

SMART ENERGY BUILDINGS

Development of a photovoltaic thermal system configuration with additional envelope-integration into a multi-family building

“
Our goal here is to fundamentally change the way the world uses energy.

Elon Musk

SMART ENERGY BUILDINGS

What did I do?

- Examined photovoltaic thermal collectors (PVT)
- Developed an energy system configuration
- Applied PVT on roof and in facade

SMART ENERGY BUILDINGS

Content



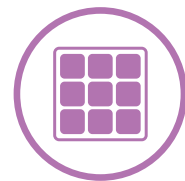
Research question



Theory and background information



Energy requirements of the multi-family building



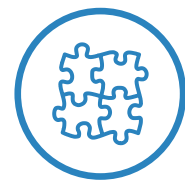
Energy outputs of the PVT collector



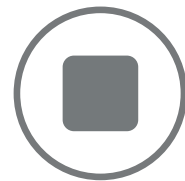
Development of the system configuration



Creation of an energy balance



Development of the integration of the PVT collector



Evaluation & conclusion



RESEARCH QUESTION

RESEARCH QUESTION

How can an energy concept with PVT be optimised or maximised in terms of renewable energy and be integrated in the envelope of a multi-family building?





THEORY AND BACKGROUND INFORMATION



THEORY AND BACKGROUND INFORMATION

Photovoltaic thermal collectors

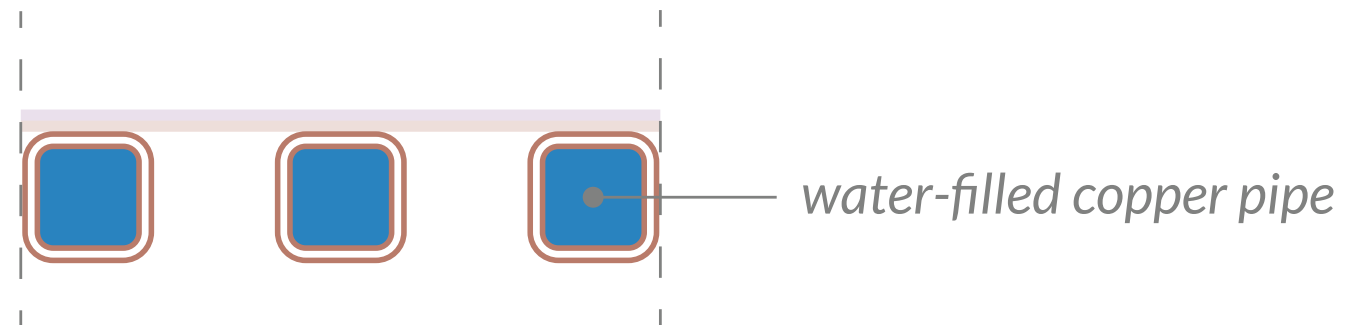


Image: courtesy of TESZEUS



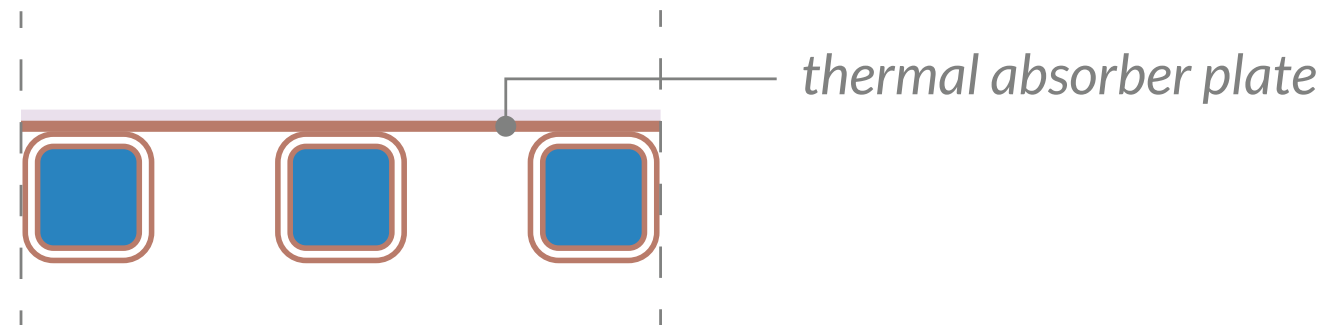
THEORY AND BACKGROUND INFORMATION

Photovoltaic thermal collectors



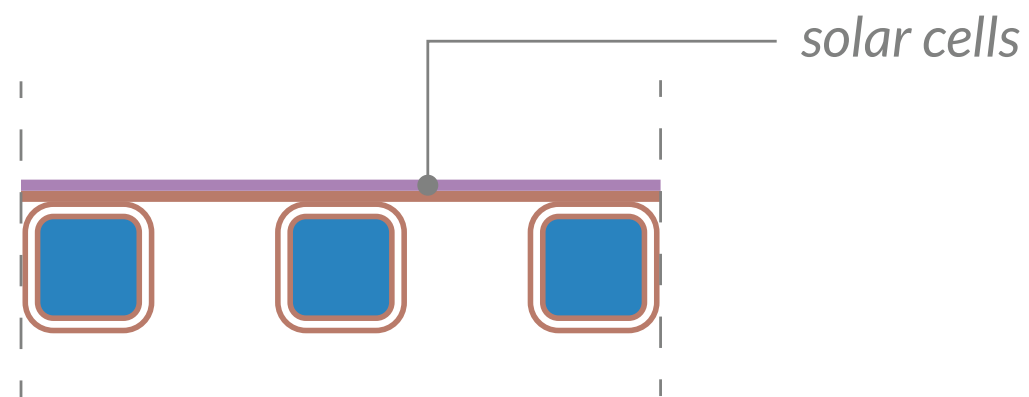
THEORY AND BACKGROUND INFORMATION

Photovoltaic thermal collectors



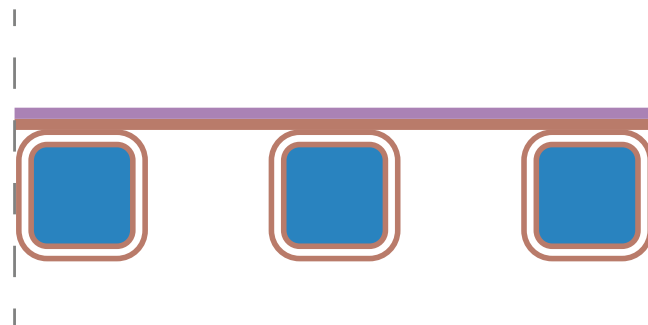
THEORY AND BACKGROUND INFORMATION

Photovoltaic thermal collectors



THEORY AND BACKGROUND INFORMATION

Photovoltaic thermal collectors

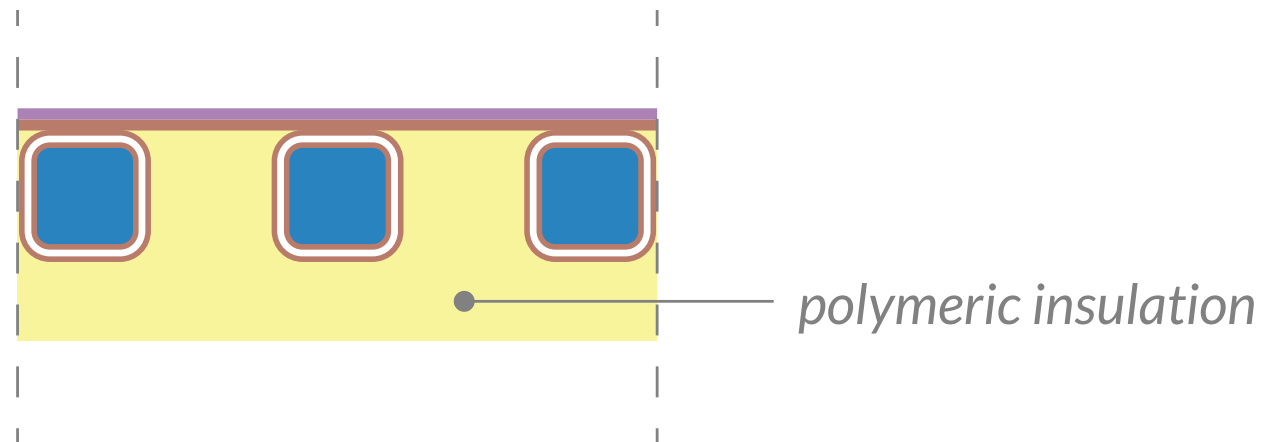


uncovered, uninsulated collector (UU)



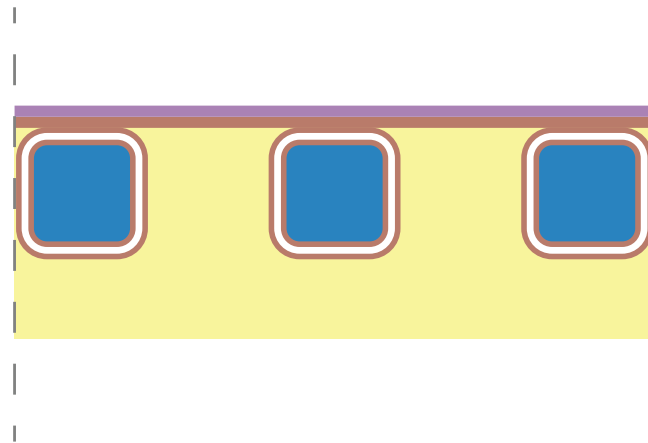
THEORY AND BACKGROUND INFORMATION

Photovoltaic thermal collectors



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Photovoltaic thermal collectors

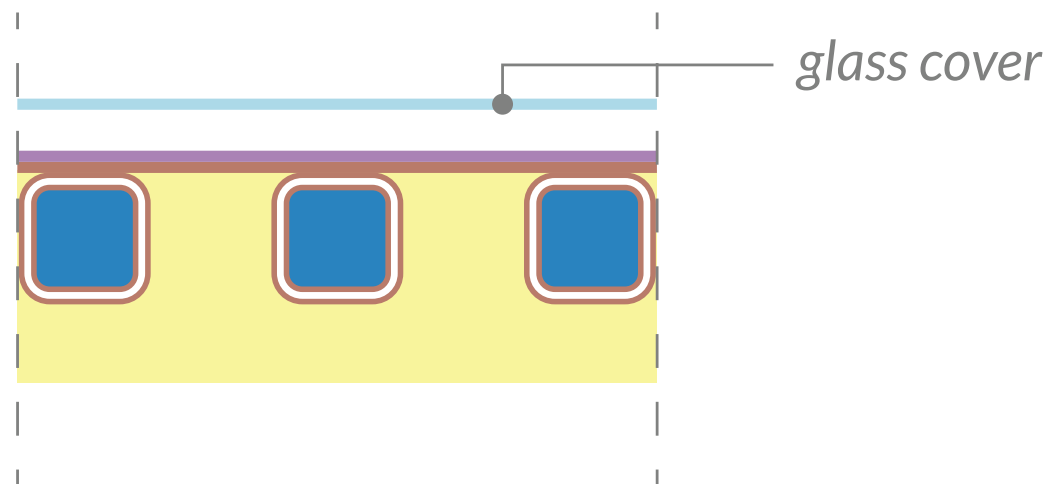


uncovered, insulated collector (UI)



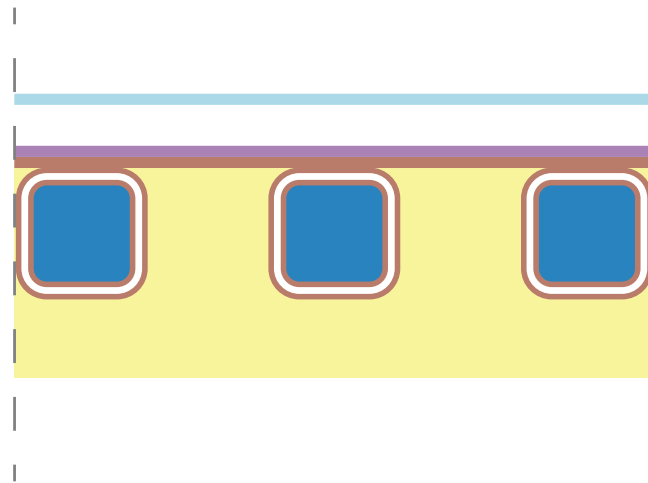
THEORY AND BACKGROUND INFORMATION

Photovoltaic thermal collectors



THEORY AND BACKGROUND INFORMATION

Photovoltaic thermal collectors



covered, insulated collector (CI)



THEORY AND BACKGROUND INFORMATION

Photovoltaic thermal collectors

- Excess heat from PV cells is given to water
- PVT has a ca. 300% higher energy output per m² than photovoltaic and solar thermal modules
- This is especially attractive for buildings with relatively many occupants and a small roof area



THEORY AND BACKGROUND INFORMATION

Renewable energy systems

- Low-temperature heating (LTH): 30 - 35°C
- High-temperature cooling (HTC): 16°C
- Domestic hot water (DHW): 60°C



THEORY AND BACKGROUND INFORMATION

Heat pump

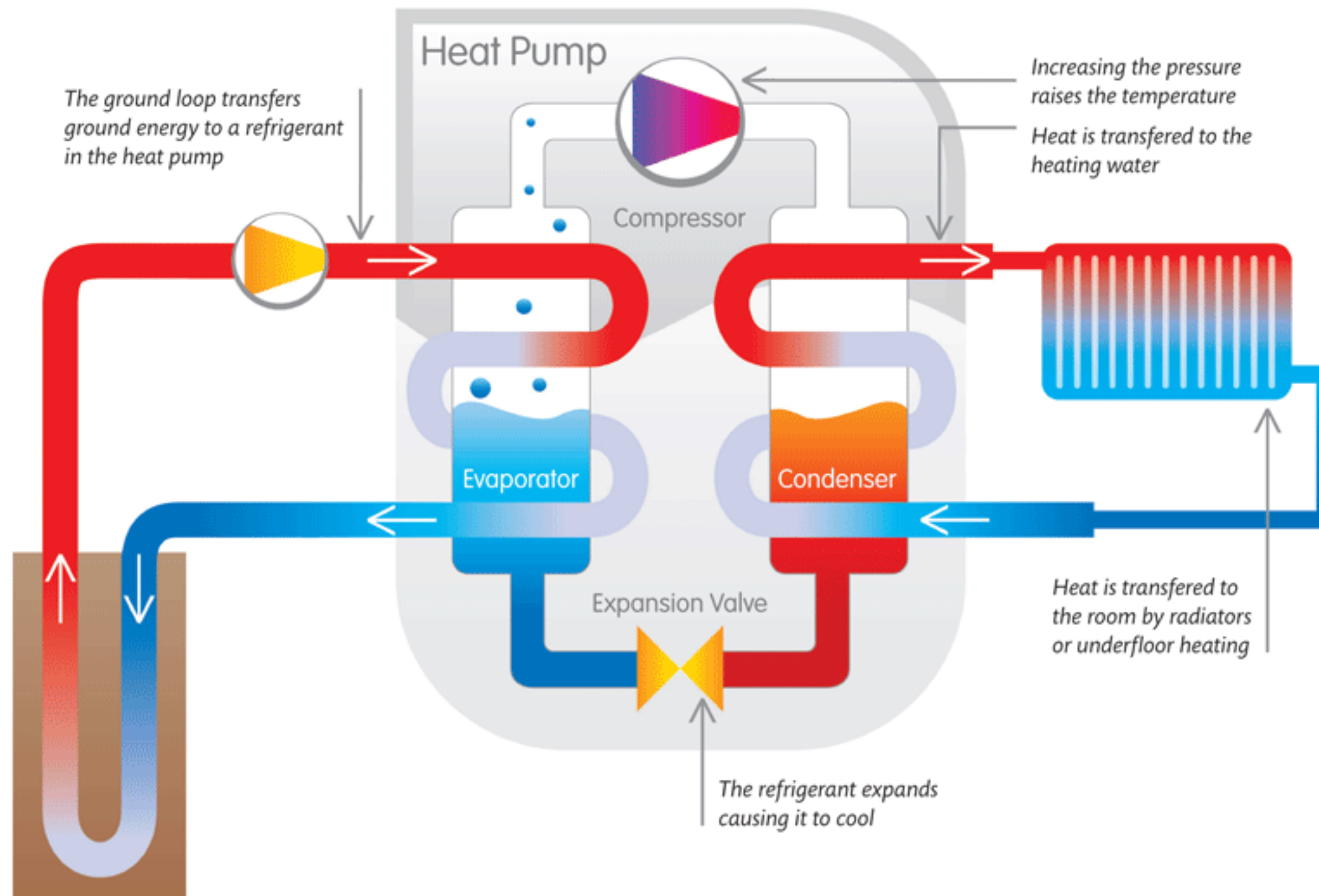


Image: courtesy of Global Energy Systems

- Coefficient of performance (COP)



THEORY AND BACKGROUND INFORMATION

Addition and integration



Image: courtesy of Modernize



Image: courtesy of Van der Leun

- Building-added modules (left)
- Building-integrated modules (right)



