: It is the documentation of the process using markdown text.
- **References**: A reference.bib file which includes references of model development and relevant data.
- **./Model**: A folder that includes the model of the unit:
  - Model File can be with different formats:
    - **.asp**: Aspen format
    - **.xls**: Xls format
    - **.lua**: ET.lua format of osmose.lua
  - **Input.csv**: Input of the model with the following format:
    - **"from"**: commend that accesses the value in osmose.
    - **"to"**: command that allows to transfer the value to Input.csv.
    - **"unit"**: physical unit of the value transferred.
    - **"Value"**: value transferred.
  - **Output.csv**: Output of the model with the following format:
    - **"from"**: commend that accesses the the location in model and extract the value after the model execution.
    - **"to"**: command that allows to transfer the value to Output.csv.
    - **"unit"**: physical unit of the value transferred.
    - **"Value"**: value resulting from the model execution.
  - **Script**: It is a Python script with the following functions:
    - **create index.qmd**: If there is no such a file, create one with a fixed format.
    - **execute ET.lua**: Find the location of the ET file, create a frontend.lua to include ET.lua, execute OSMOSE, read the results in .jason.

Website - Overview



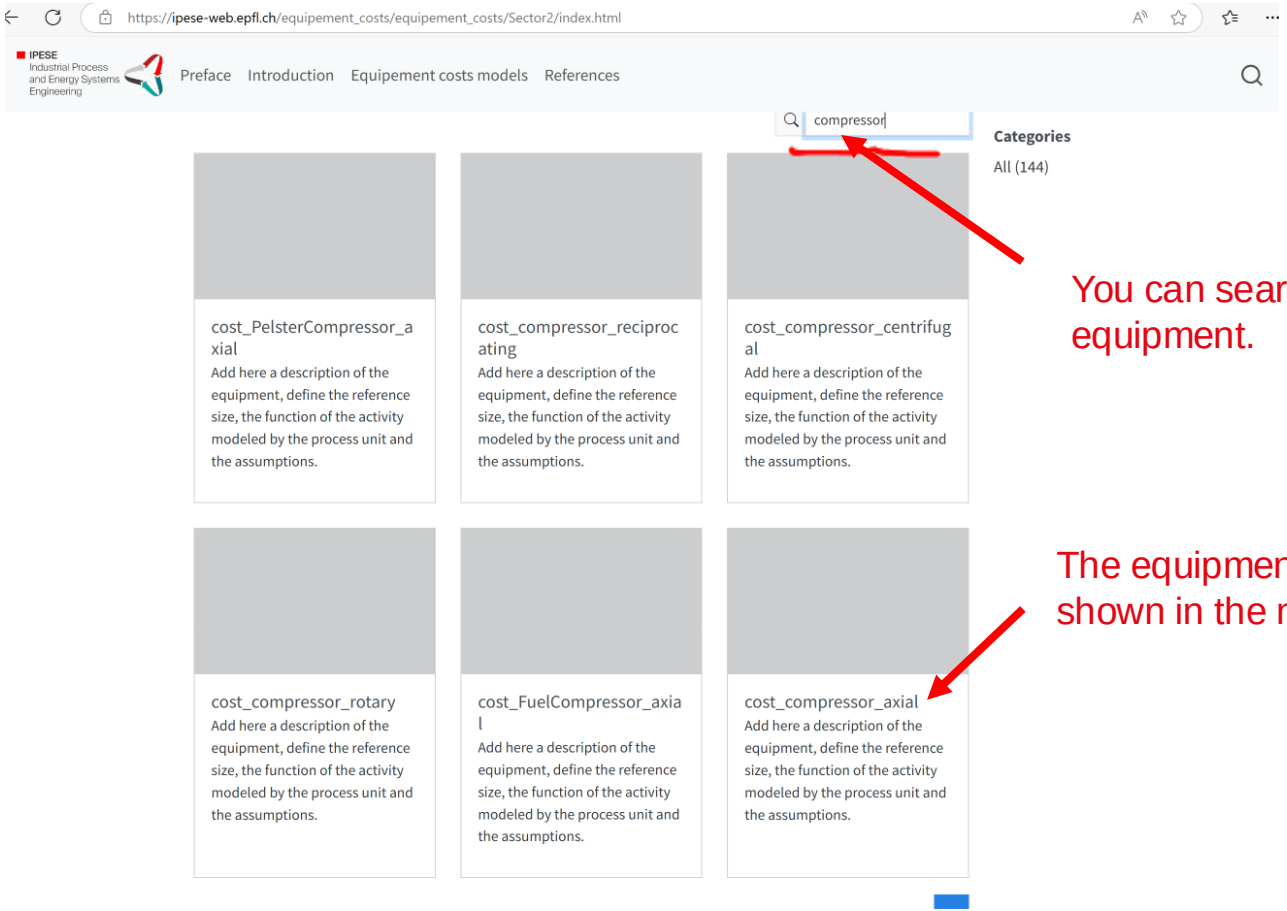
Find the equipment cost library here.

Website – Equipment Cost Library



We put the underlying code here. You can look at the documentation, inputs, and outputs.

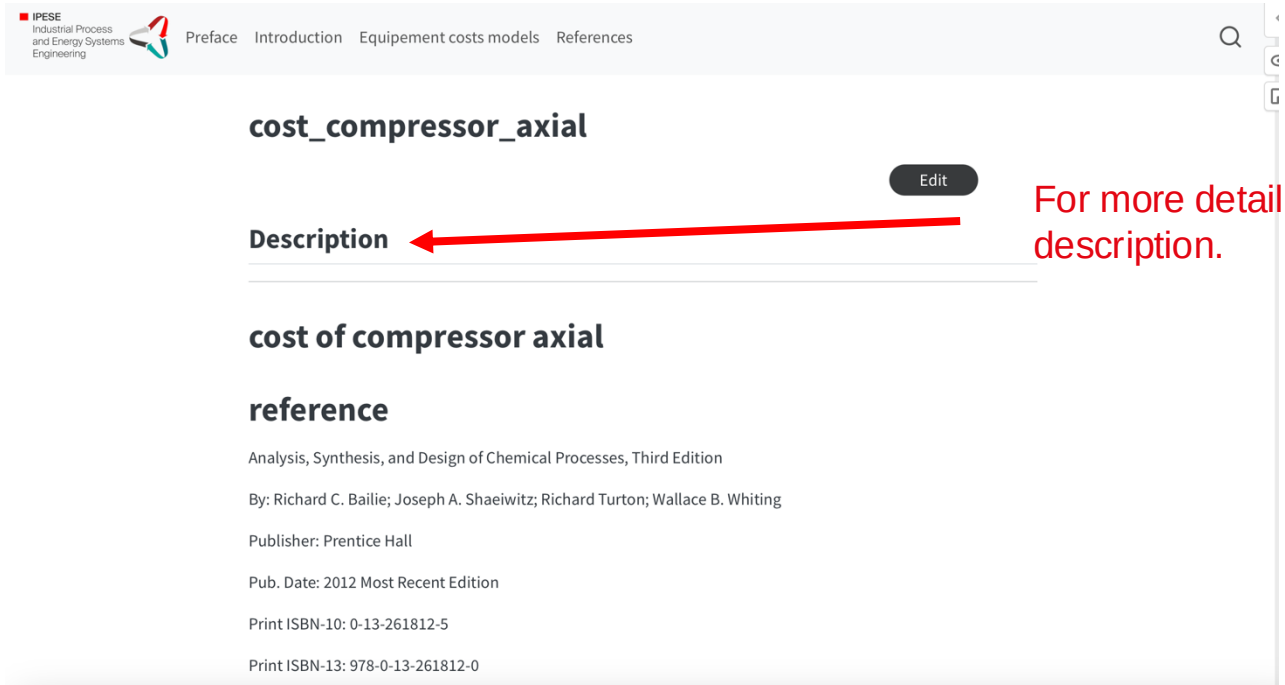
Website – Equipment Cost Library



You can search for the equipment.