THEORY AND BACKGROUND INFORMATION

Aesthetical appearance



Image: courtesy of RobAid

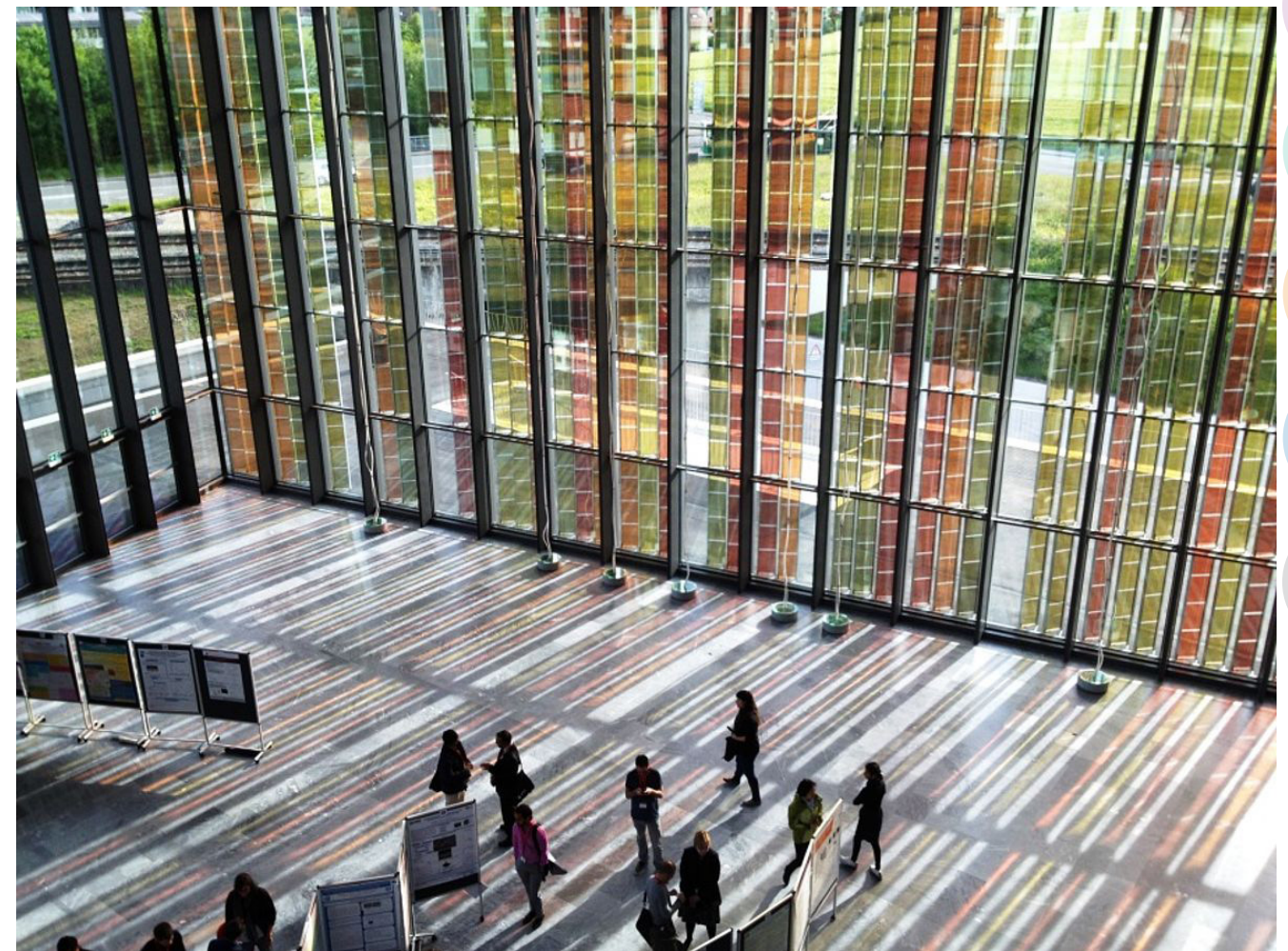


Image: courtesy of Ulm University

- Dye-sensitised solar cells





ENERGY REQUIREMENTS OF THE MULTI-FAMILY BUILDING



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Case-study building

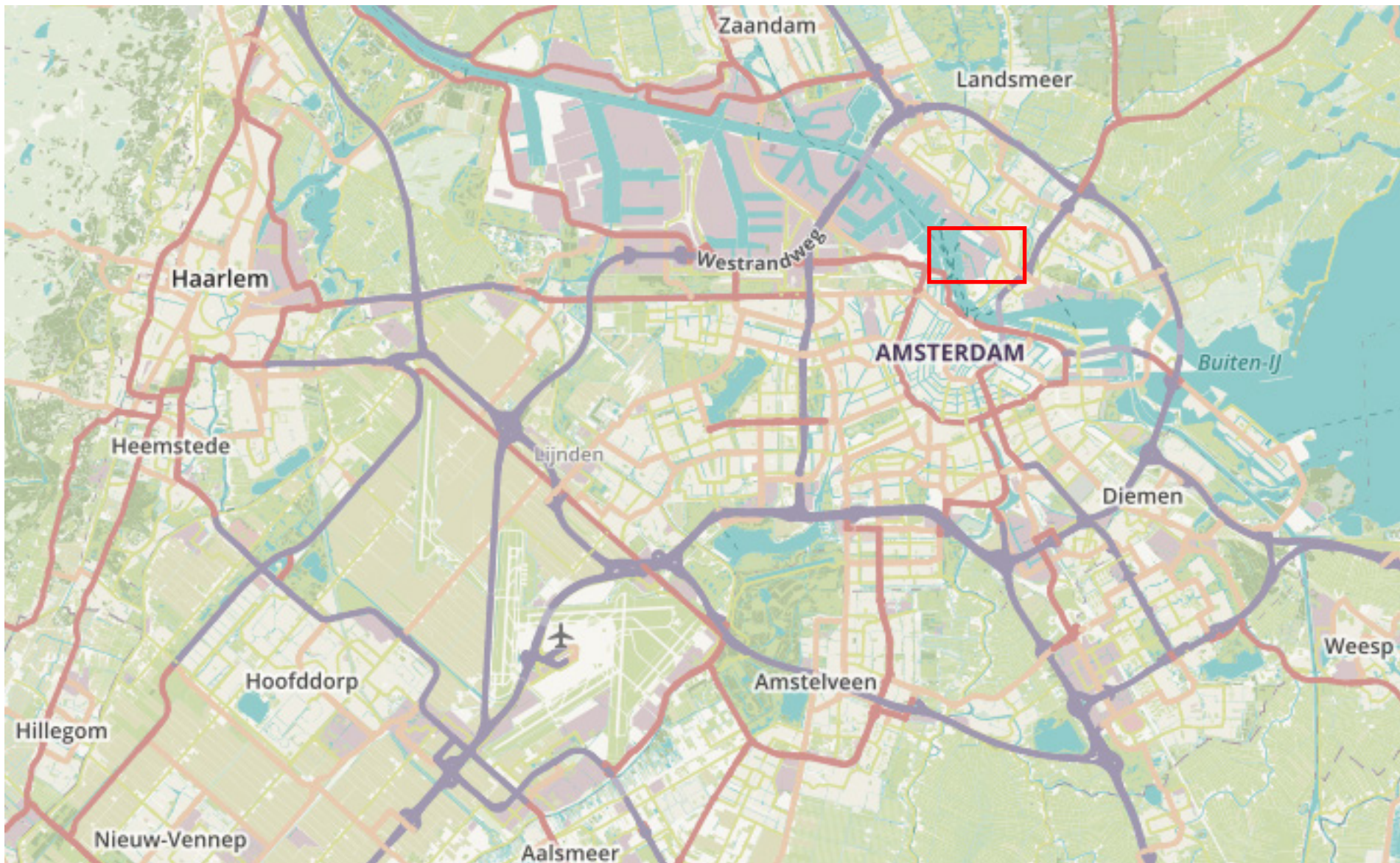
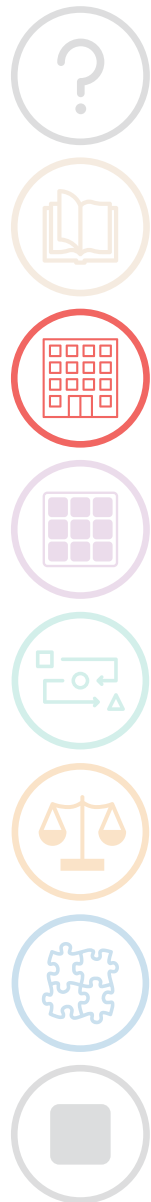


Image: courtesy of OpenStreetMap



ENERGY REQUIREMENTS OF THE MULTI-FAMILY BUILDING

Case-study building

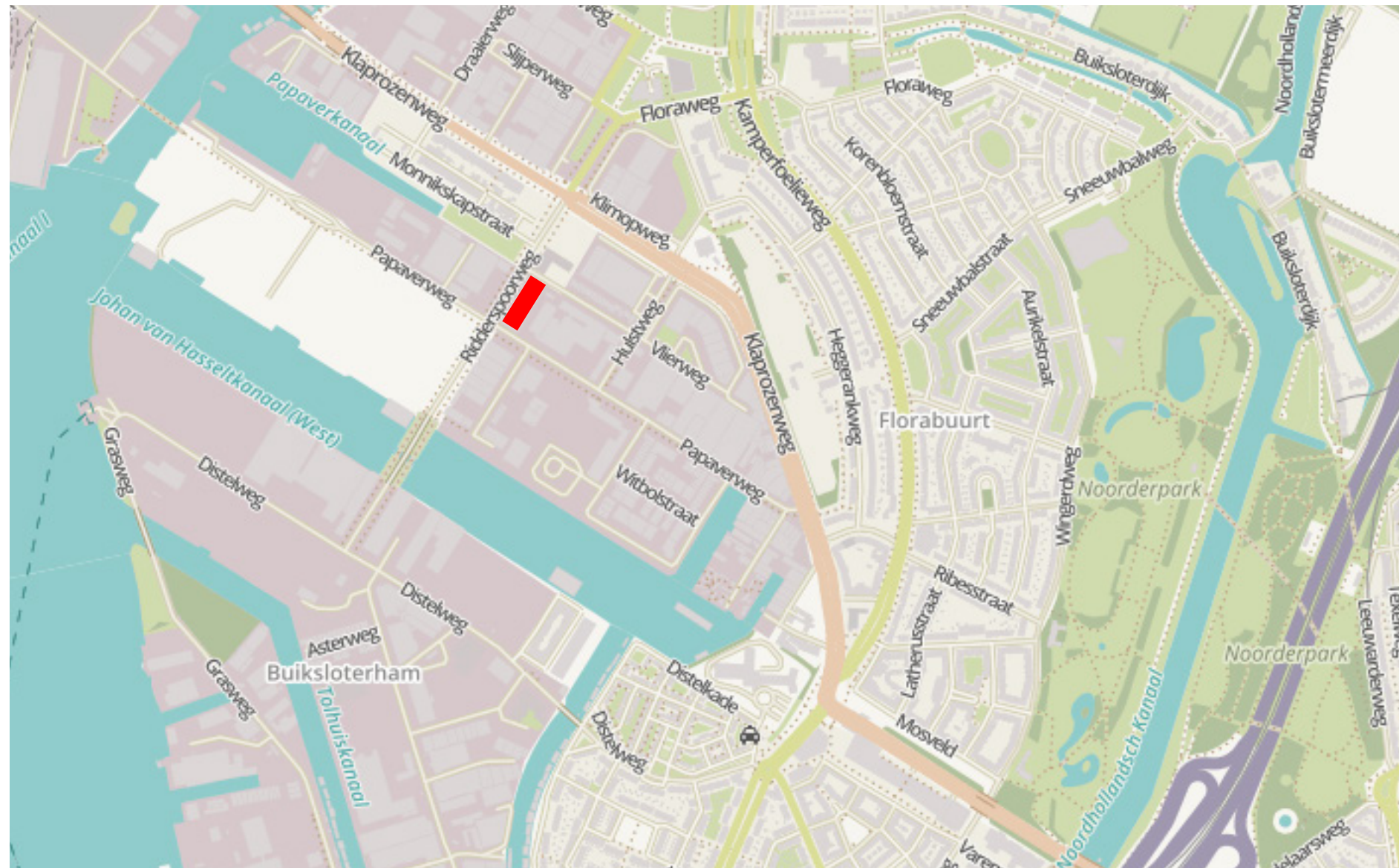
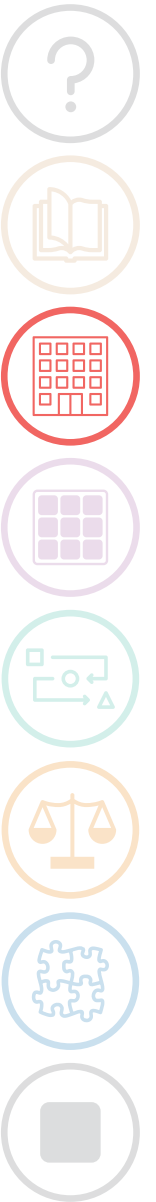


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ENERGY REQUIREMENTS OF THE MULTI-FAMILY BUILDING

Case-study building



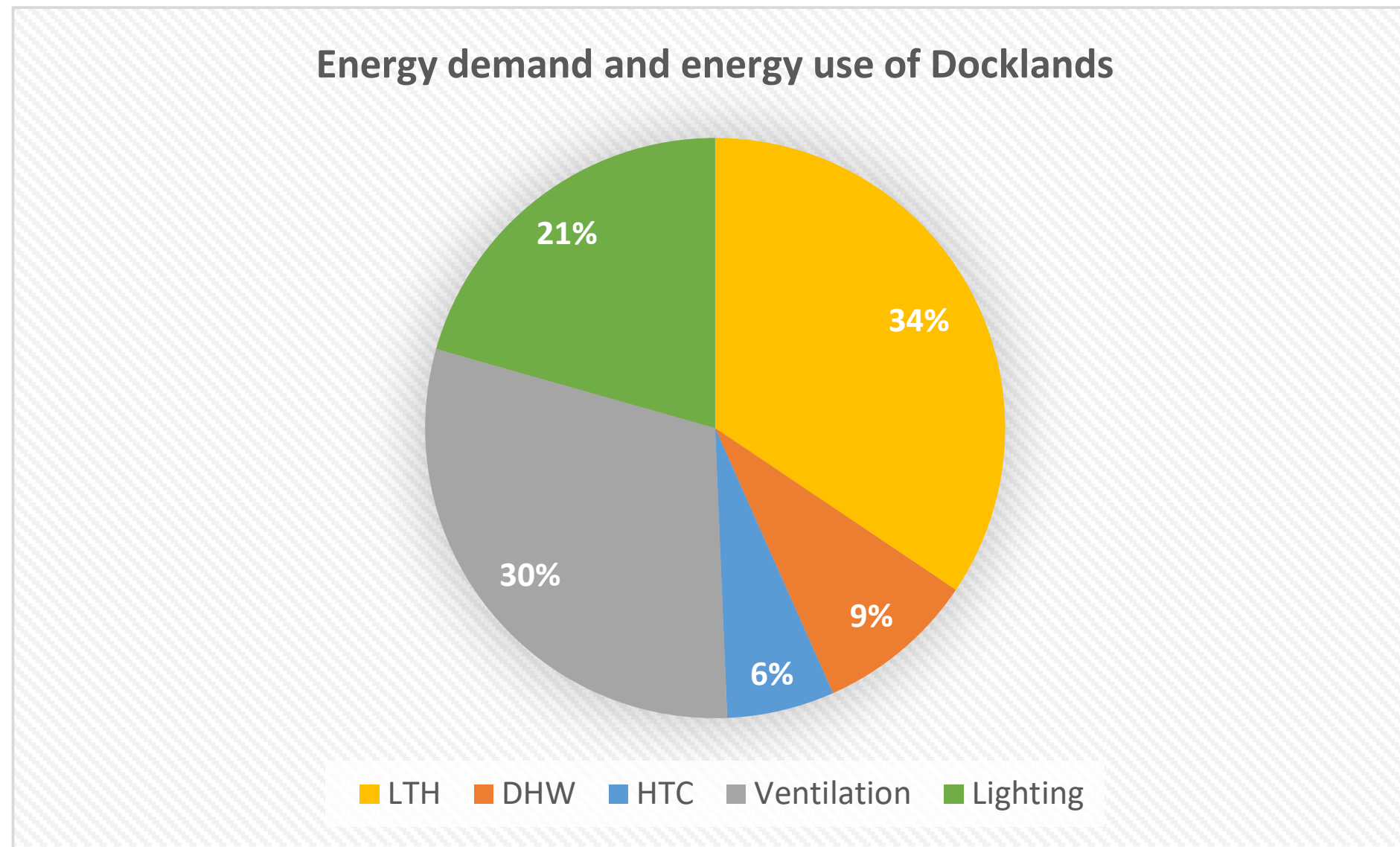
Image: courtesy of Vink Bouw

- Docklands
- Multi-family building
- PV panels and solar thermal collectors



ENERGY REQUIREMENTS OF THE MULTI-FAMILY BUILDING

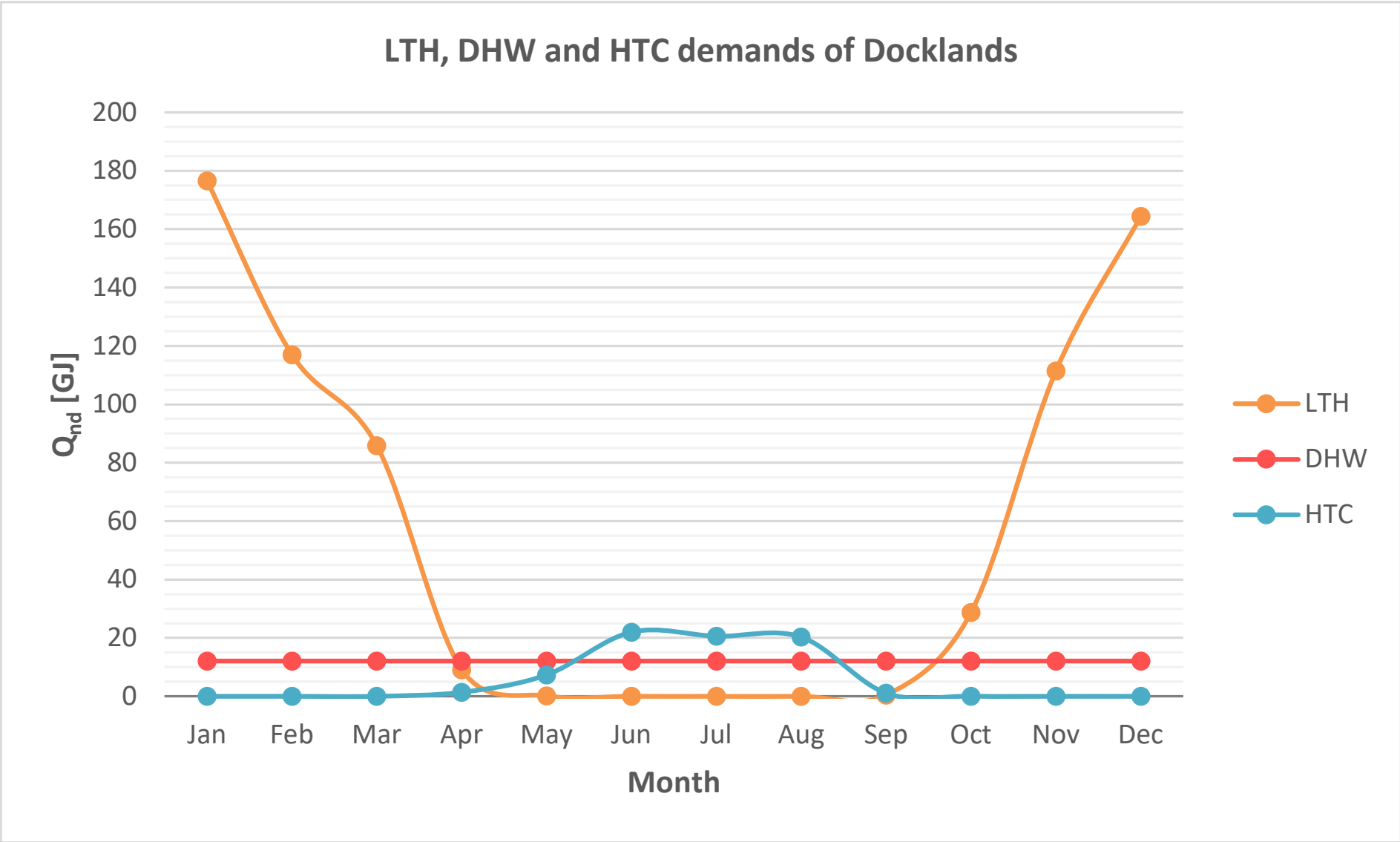
Energy requirements



- Distinction between energy demand and energy use
- LTH = low-temperature heat
- DHW = domestic hot water
- HTC = high-temperature cooling

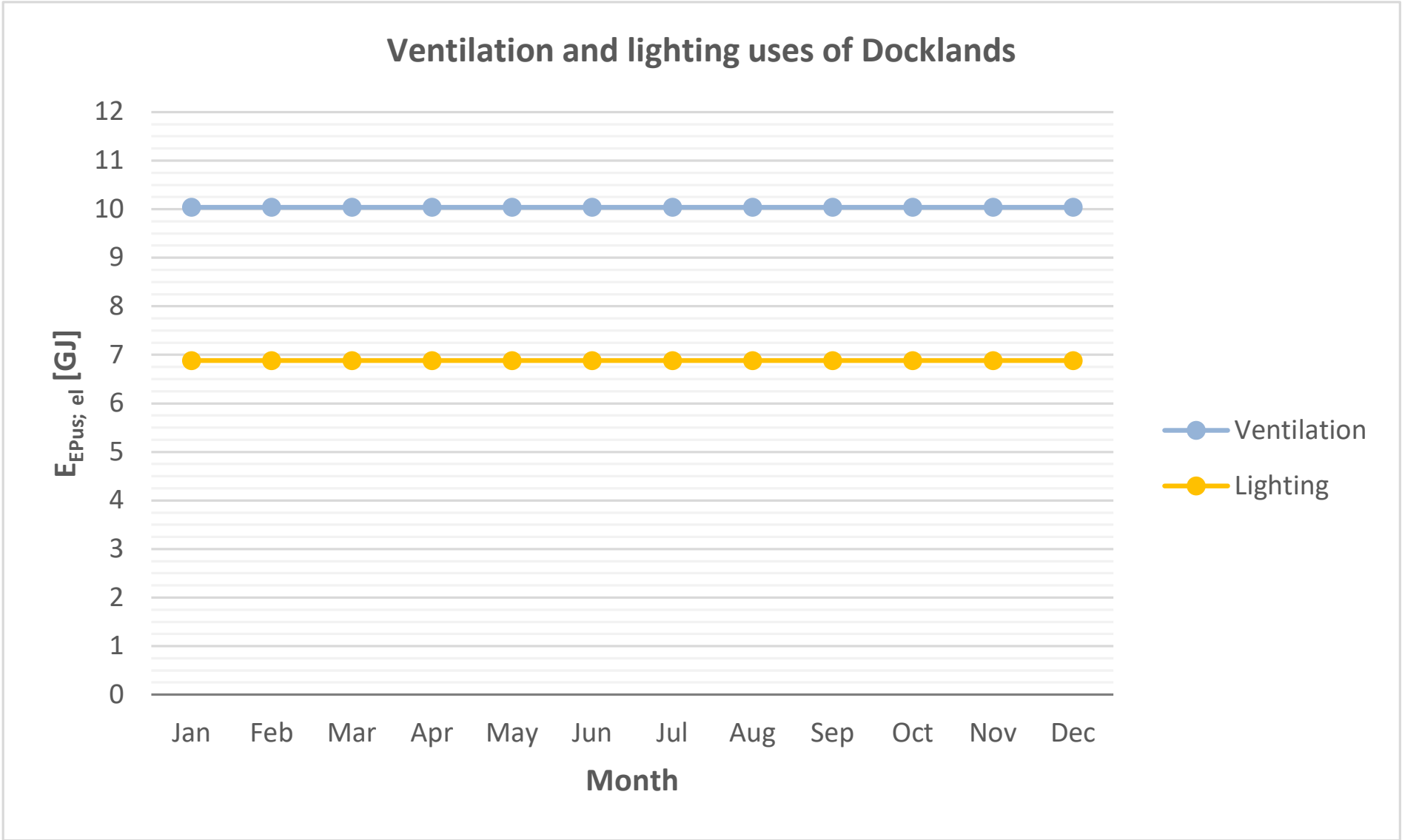
ENERGY REQUIREMENTS OF THE MULTI-FAMILY BUILDING

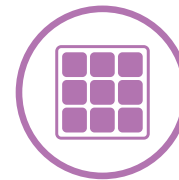
Energy demands



ENERGY REQUIREMENTS OF THE MULTI-FAMILY BUILDING

Energy uses





ENERGY OUTPUTS OF THE PVT COLLECTOR



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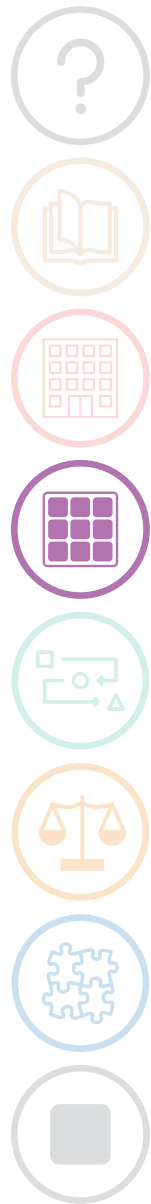
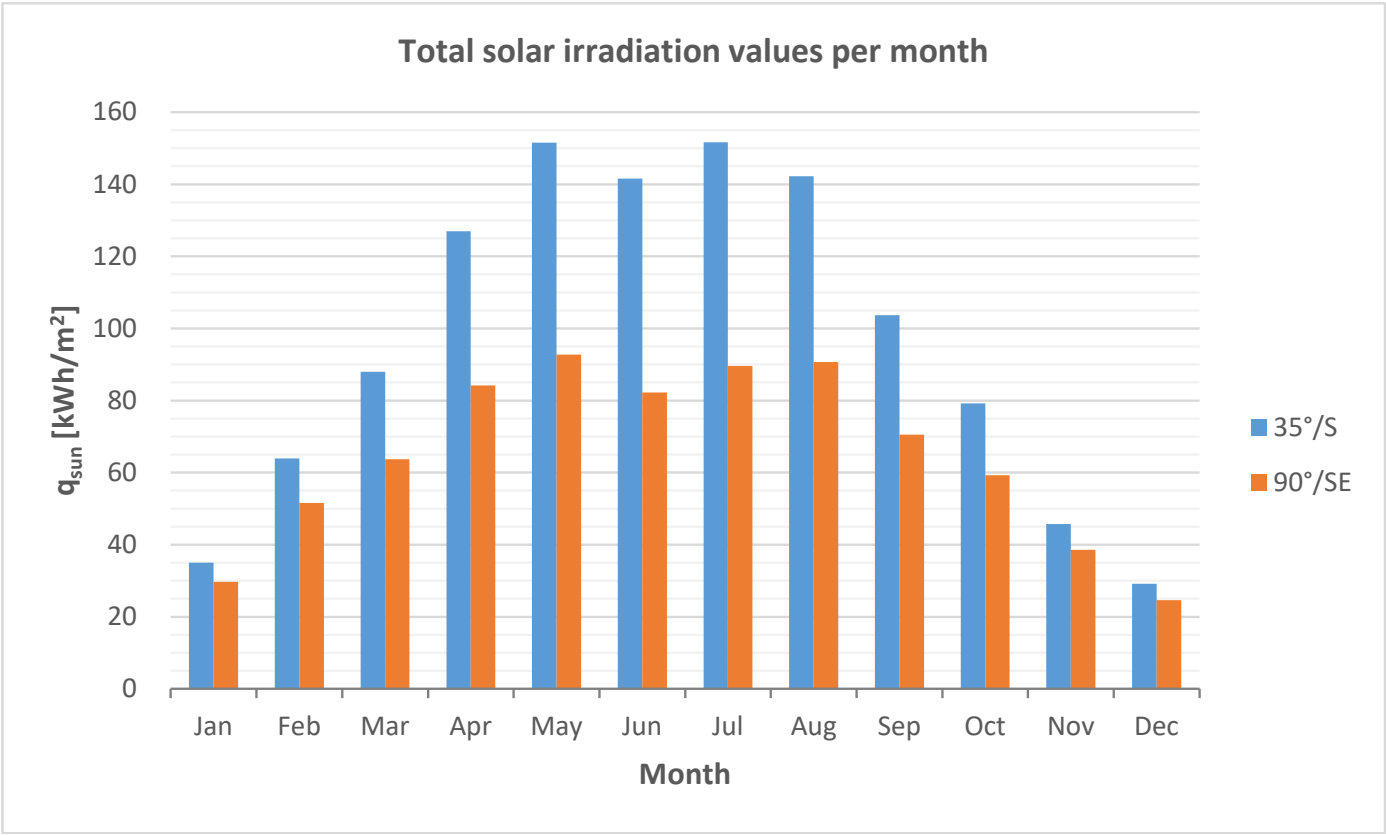
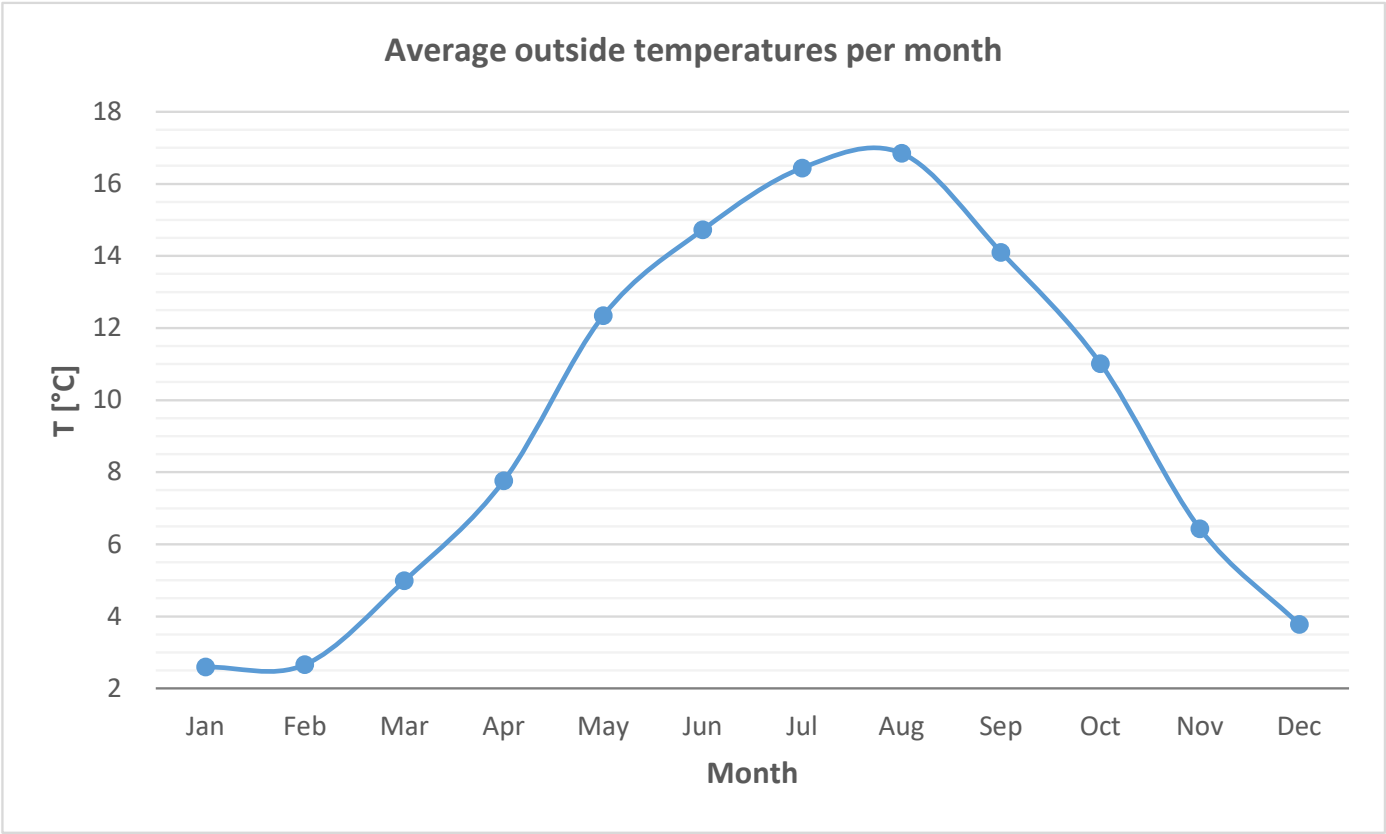
Collector outputs

- Thermal output
- Temperature output
- Electricity output



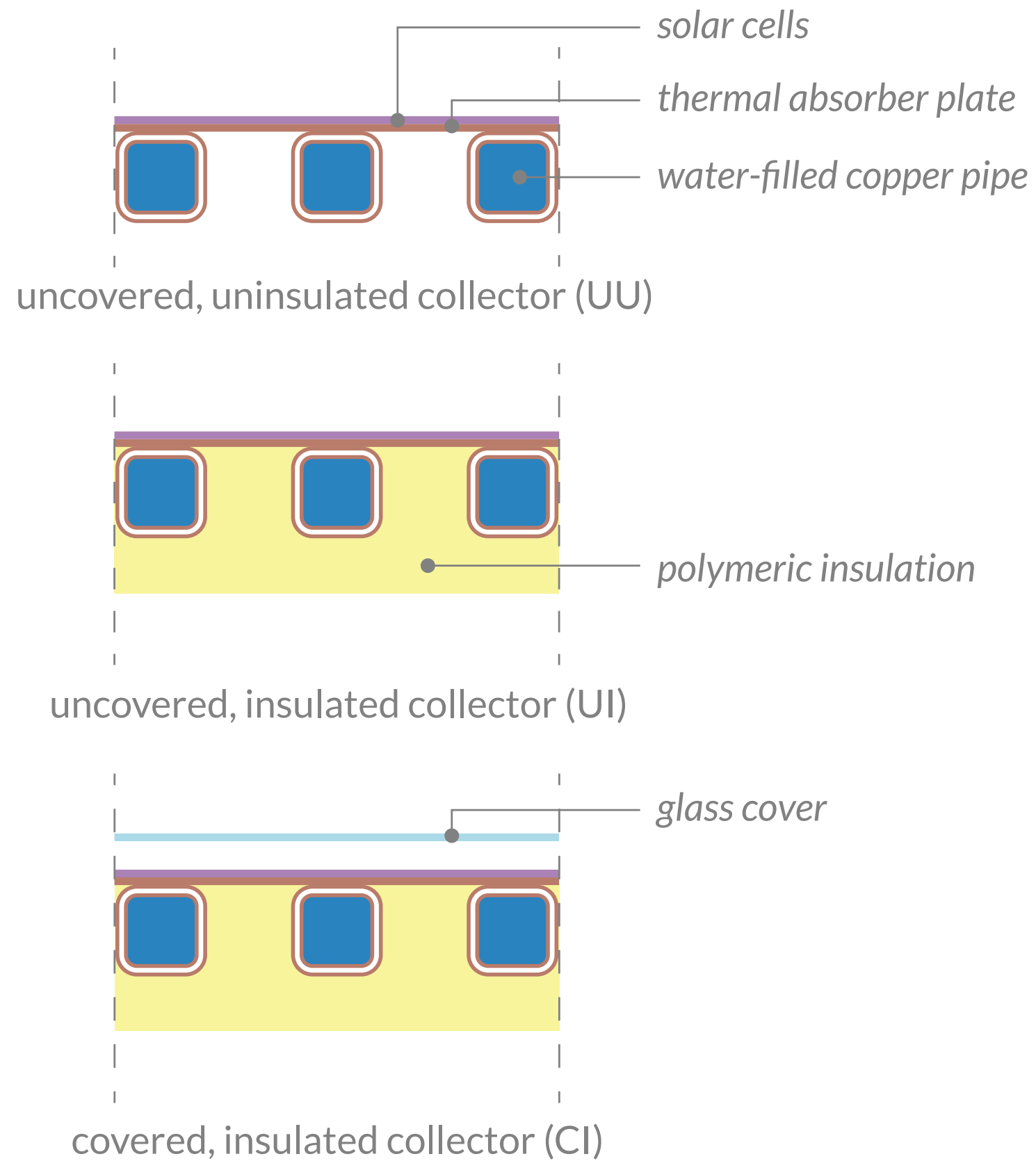
ENERGY OUTPUTS OF THE PVT COLLECTOR

Weather data



ENERGY OUTPUTS OF THE PVT COLLECTOR

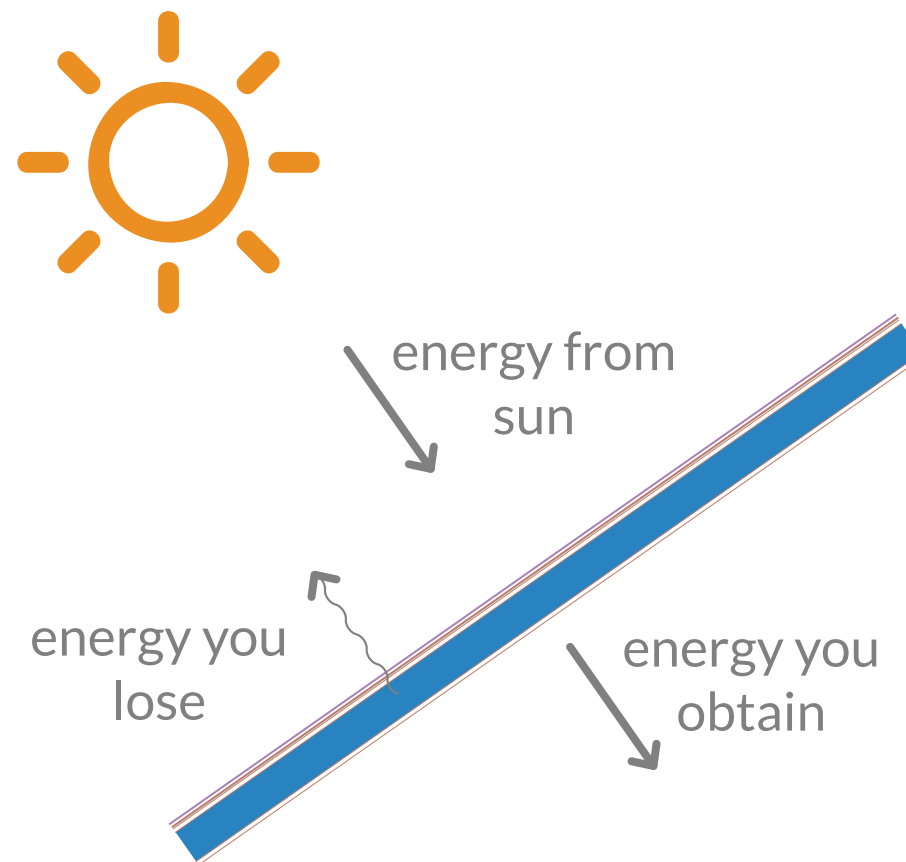
Chosen collector types



ENERGY OUTPUTS OF THE PVT COLLECTOR

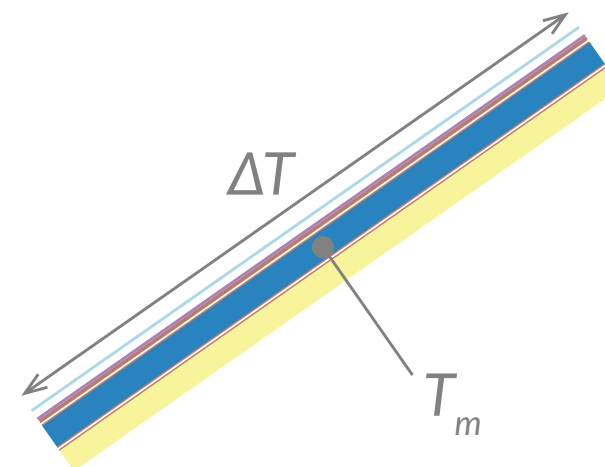
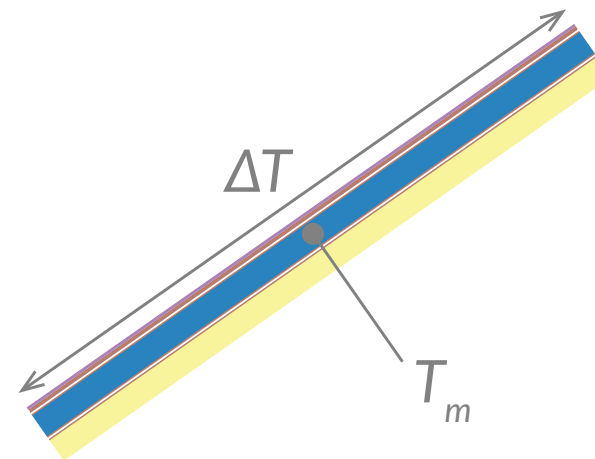
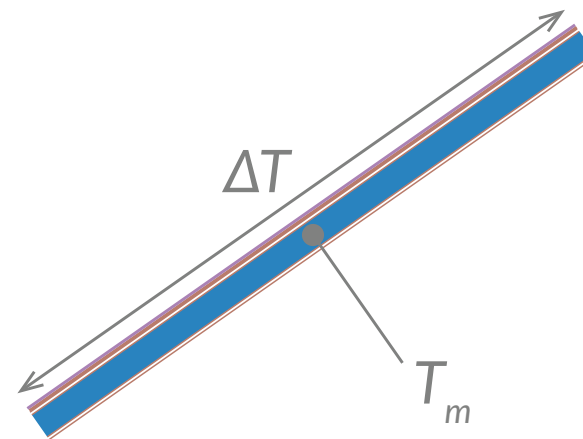
Thermal output