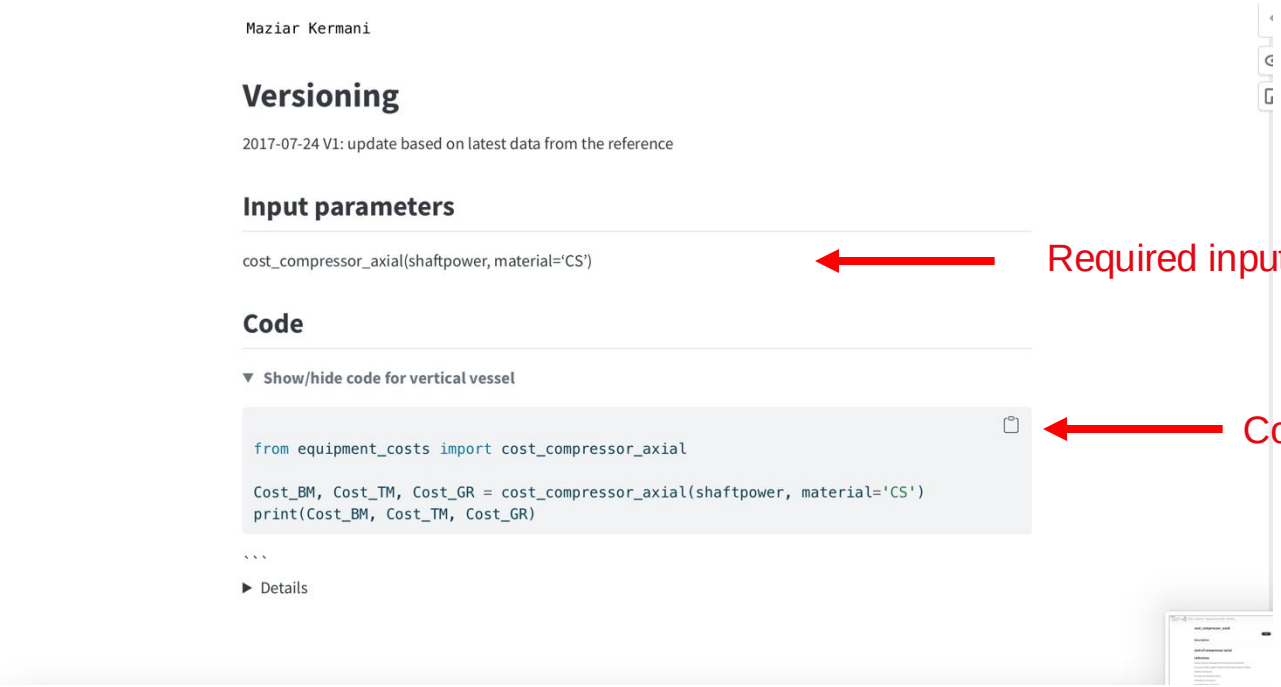
The equipment subcategory is shown in the name.

Website – Axial Compressor



For more details, you can check the description.

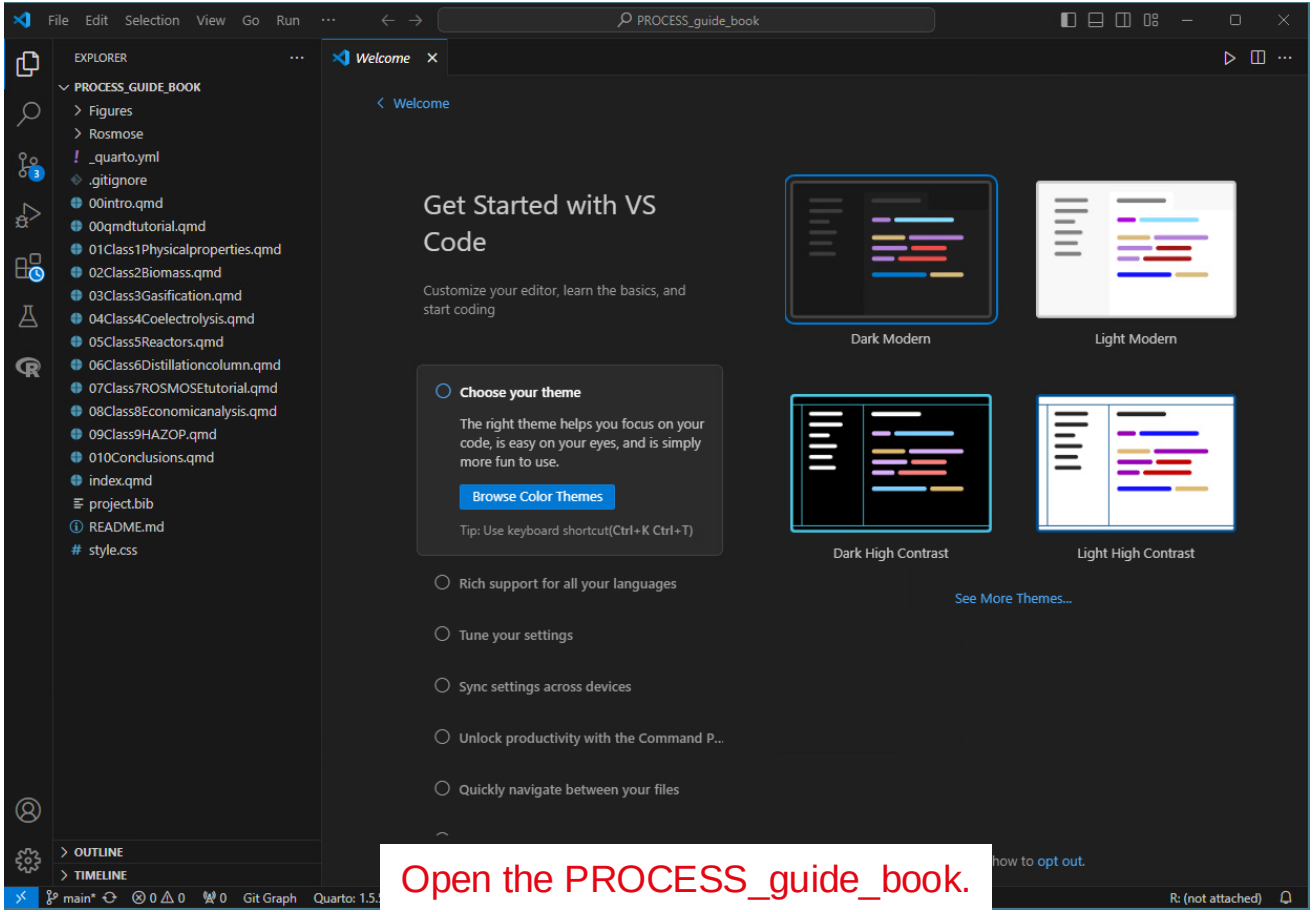
Website – Axial Compressor



Required inputs

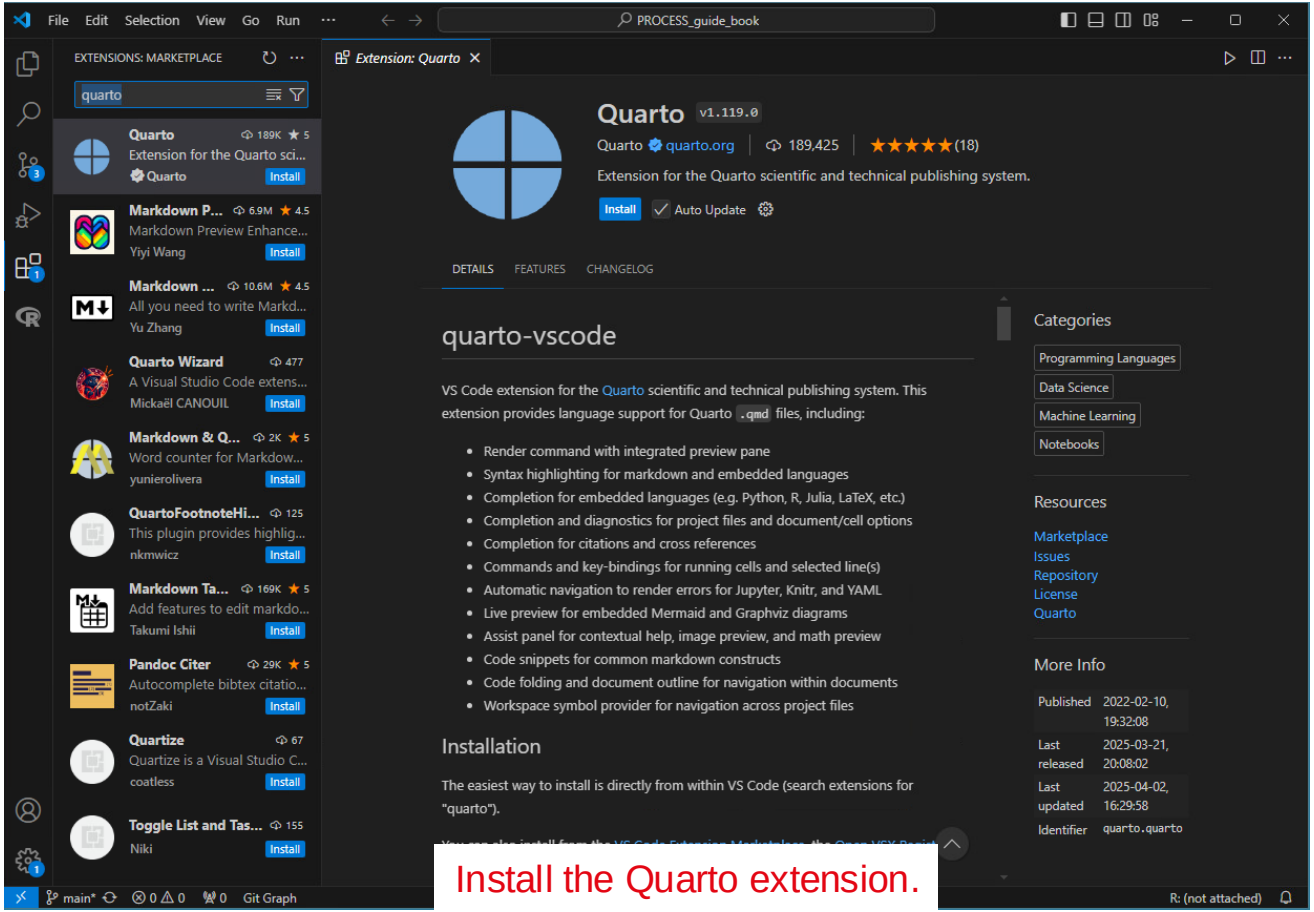
Copy and paste

Equipment Cost Calculation - Overview



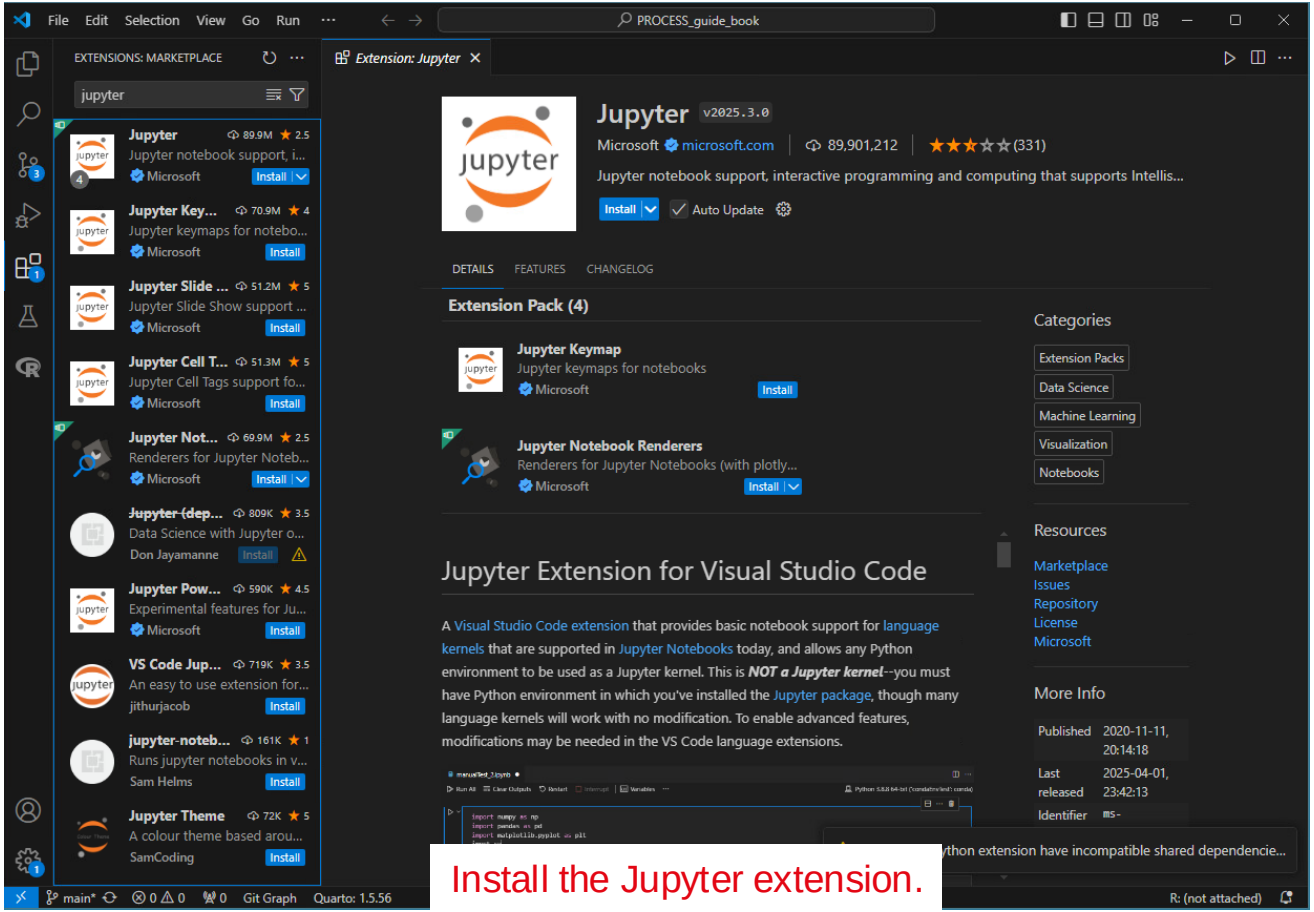
Open the PROCESS_guide_book.