$$Q_{coll} = Q_{sun} - Q_{trans} [W]$$



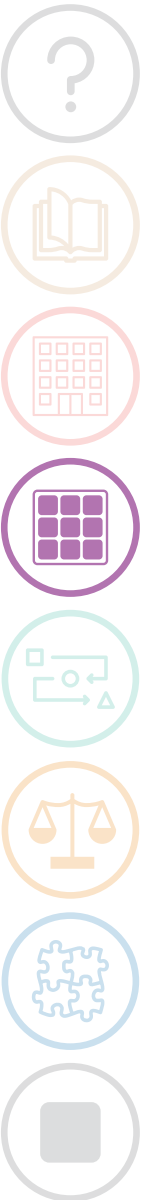
ENERGY OUTPUTS OF THE PVT COLLECTOR

Temperature output



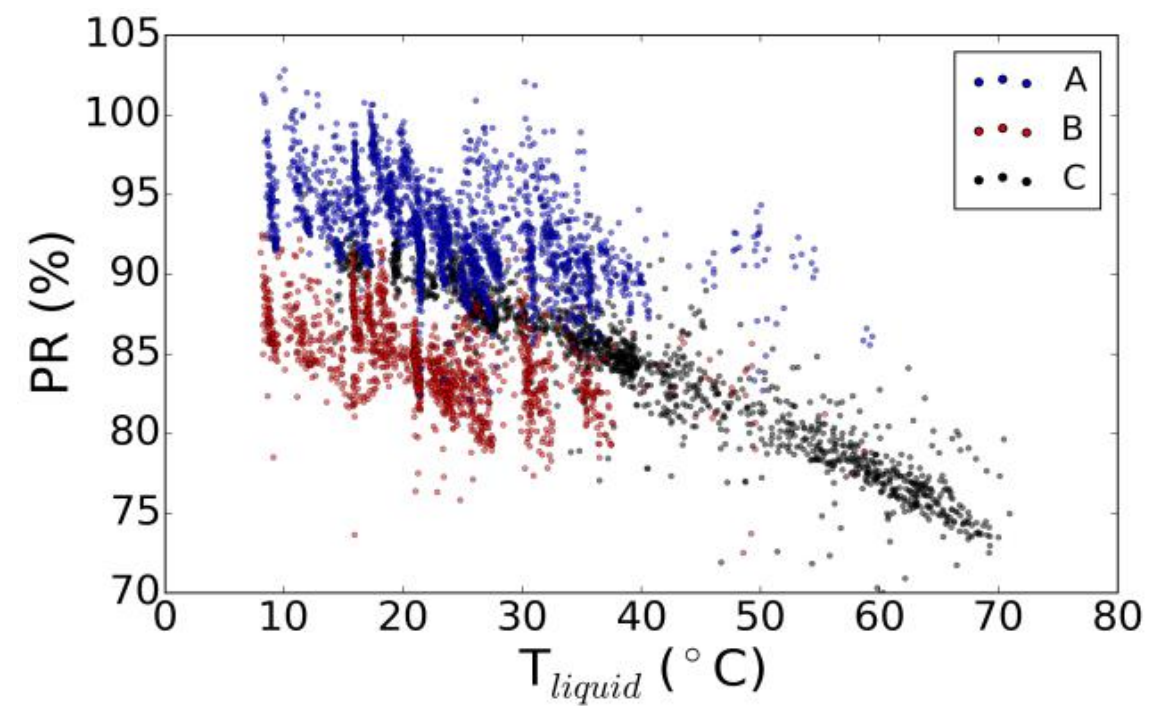
$$\Delta T = \frac{Q_{coll}}{\dot{m}c_w} [^{\circ}\text{C}]$$

- Collectors in series
- Different mass flow rates for summer and winter
- Different mean water temperatures for summer and winter
- Different temperature differences for summer and winter



ENERGY OUTPUTS OF THE PVT COLLECTOR

Electricity output



Performance ratios of various PVTs
(De Keizer et al., 2016)

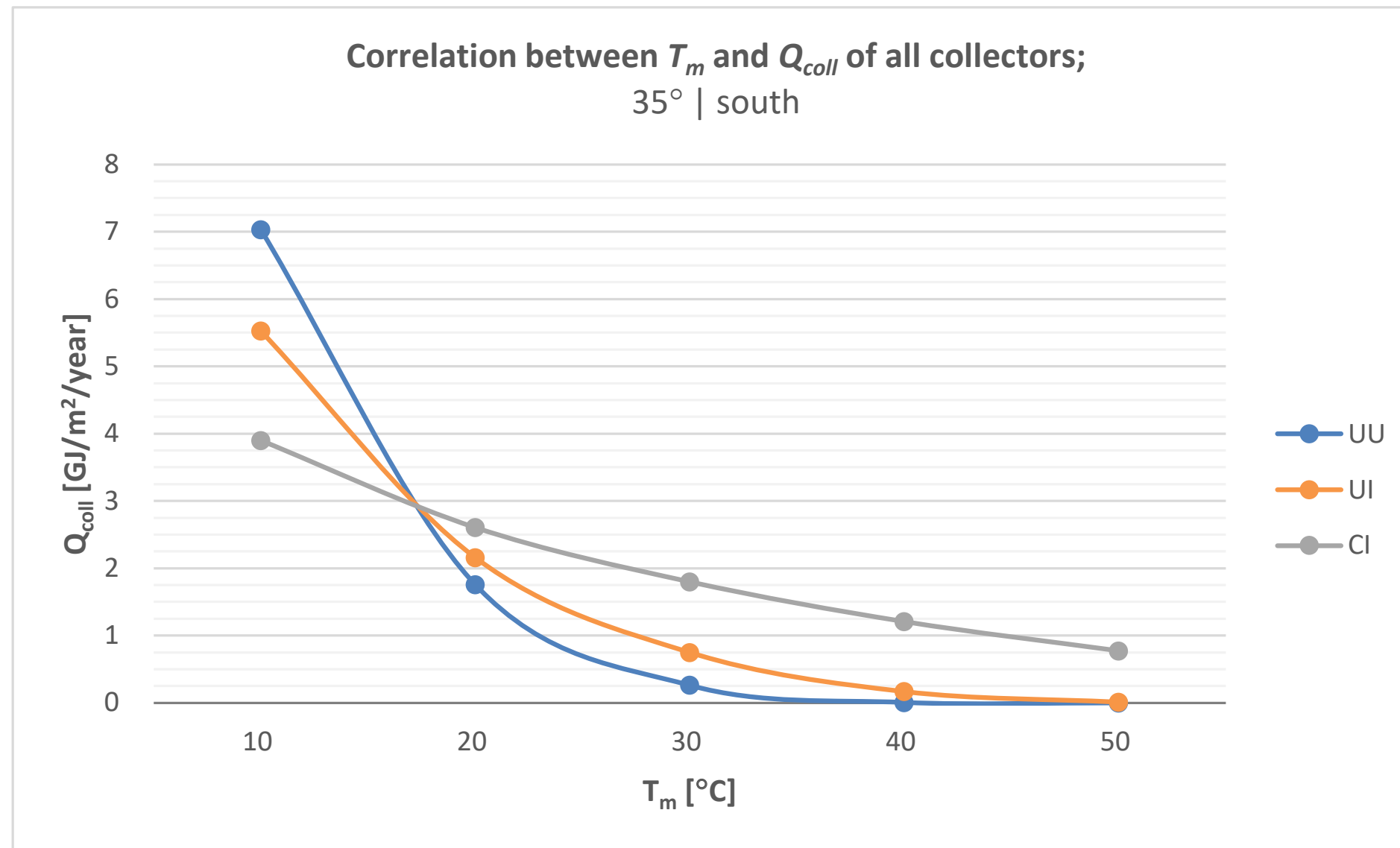
$$E = A r q_{sun} PR [kWh]$$

- Performance ratio decreases for higher temperatures

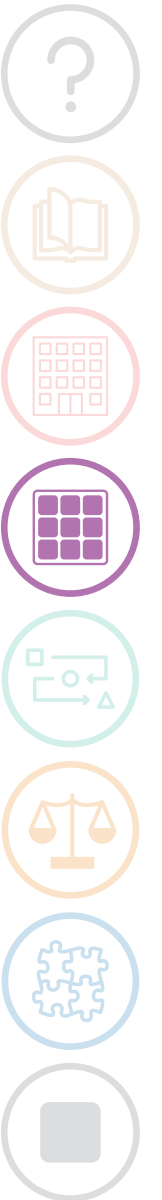


ENERGY OUTPUTS OF THE PVT COLLECTOR

Thermal output results

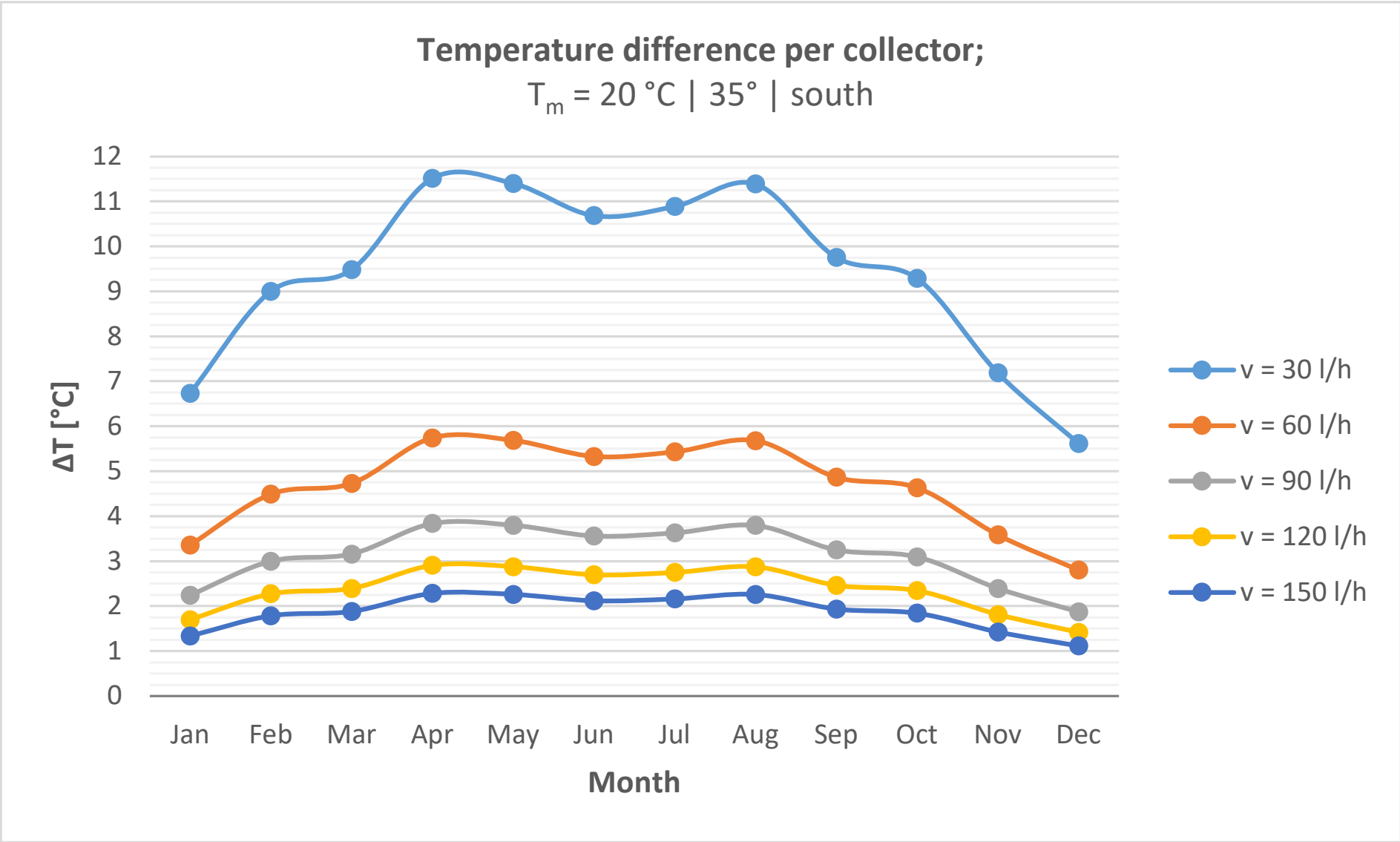


- Thermal output versus mean water temperature
- Insulation capacities affect temperature losses
- Covered, insulated (CI) collector has the most favourable outputs

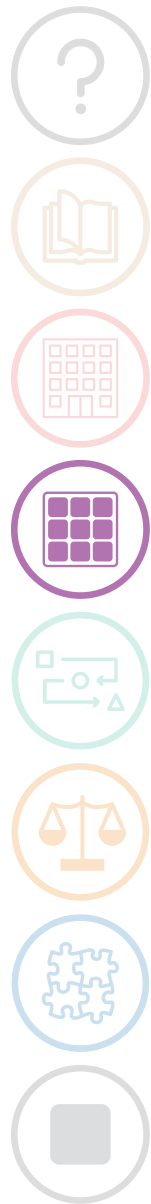


ENERGY OUTPUTS OF THE PVT COLLECTOR

Temperature output results

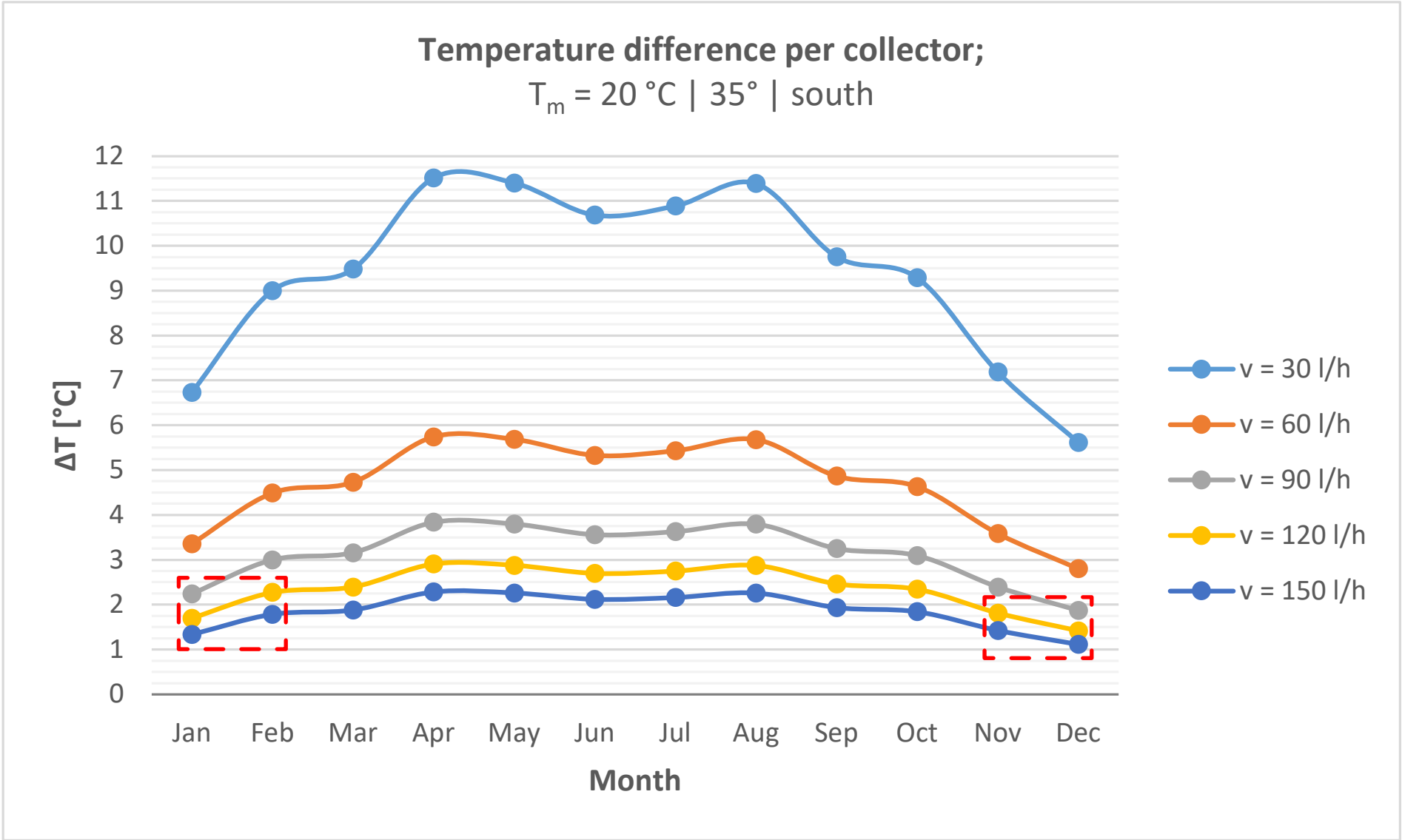


- ΔT = temperature difference
- Desired ΔT in winter: $5\text{-}8^{\circ}\text{C}$

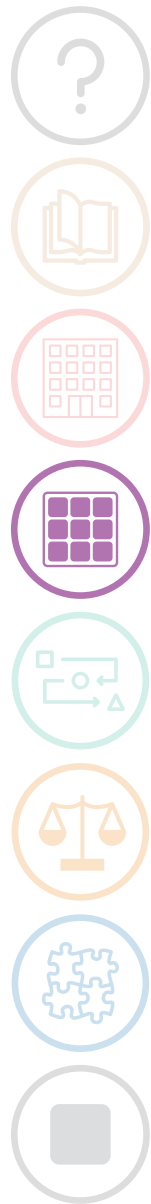


ENERGY OUTPUTS OF THE PVT COLLECTOR

Temperature output results

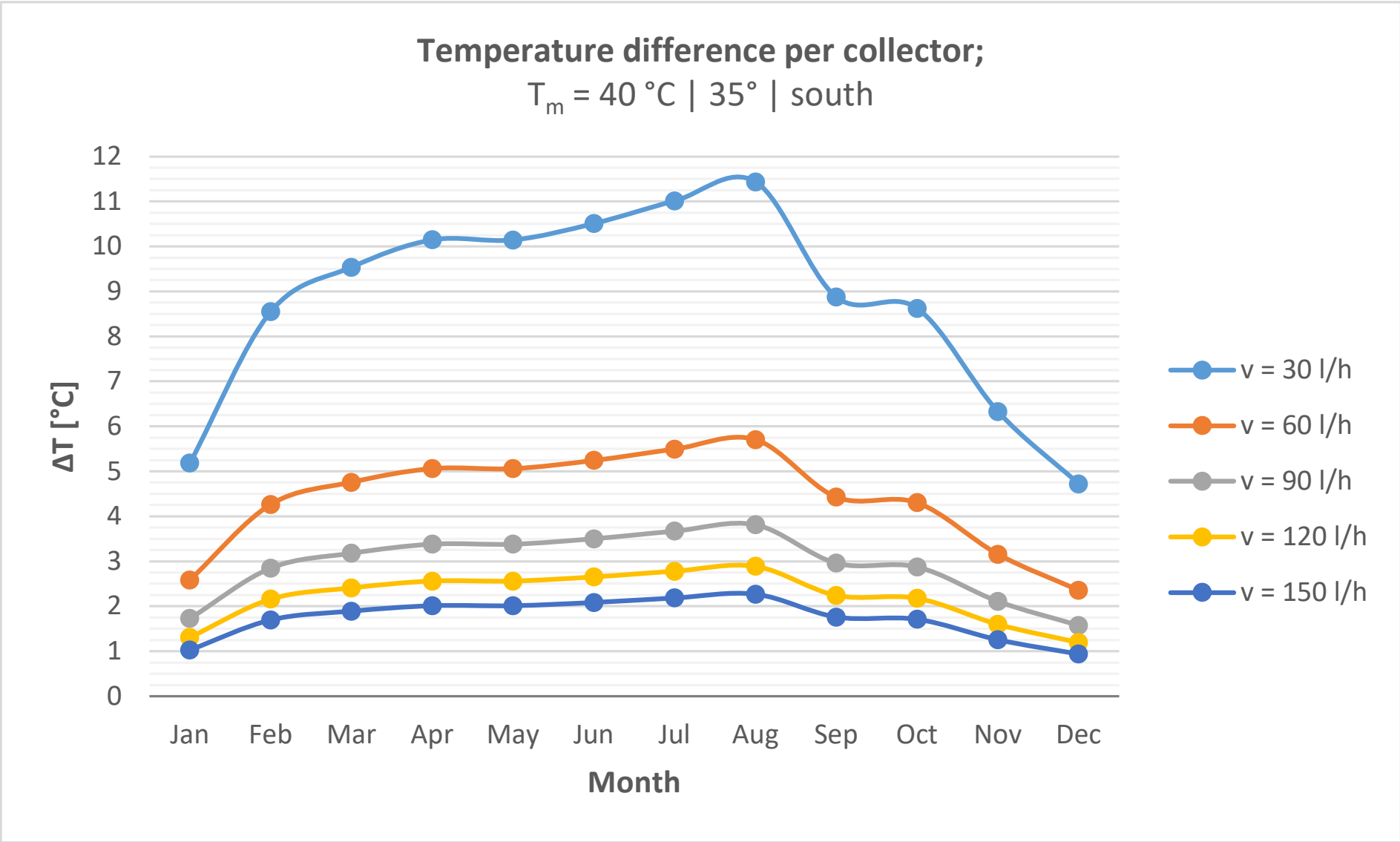


- Desired ΔT in winter: 5-8 $^{\circ}\text{C}$
- Amount of PVTs connected in series: 4-5