Equipment Cost Calculation - Overview



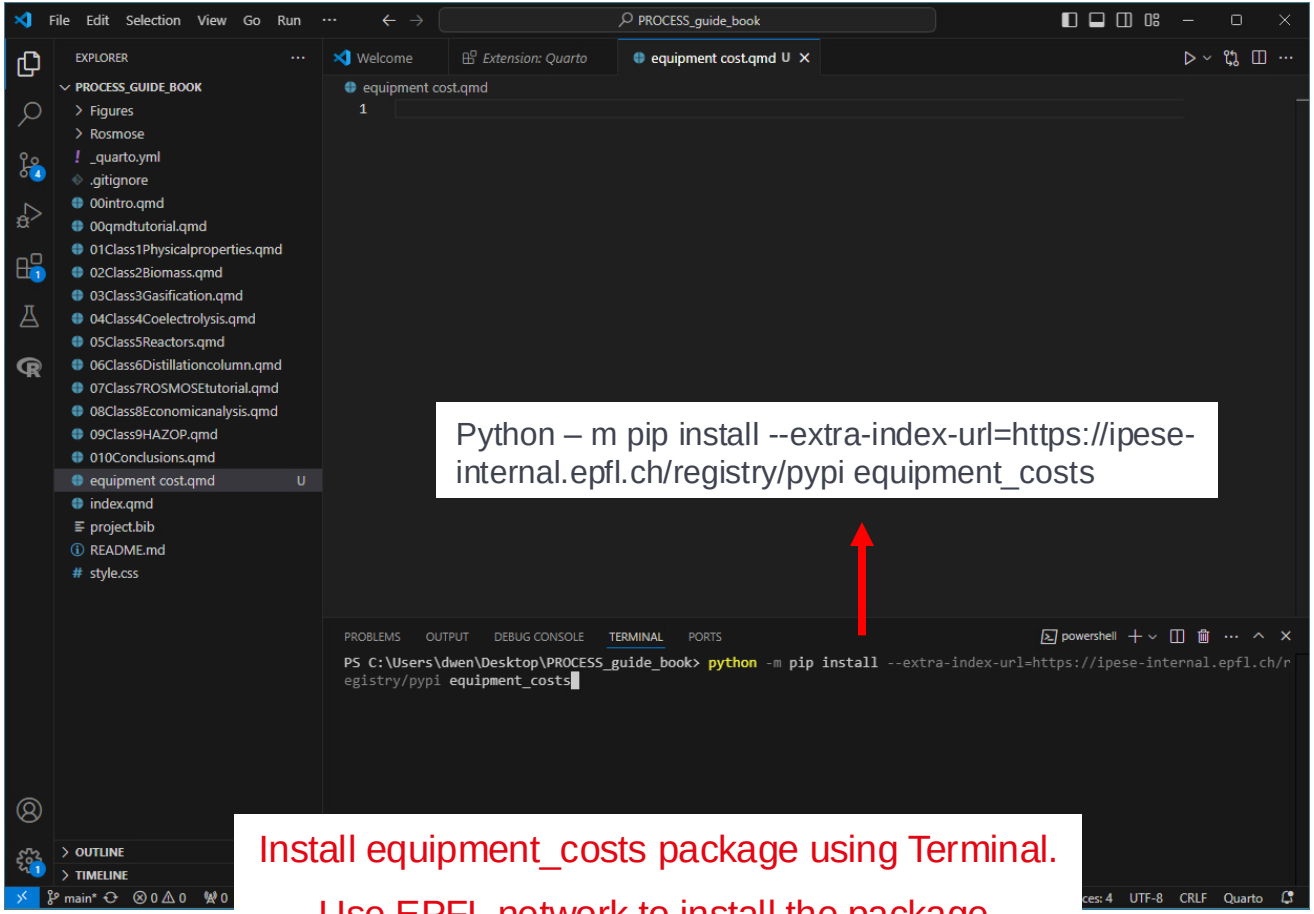
Install the Quarto extension.

Equipment Cost Calculation - Overview



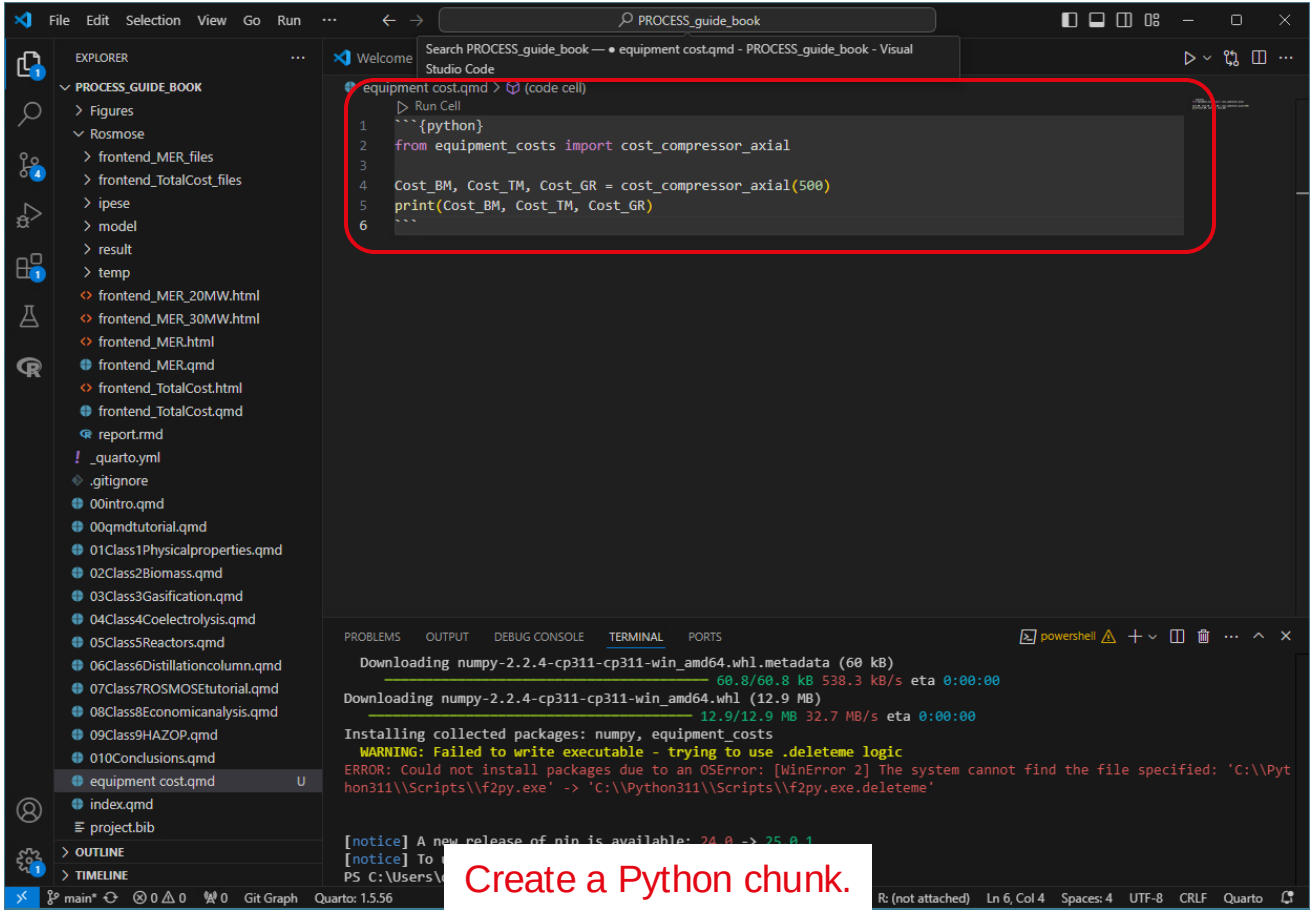
Install the Jupyter extension.

Equipment Cost Calculation - Overview



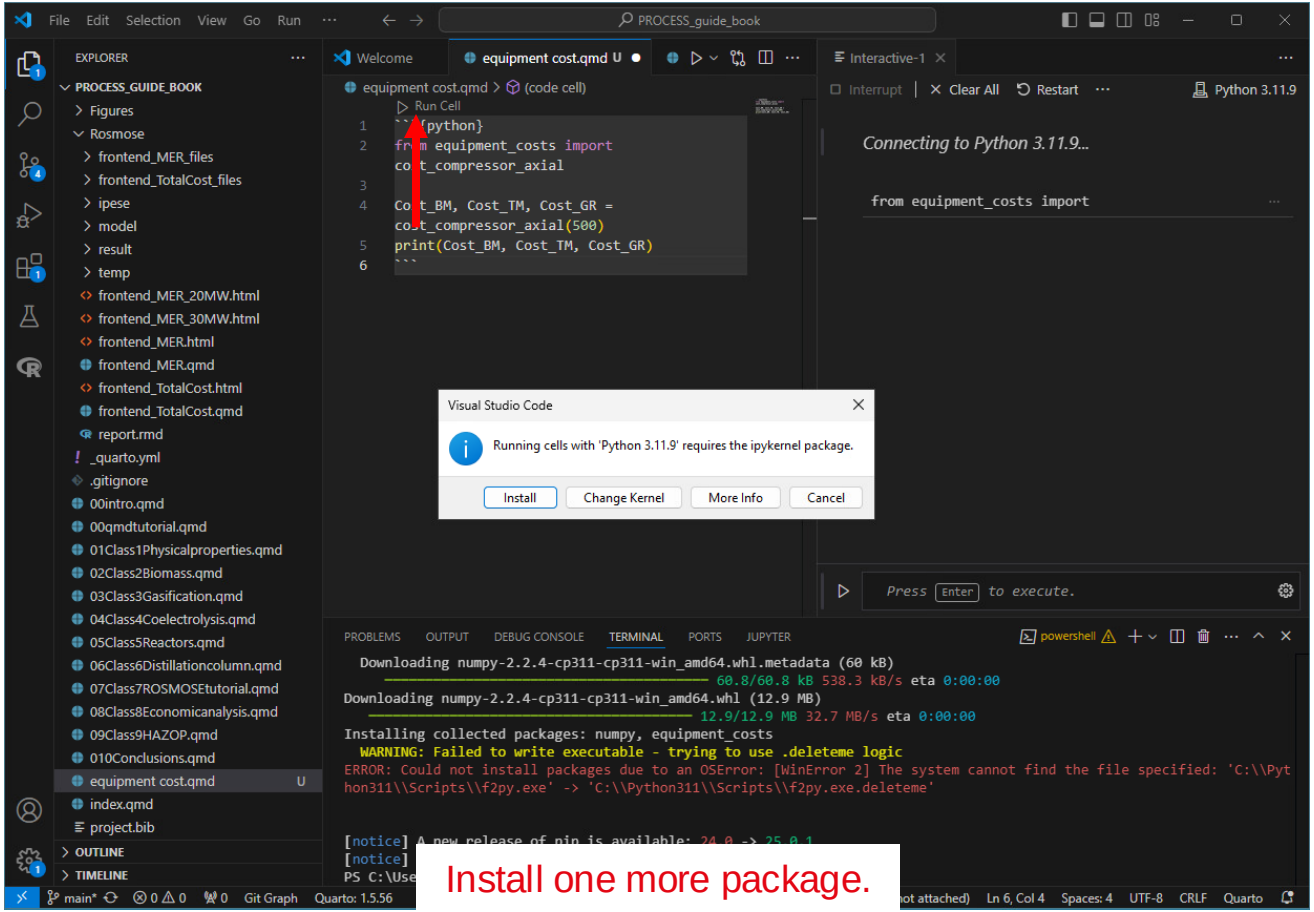
Economic Analysis Tutorial

Equipment Cost Calculation - Overview

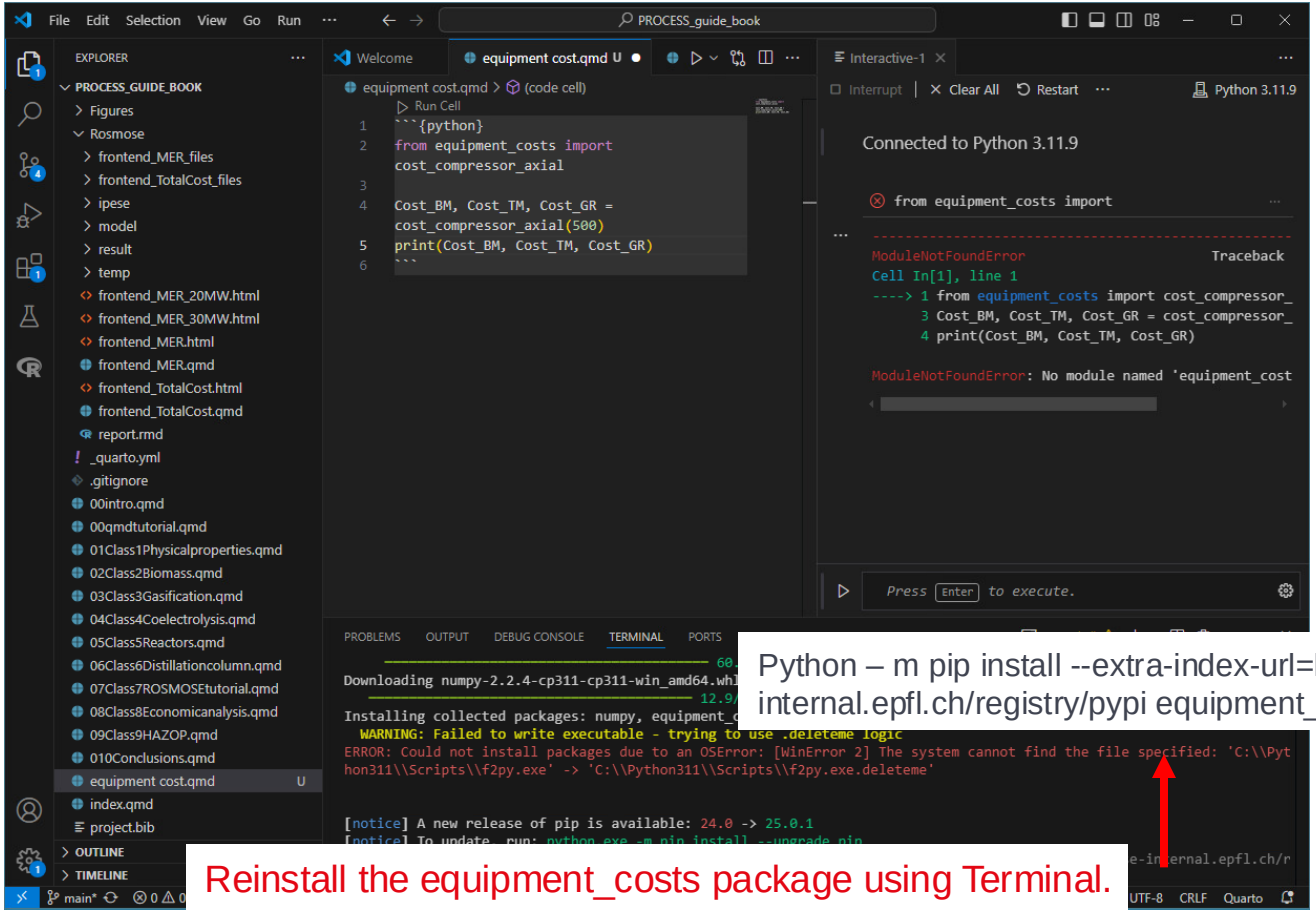


Economic Analysis Tutorial