ENERGY OUTPUTS OF THE PVT COLLECTOR

Temperature output results

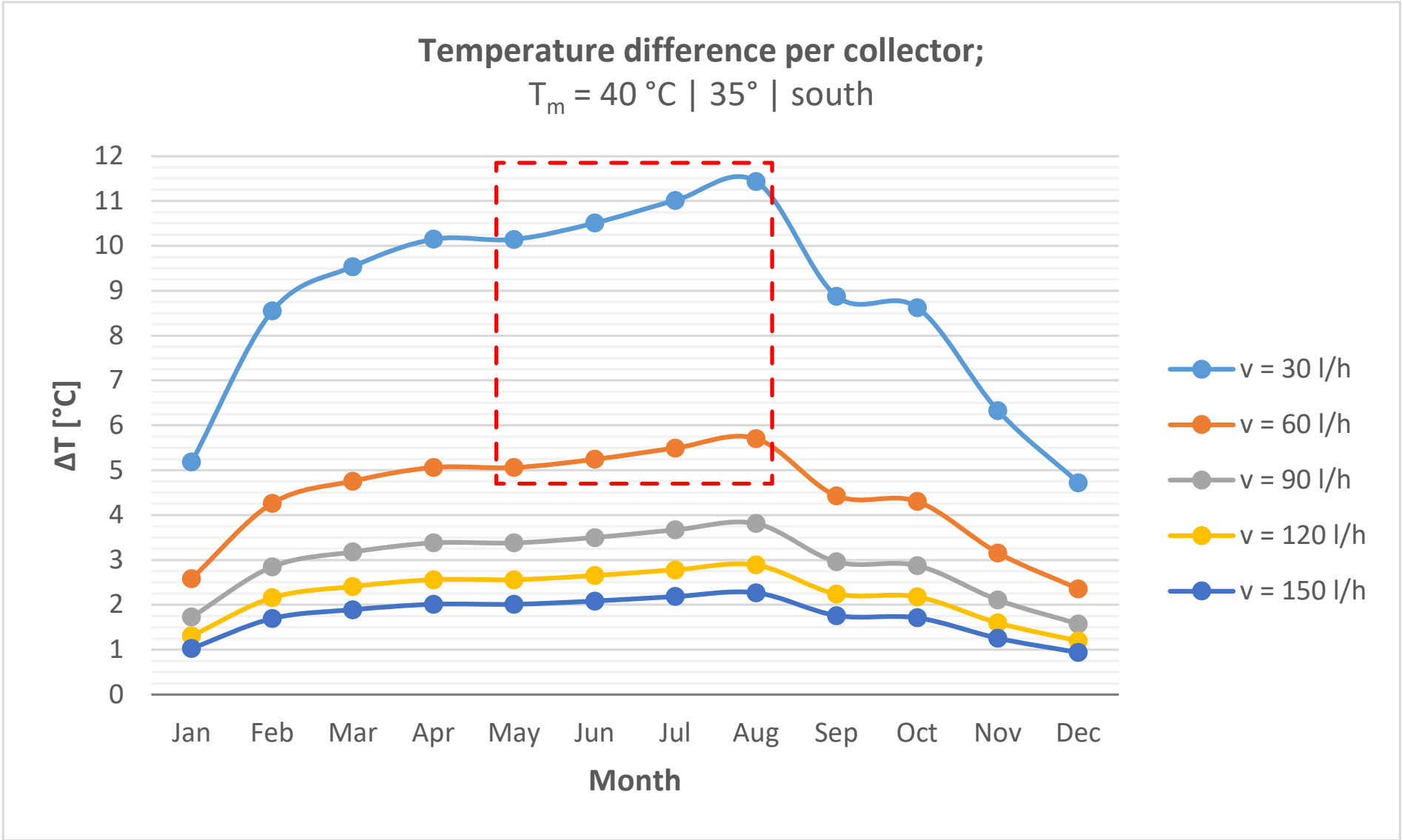


● Desired ΔT in summer: 25-30 $^{\circ}\text{C}$

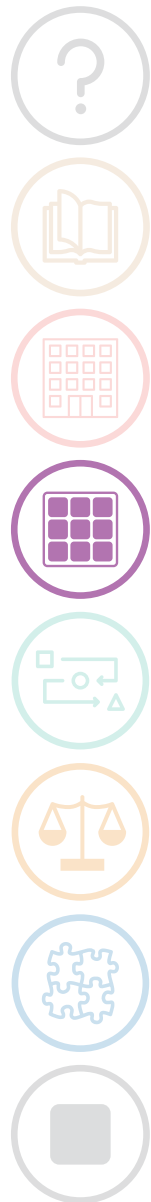


ENERGY OUTPUTS OF THE PVT COLLECTOR

Temperature output results



- Desired ΔT in summer: 25-30 $^{\circ}\text{C}$
- Amount of PVTs connected in series: 4



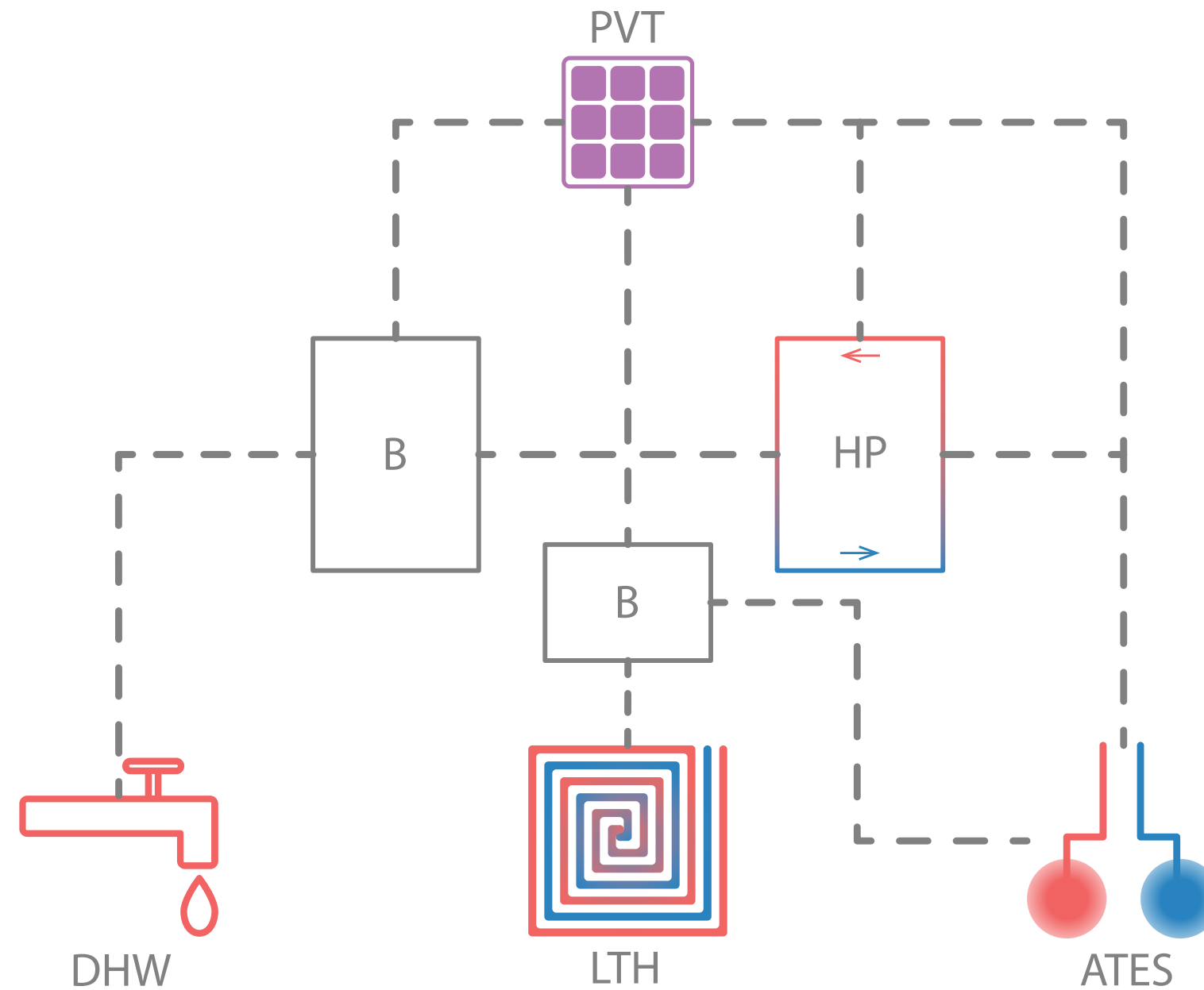


DEVELOPMENT OF THE SYSTEM CONFIGURATION



DEVELOPMENT OF THE SYSTEM CONFIGURATION

Selected technologies

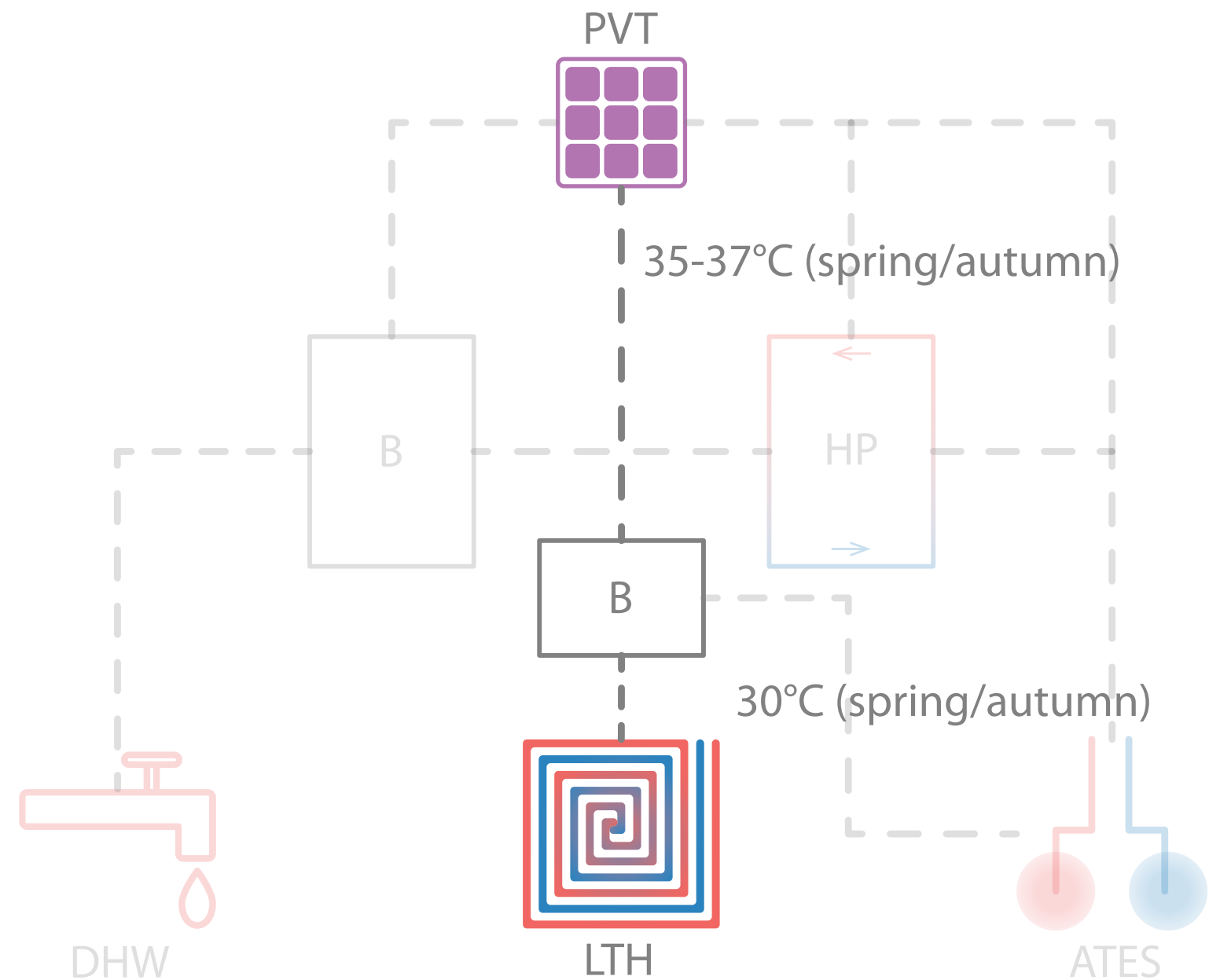


HP = heat pump
B = boiler/buffer tank
ATES = aquifer thermal energy storage
LTH = low-temperature heat
DHW = domestic hot water



DEVELOPMENT OF THE SYSTEM CONFIGURATION

Operation mode in spring/autumn

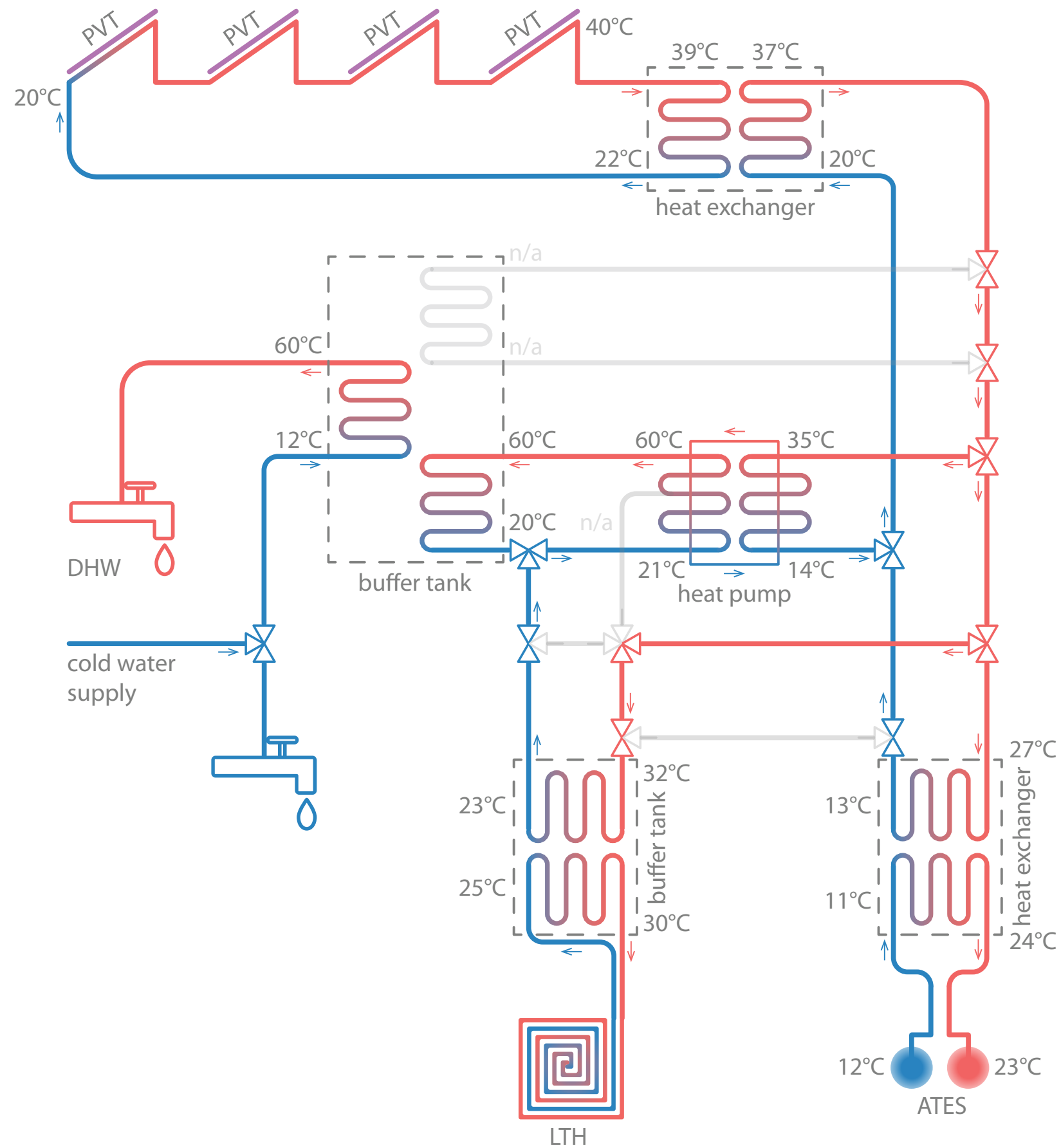


2. Direct-heating/storage mode LTH



DEVELOPMENT OF THE SYSTEM CONFIGURATION

Energy distribution in spring/autumn





CREATION OF AN ENERGY BALANCE



CREATION OF AN ENERGY BALANCE

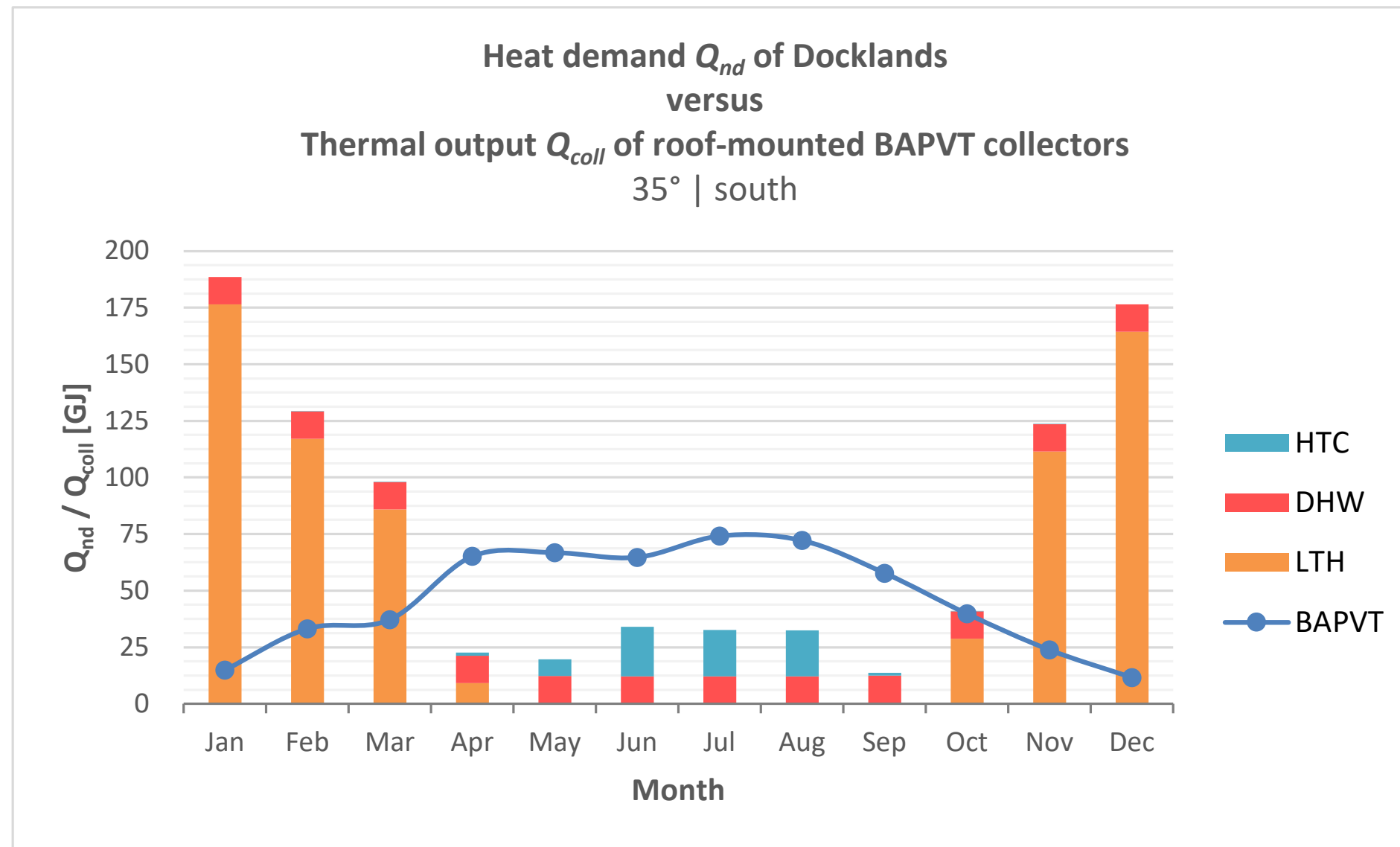
Explanation

- Self-sufficient and independent
- For example: you need 10 MJ and PVT gives you 10 MJ
- Extremely difficult
- Integration is a solution