Equipment Cost Calculation - Overview



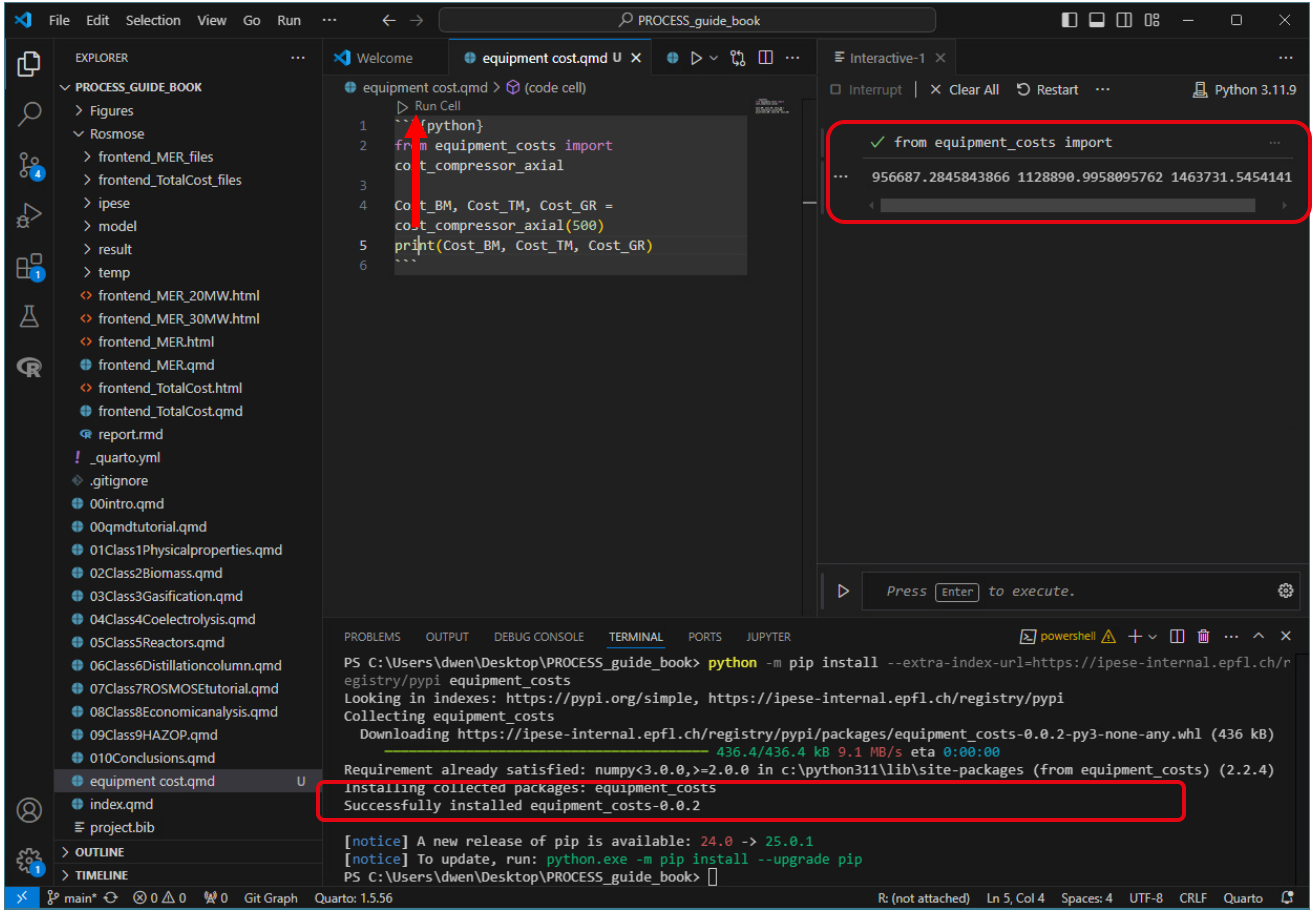
Equipment Cost Calculation - Overview



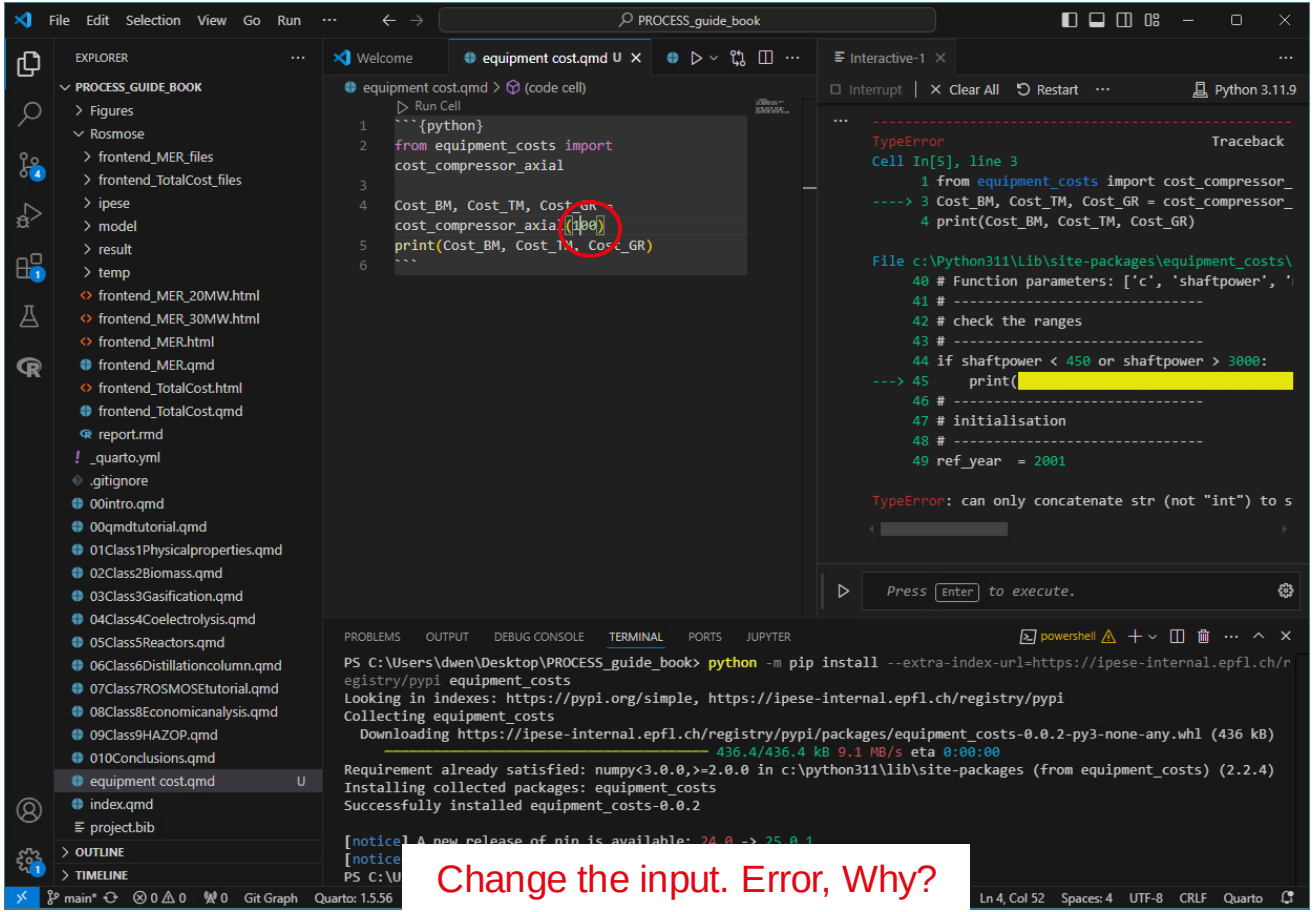
Python – m pip install --extra-index-url=https://ipese-internal.epfl.ch/registry/pypi equipment_costs