CREATION OF AN ENERGY BALANCE

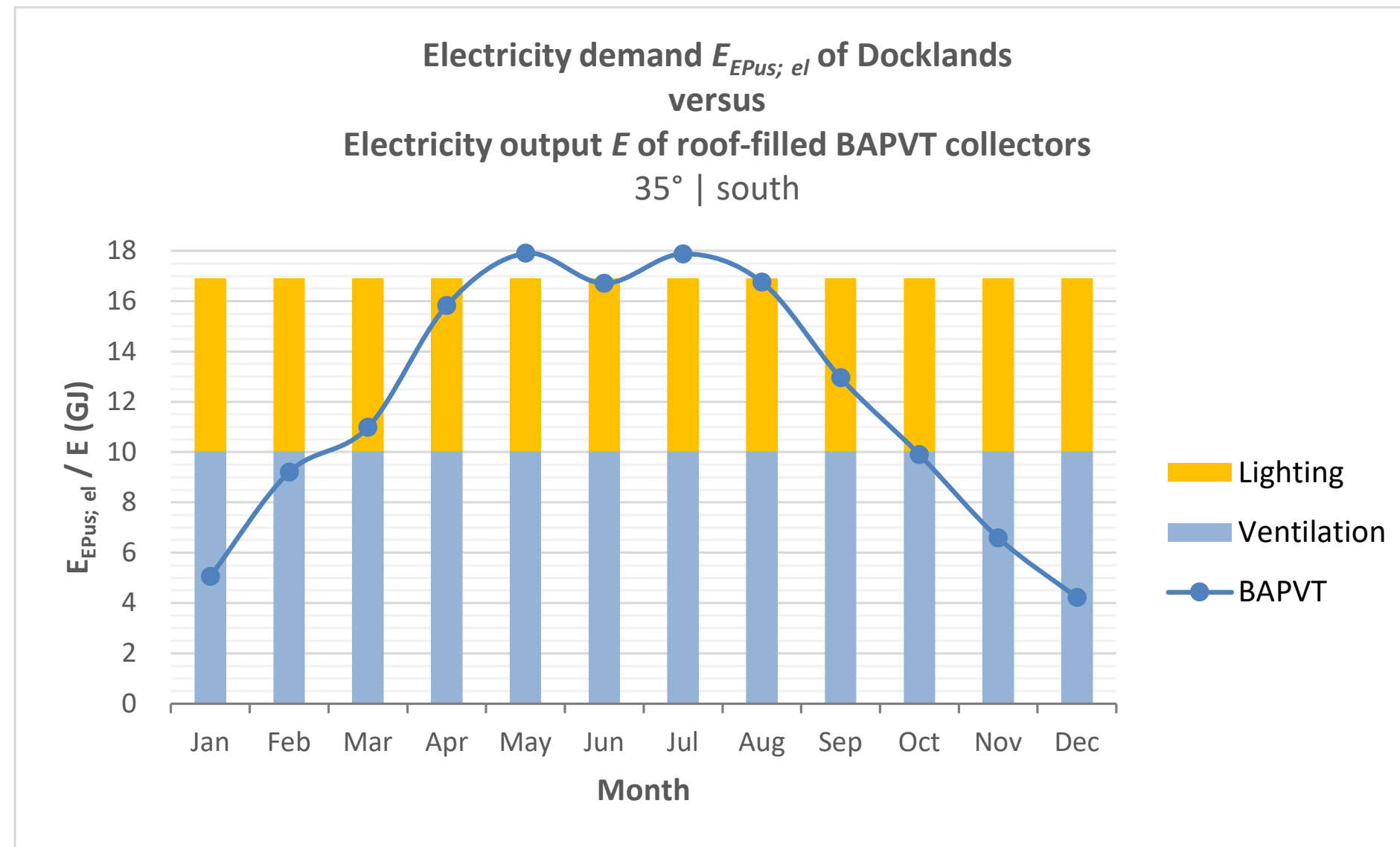
Thermal energy of roof collectors



- Thermal energy output versus energy demand
- BAPVT = building-added PVT (on the roof)

CREATION OF AN ENERGY BALANCE

Electrical energy of roof collectors



- Electrical energy output versus electrical energy demand
- BAPVT = building-added PVT (on the roof)



CREATION OF AN ENERGY BALANCE

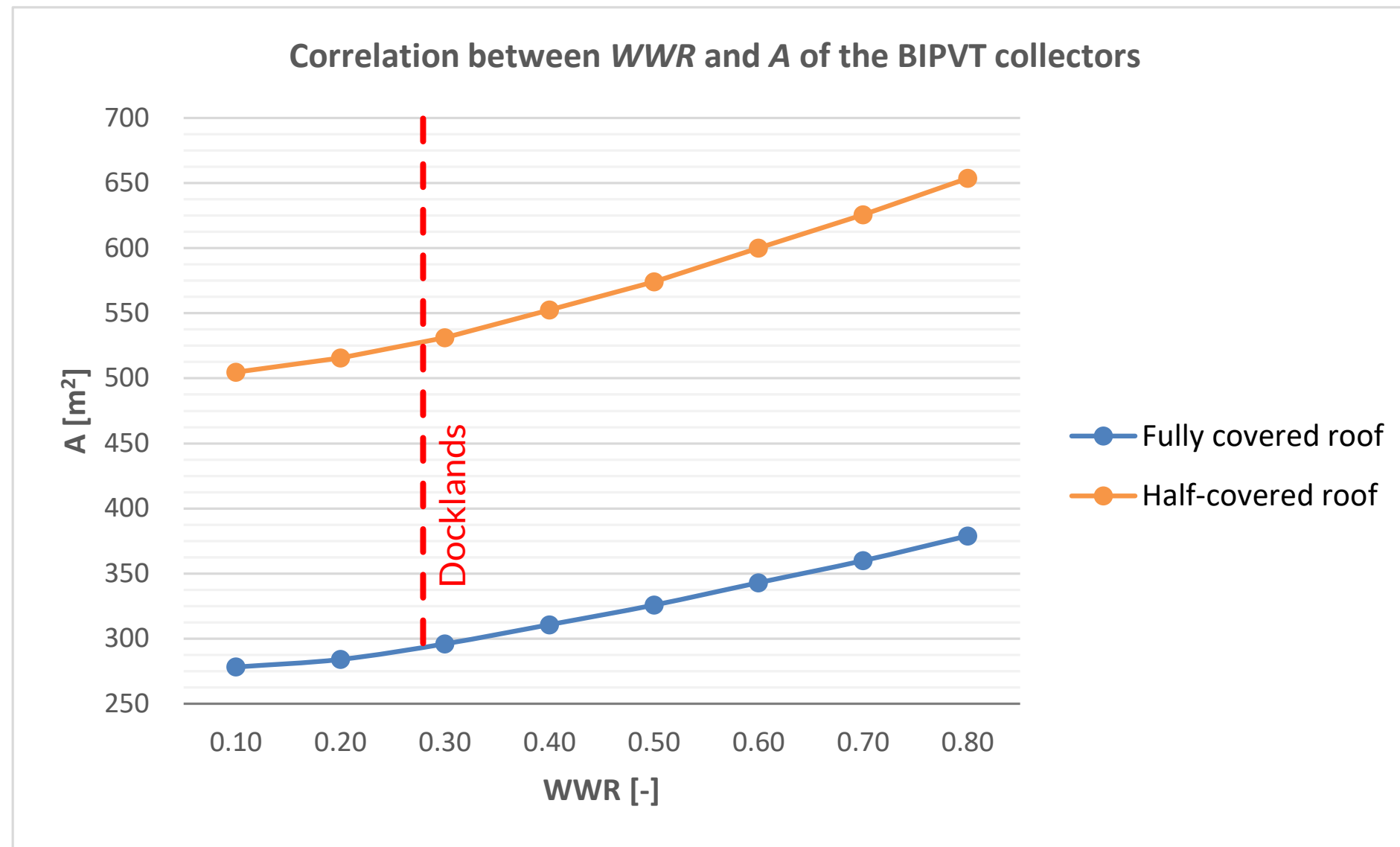
Energy balance

- Two situations: fully covered roof and a half-covered roof
- Fully covered roof: 293 m² of facade-collectors
- Half-covered roof: 527 m² of facade-collectors



CREATION OF AN ENERGY BALANCE

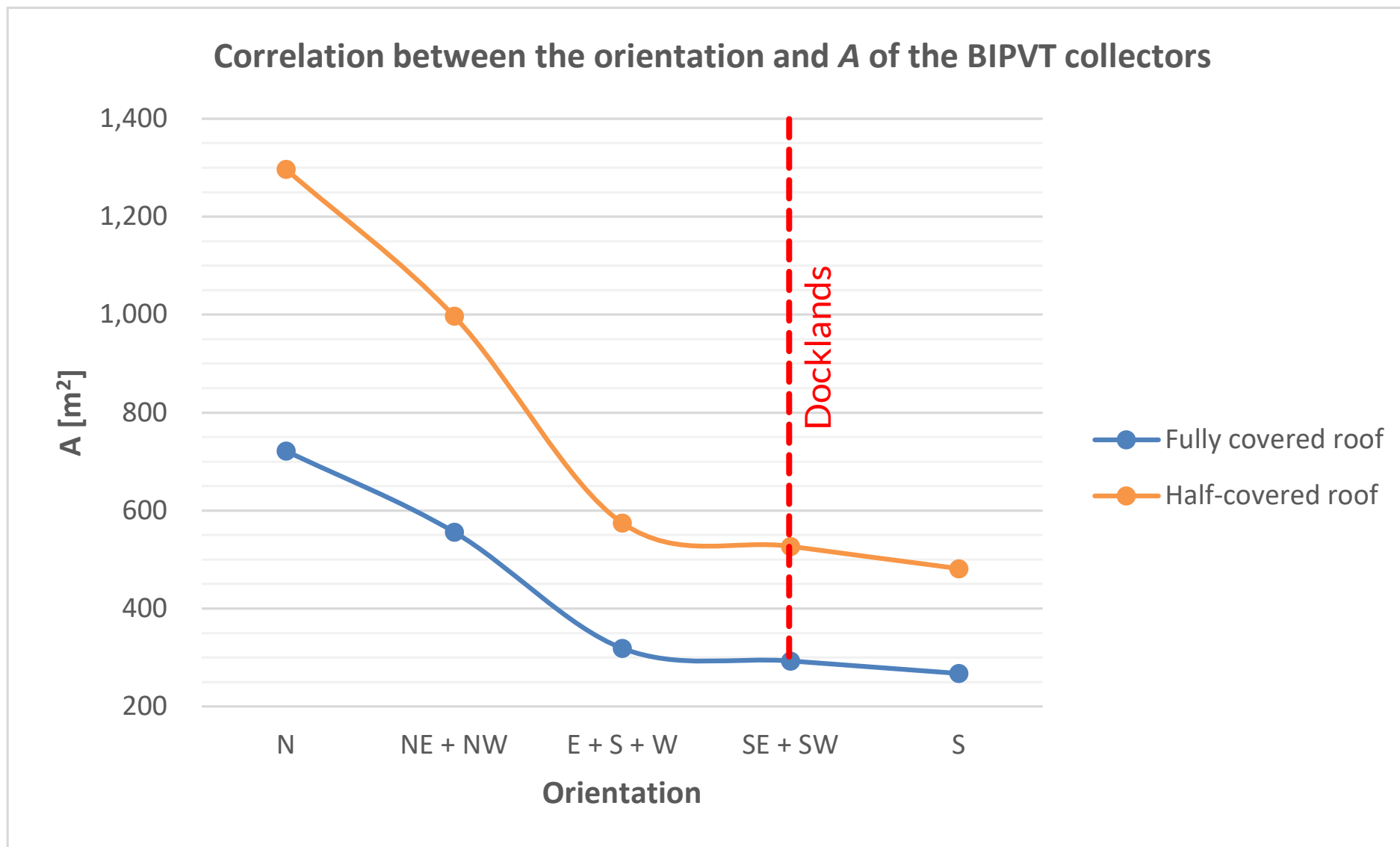
Influence of design parameters

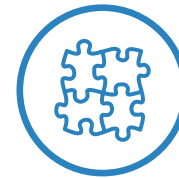


● Collector area versus window-to-wall ratio

CREATION OF AN ENERGY BALANCE

Influence of design parameters





DEVELOPMENT OF THE INTEGRATION OF THE PVT COLLECTOR



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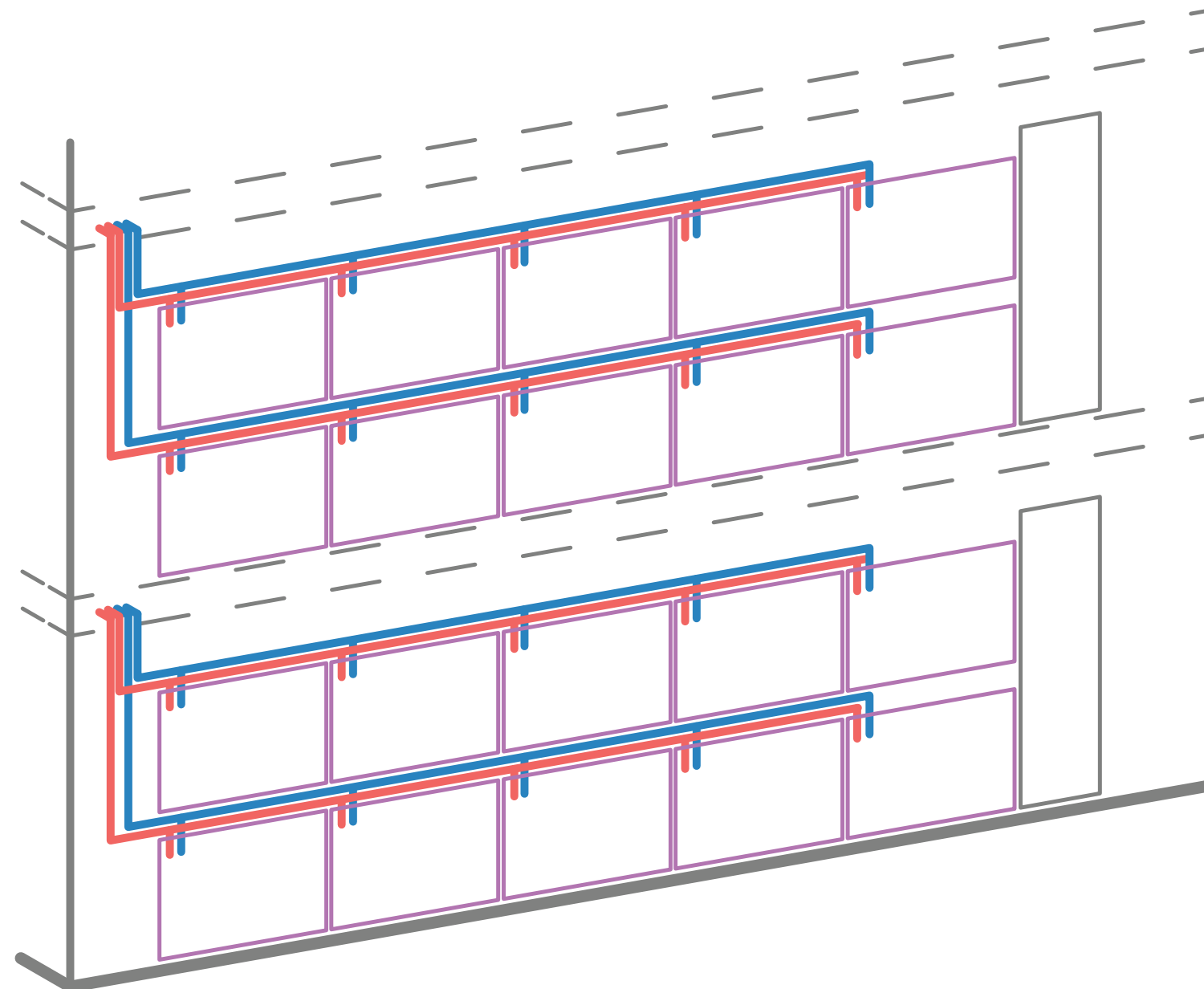
Focus areas of PVT integration

- Partial substitution of facade elements
- Piping system
- Maintenance
- Dimension flexibility



DEVELOPMENT OF THE INTEGRATION OF THE PVT COLLECTOR

Piping system

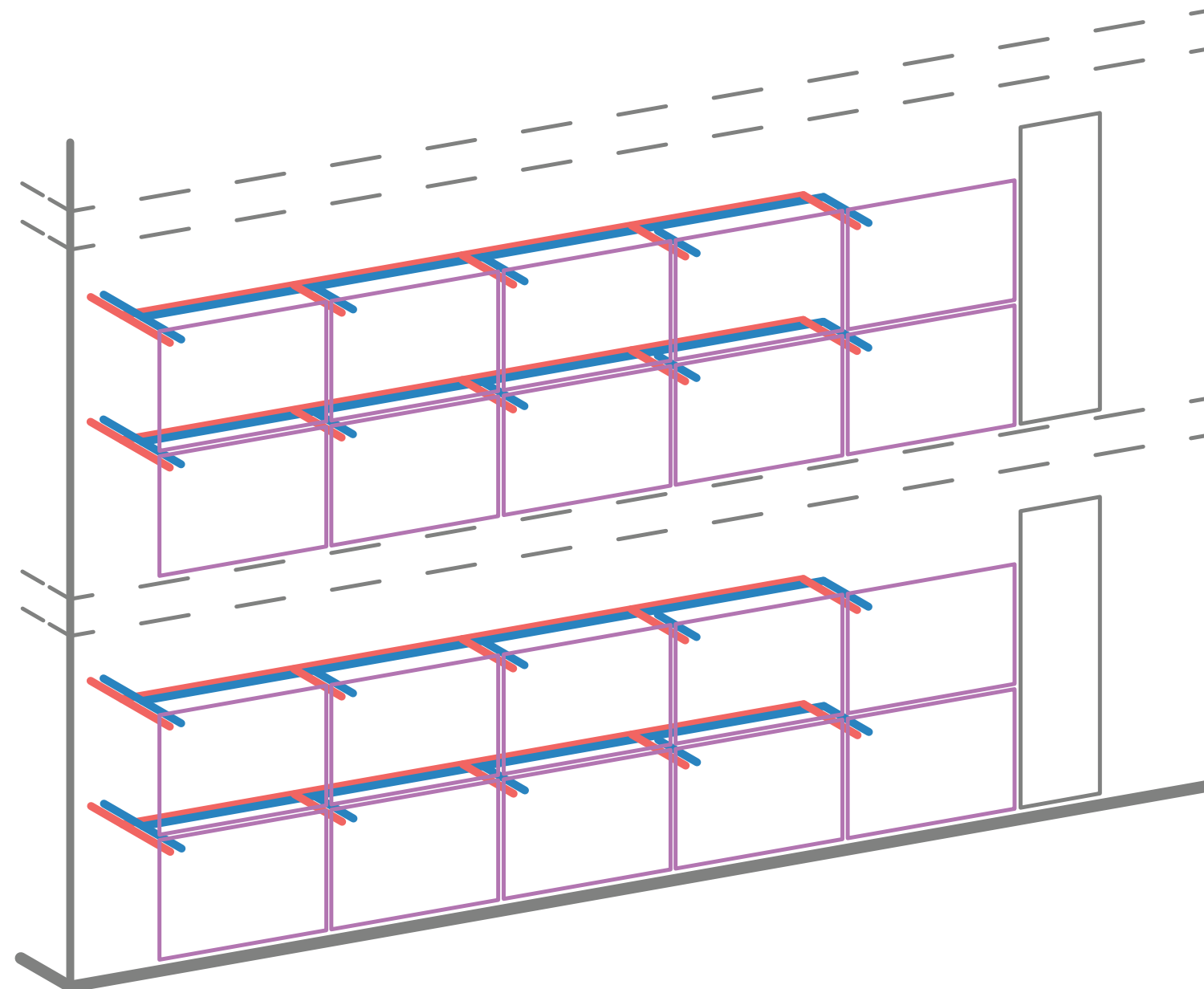


- Water pipes per floor to the inside



DEVELOPMENT OF THE INTEGRATION OF THE PVT COLLECTOR

Piping system



- Water pipes per collector to the inside



Piping system

PIPING SYSTEM IN OUTER PART OF FACADE:

-  less thermal bridges
-  less recesses
-  less design freedom
-  higher thermal losses

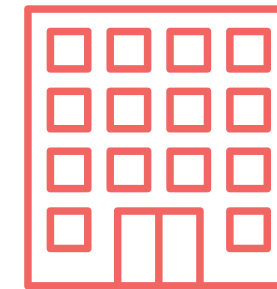
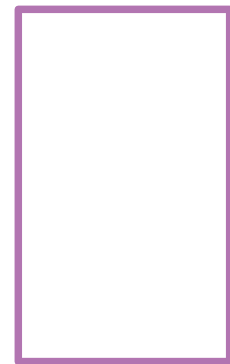
PIPING SYSTEM IN INNER PART OF FACADE:

-  more design freedom
-  less thermal losses
-  more thermal bridges
-  more recesses

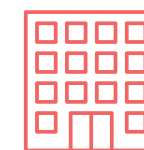
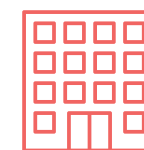
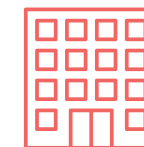
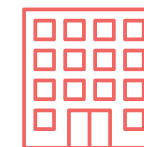
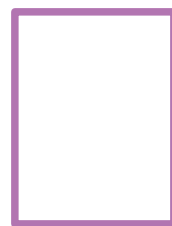


DEVELOPMENT OF THE INTEGRATION OF THE PVT COLLECTOR

Dimension flexibility



CURRENT SITUATION: INTEGRATION LIMITATION

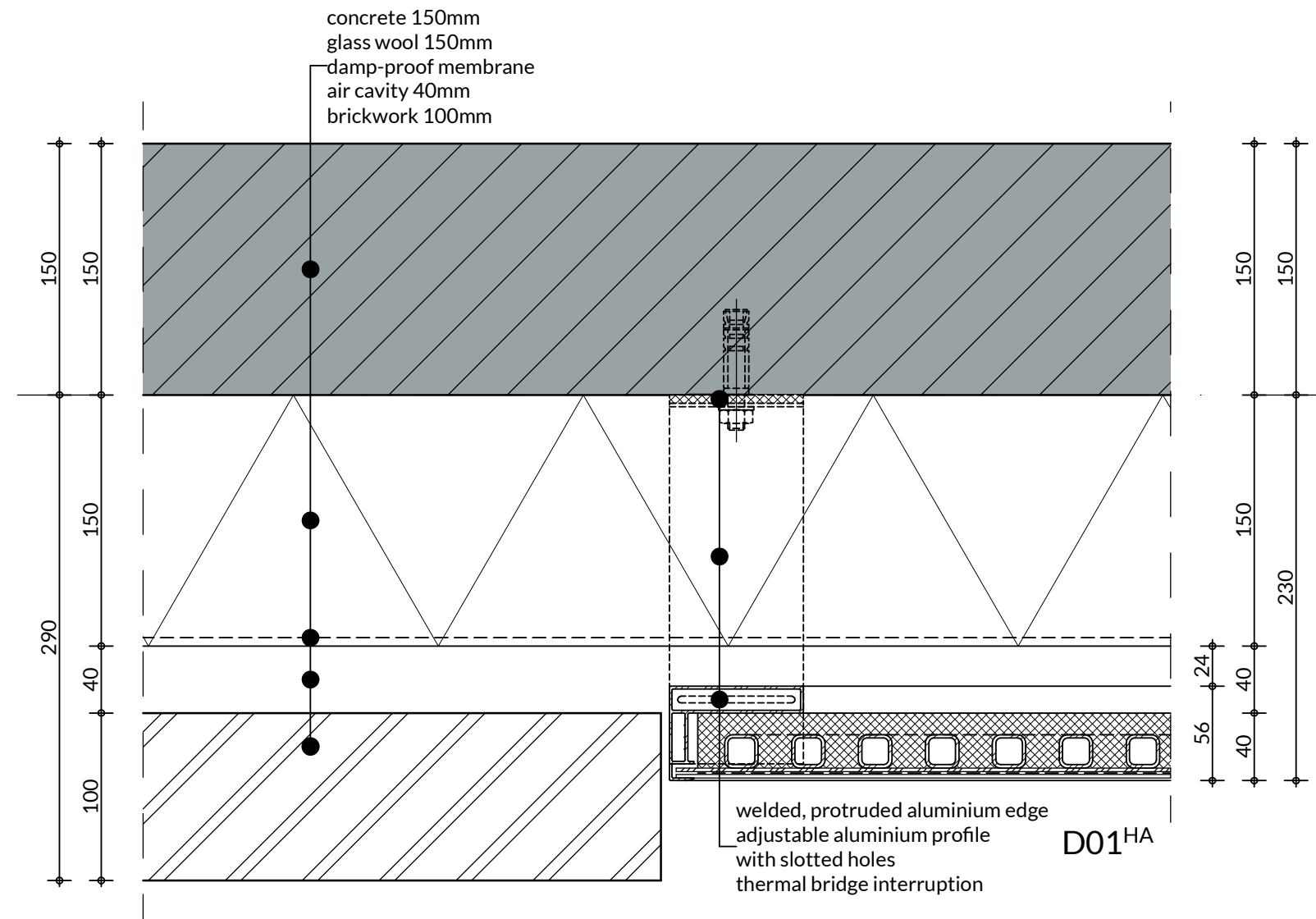


DESIRED SITUATION: INTEGRATION FLEXIBILITY



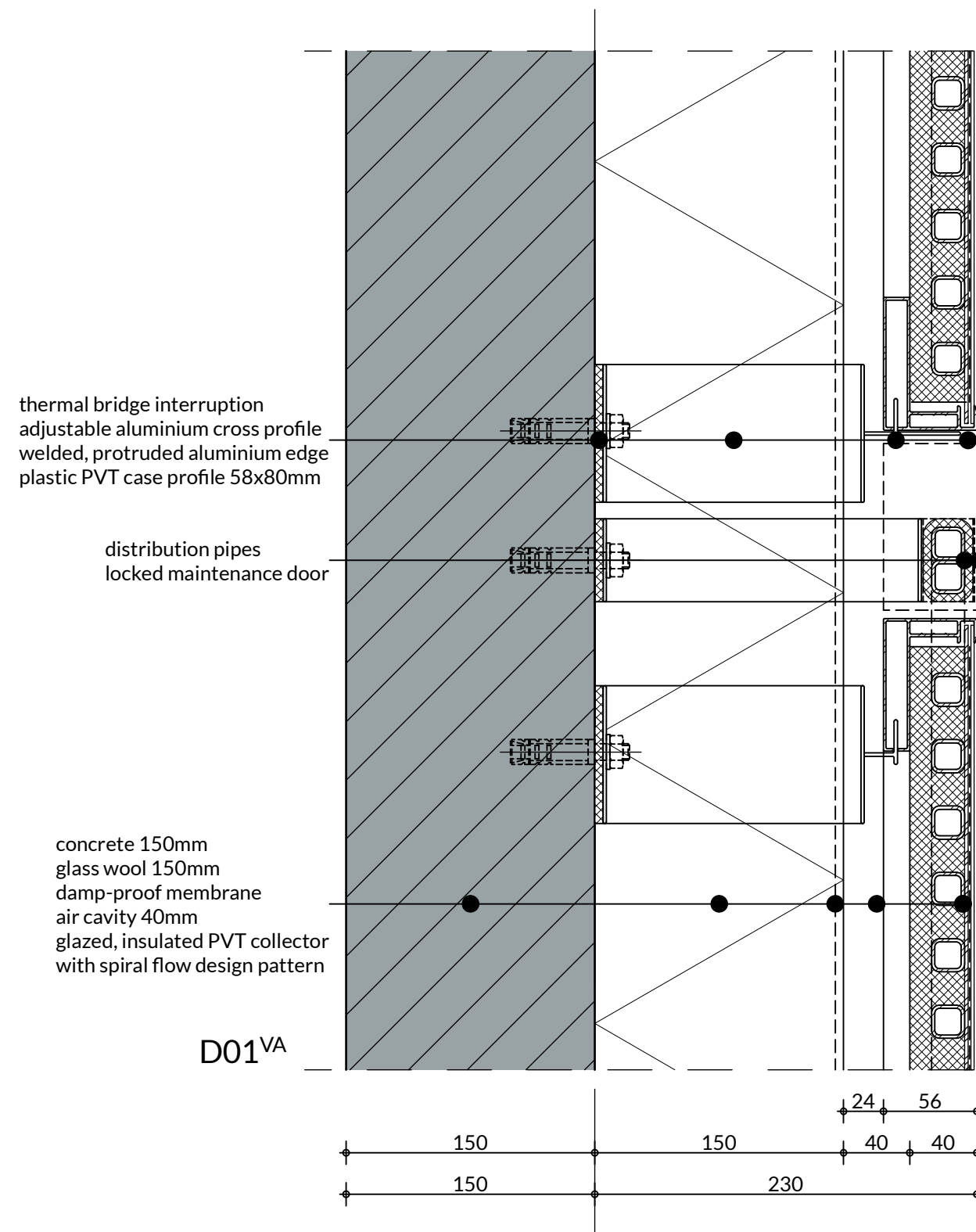
DEVELOPMENT OF THE INTEGRATION OF THE PVT COLLECTOR

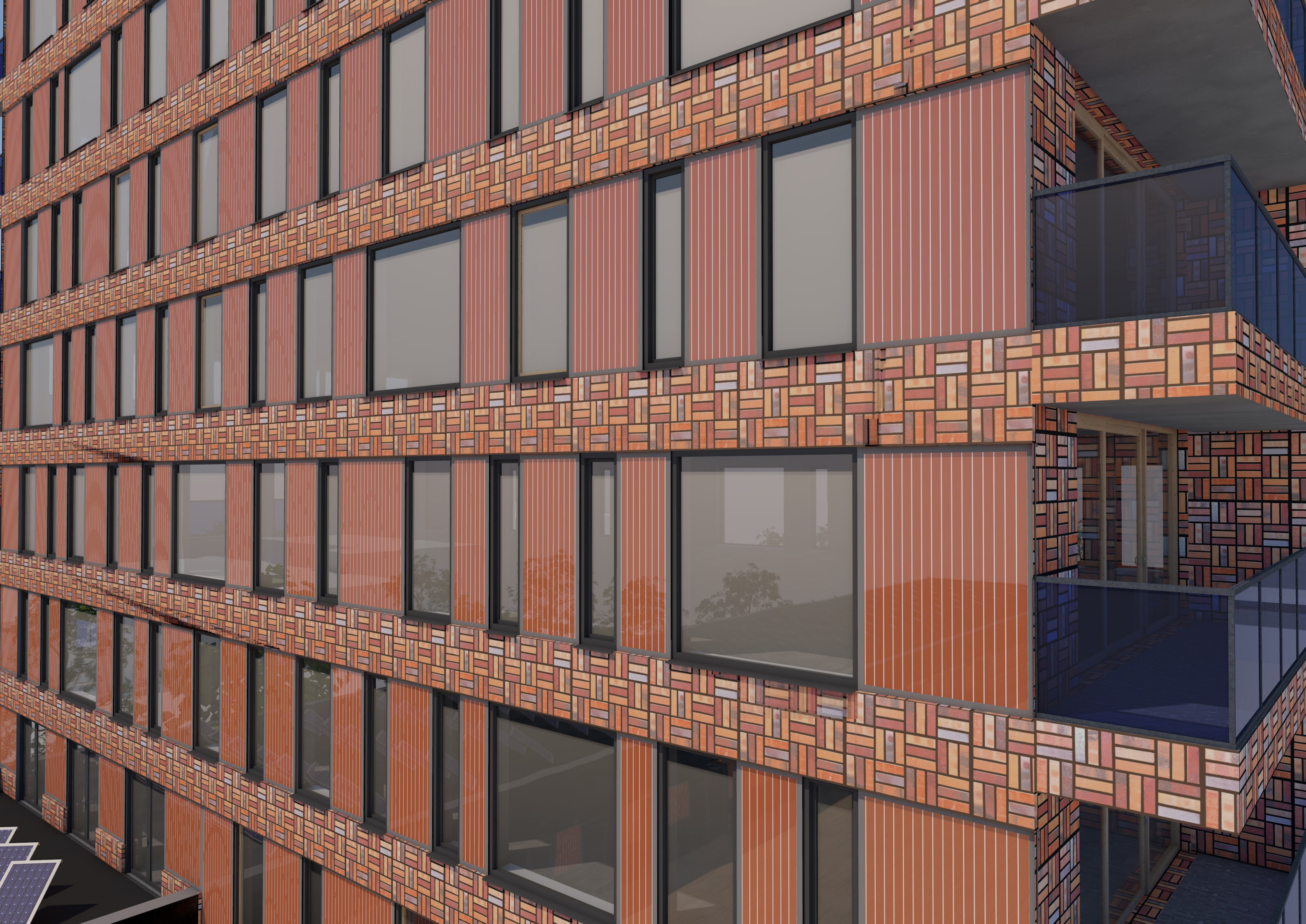
Integration in Docklands

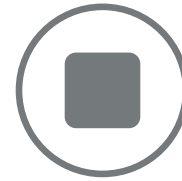


DEVELOPMENT OF THE INTEGRATION OF THE PVT COLLECTOR

Integration in Docklands





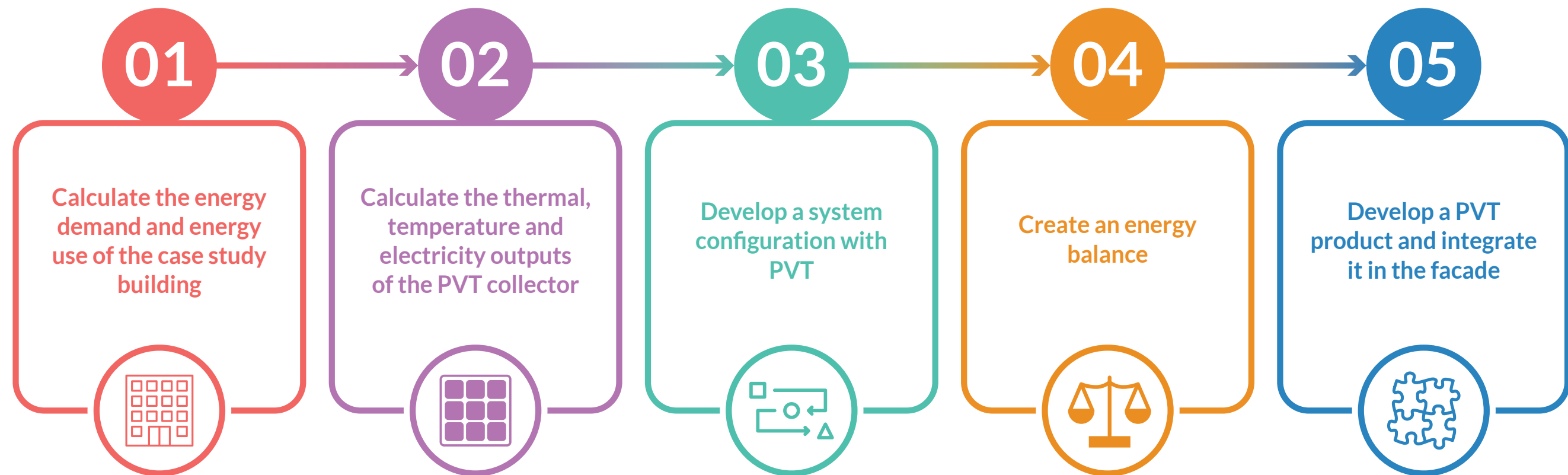


EVALUATION & CONCLUSION

EVALUATION & CONCLUSION

Design process

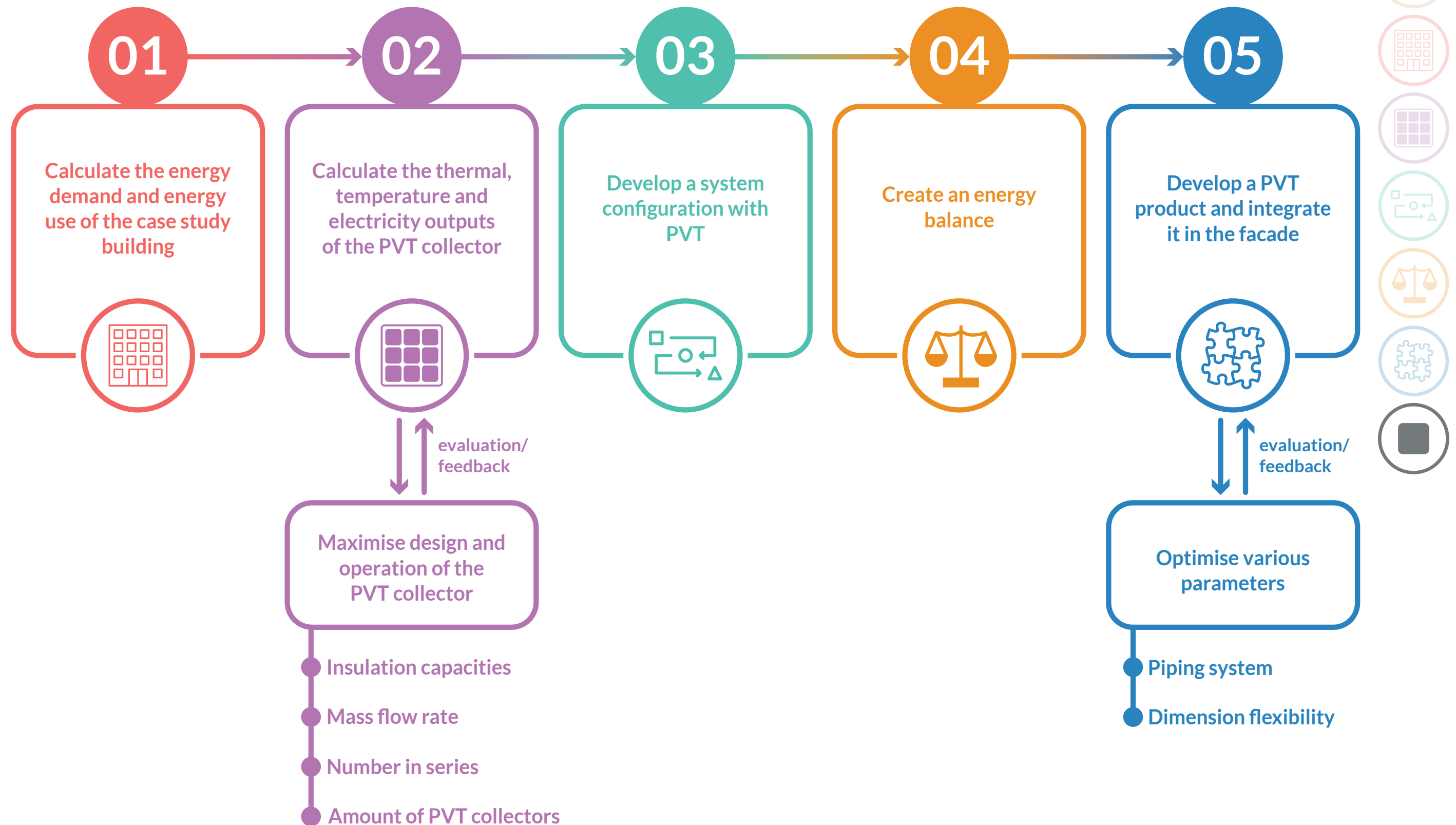
OWN PROCESS FOR DEVELOPING AND INTEGRATING A PVT CONCEPT