Reinstall the equipment_costs package using Terminal.

Equipment Cost Calculation - Compressor



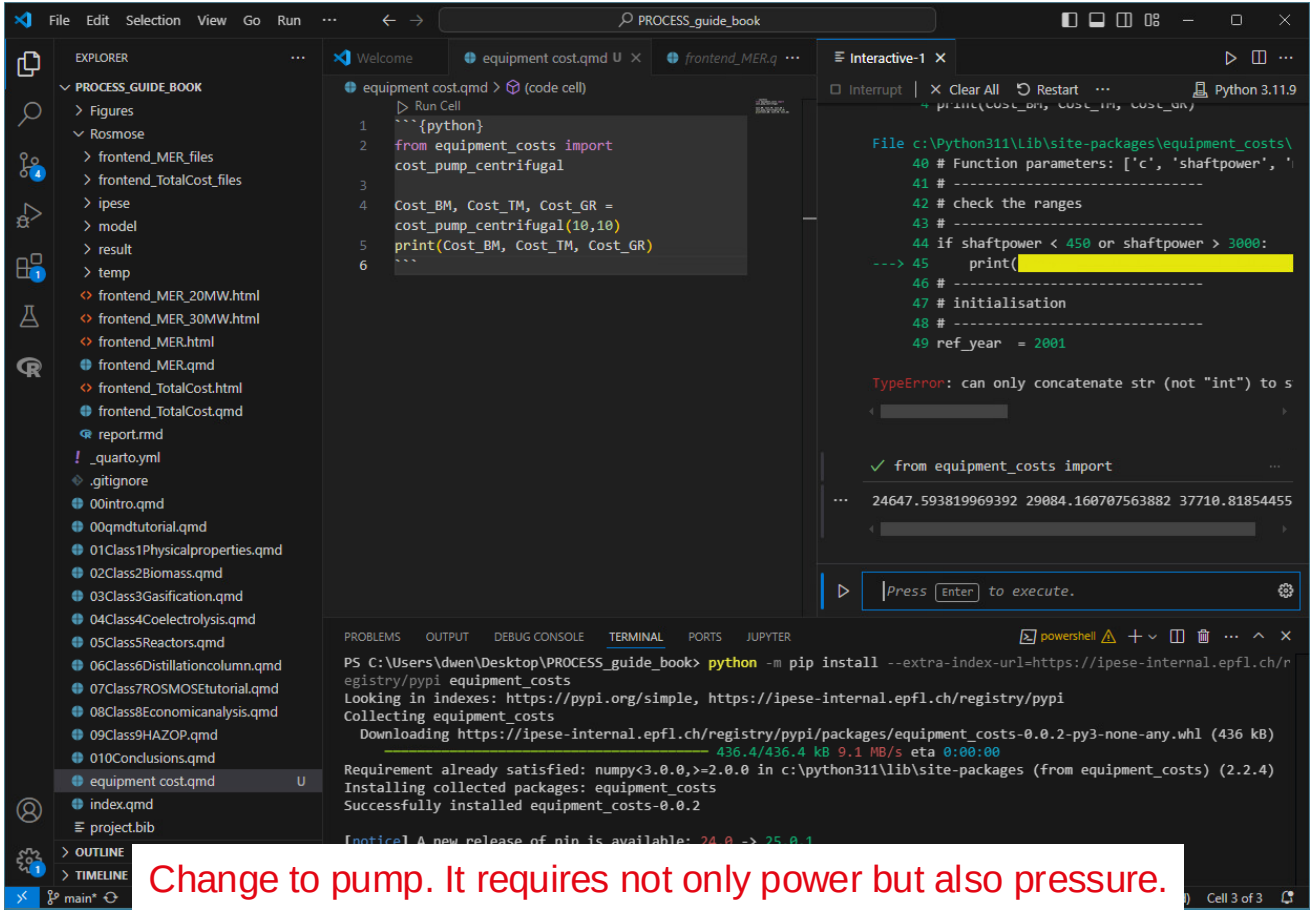
Equipment Cost Calculation - Compressor



Change the input. Error, Why?

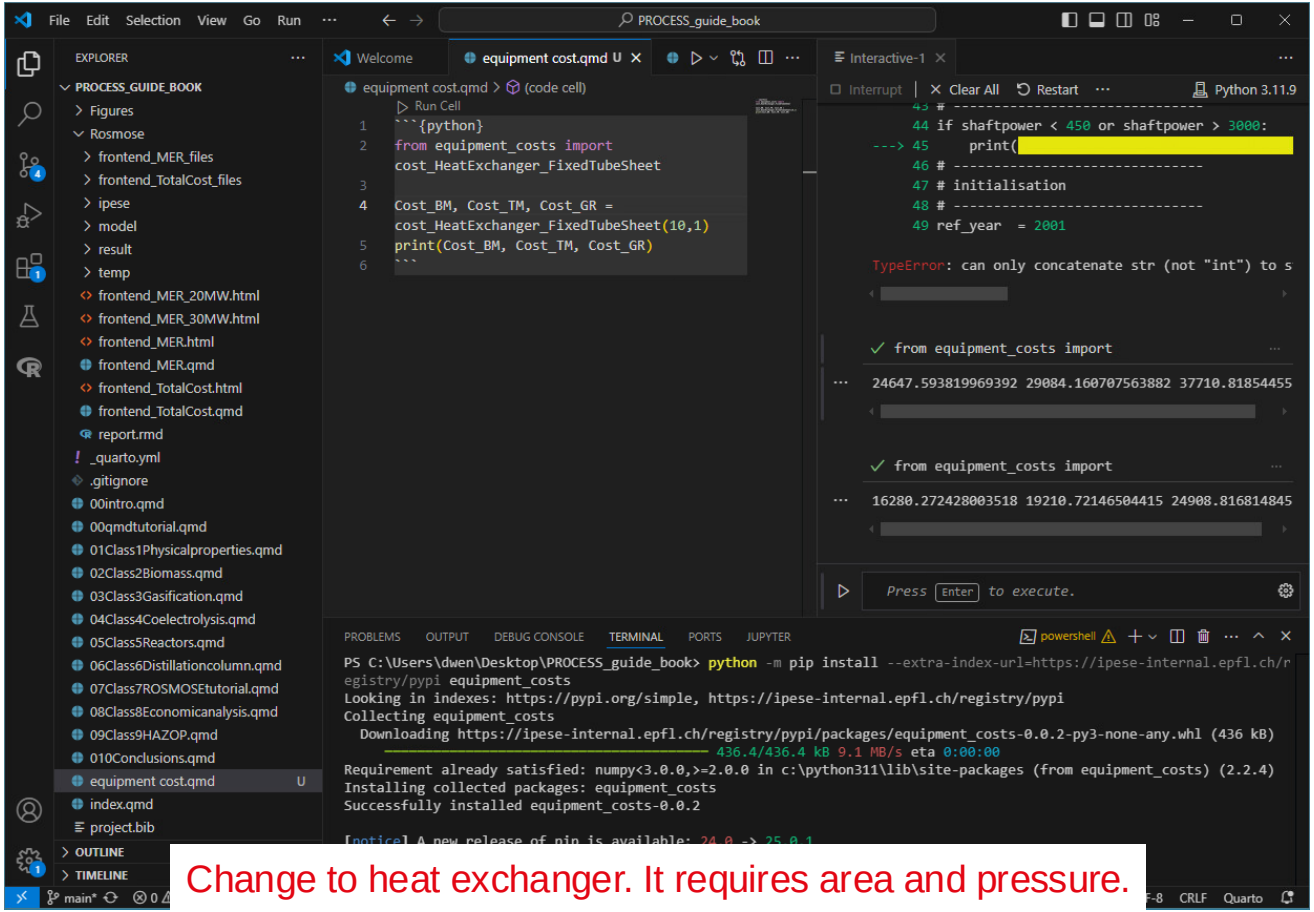
Economic Analysis Tutorial

Equipment Cost Calculation - Pump



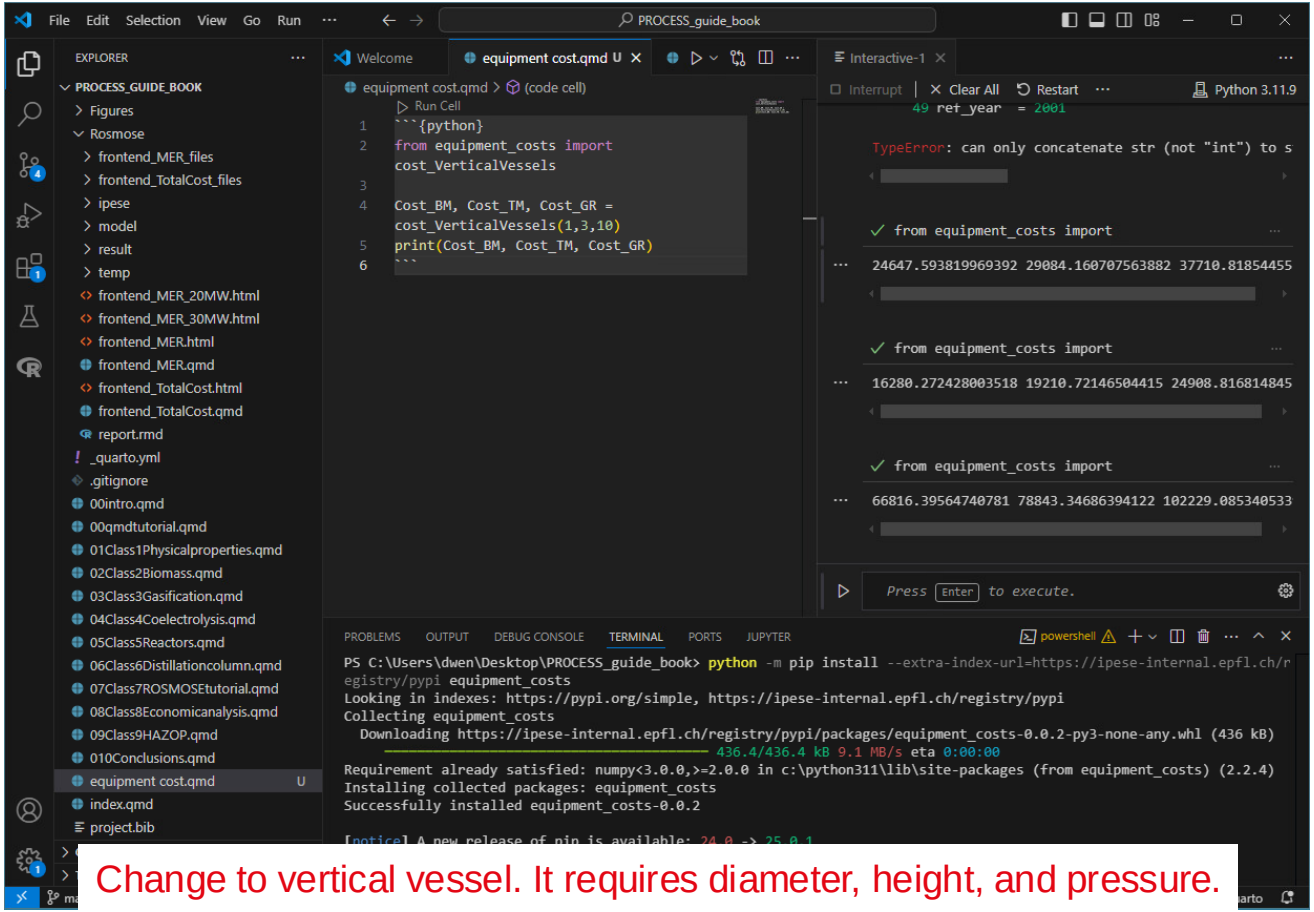
Change to pump. It requires not only power but also pressure.

Equipment Cost Calculation – Heat Exchanger



Change to heat exchanger. It requires area and pressure.

Equipment Cost Calculation - Overview



Change to vertical vessel. It requires diameter, height, and pressure.

Questions

What is the bare module cost of a centrifugal compressor with 500 kW?

What is the bare module cost of a reciprocating pump with 100 kW and 1 bar?

What is the bare module cost of a double pipe heat exchanger with 100 m2 and 10 bar?

What is the bare module cost of a horizontal vessel with 1 m in diameter, 3 m in length, and 10 bar?