EVALUATION & CONCLUSION

Design process

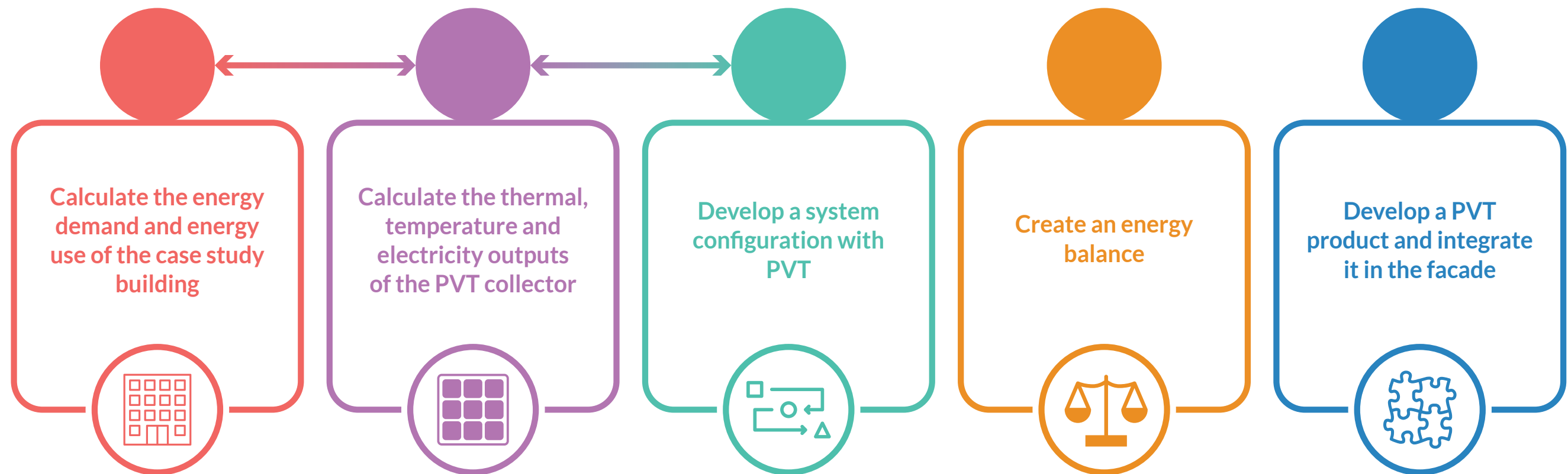
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EVALUATION & CONCLUSION

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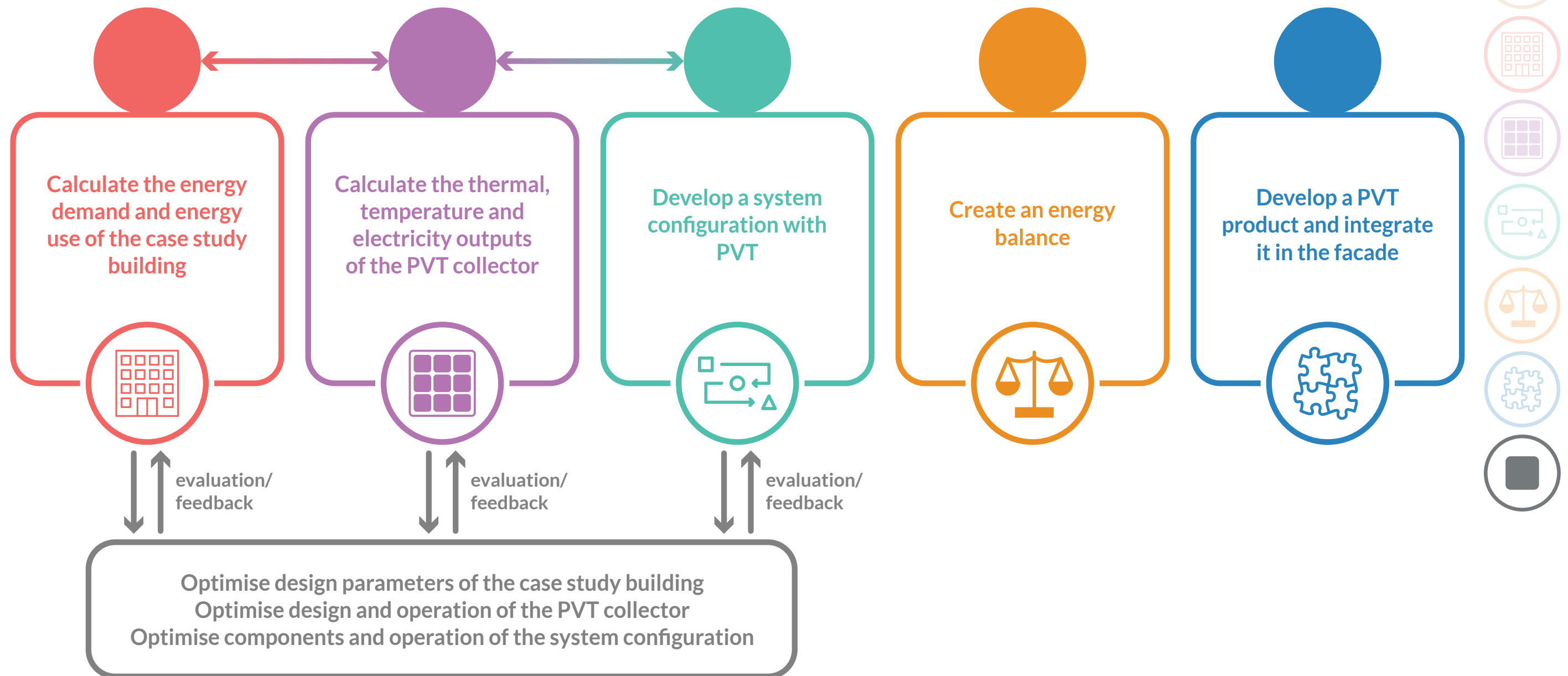
WIDER APPROACH FOR DEVELOPING AND INTEGRATING A PVT CONCEPT



EVALUATION & CONCLUSION

Design process

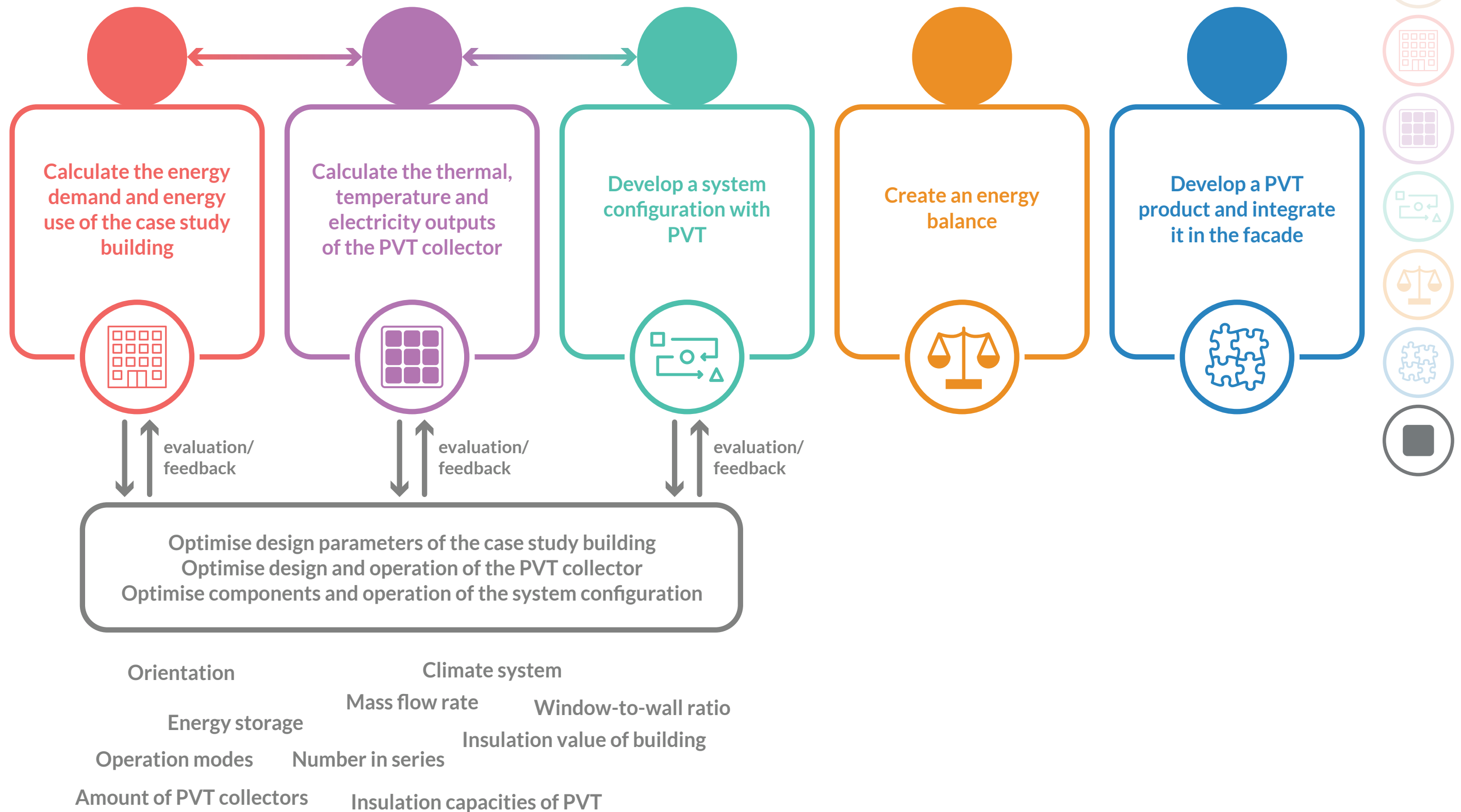
WIDER APPROACH FOR DEVELOPING AND INTEGRATING A PVT CONCEPT



EVALUATION & CONCLUSION

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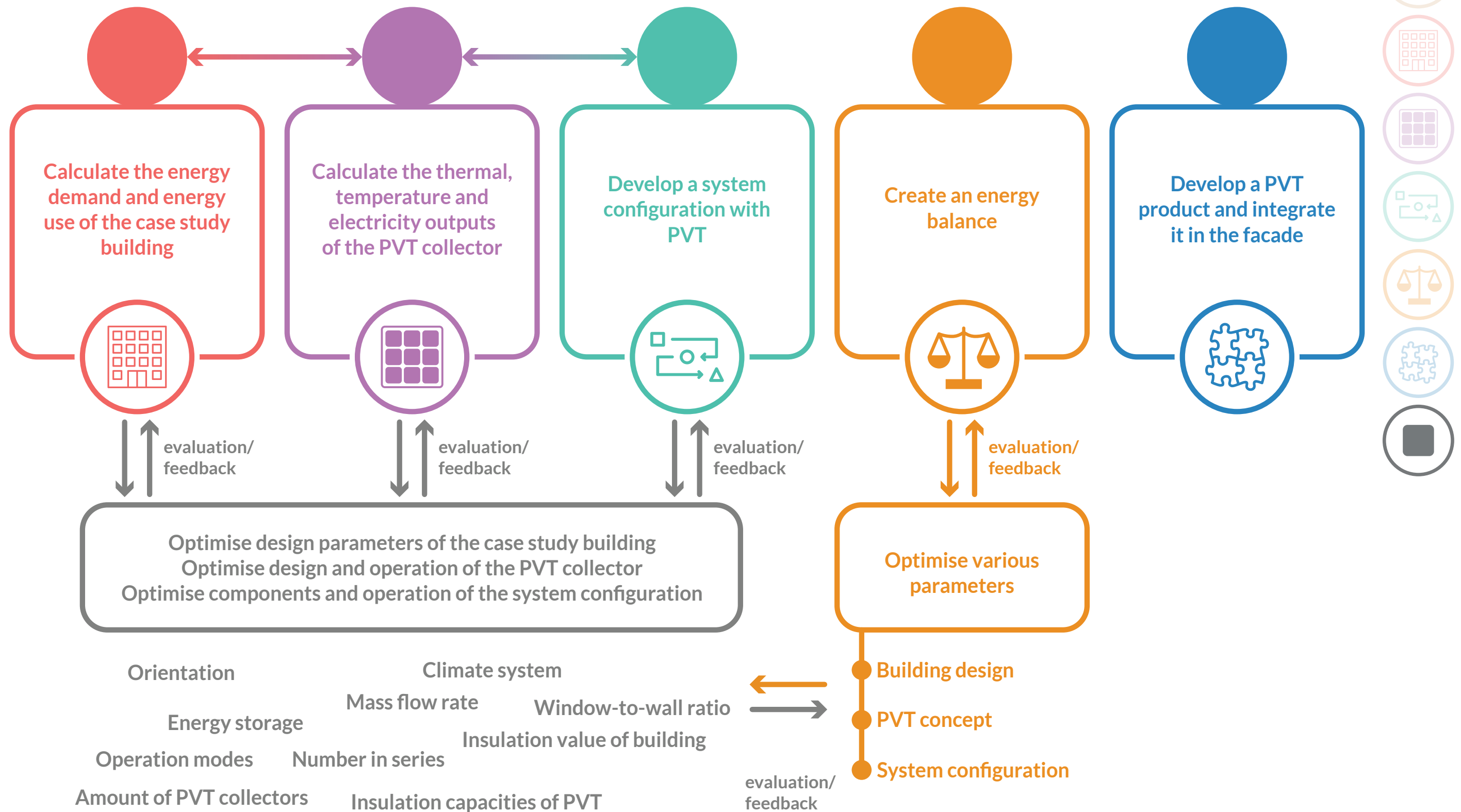
WIDER APPROACH FOR DEVELOPING AND INTEGRATING A PVT CONCEPT



EVALUATION & CONCLUSION

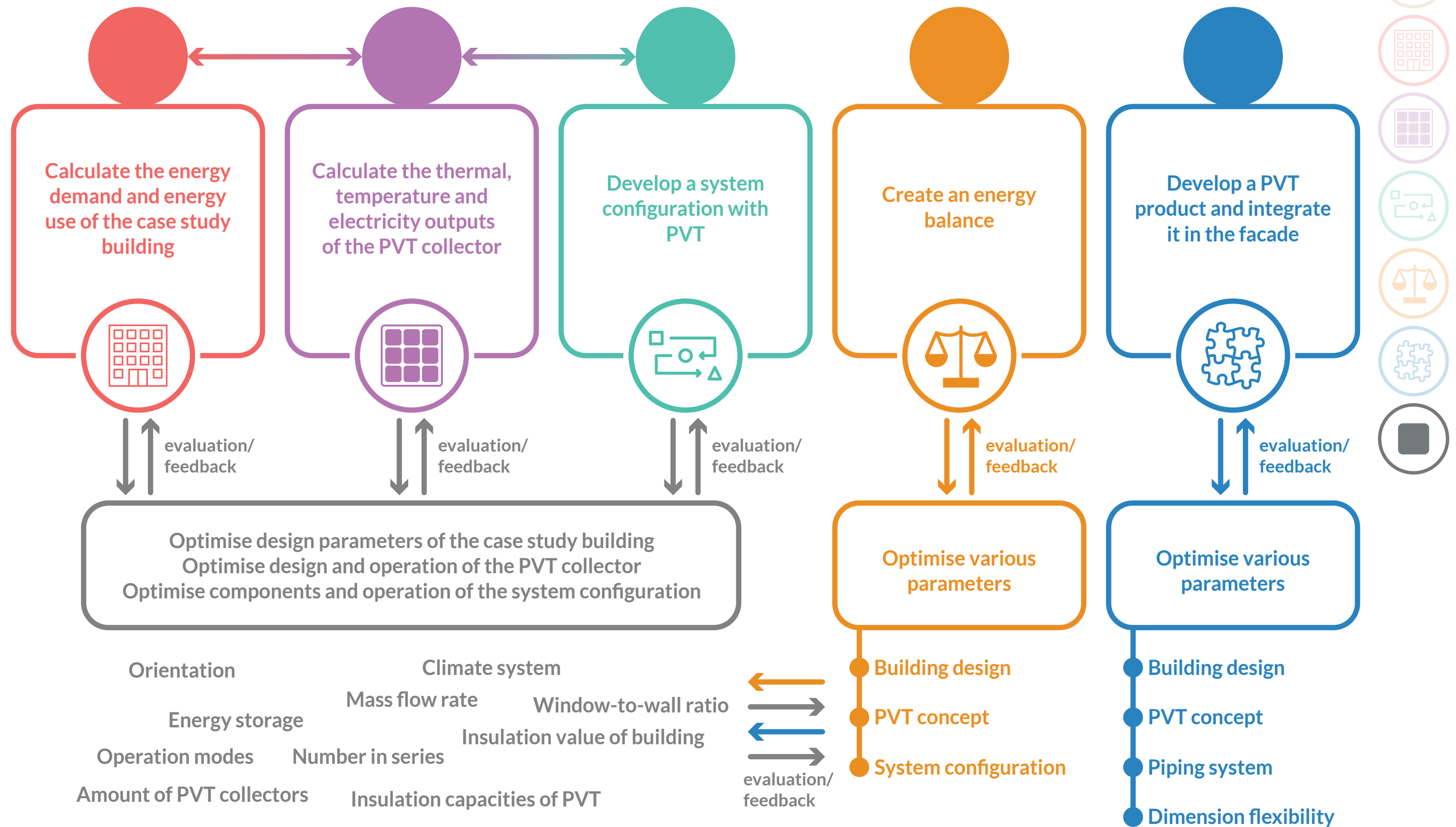
Design process

WIDER APPROACH FOR DEVELOPING AND INTEGRATING A PVT CONCEPT



Design process

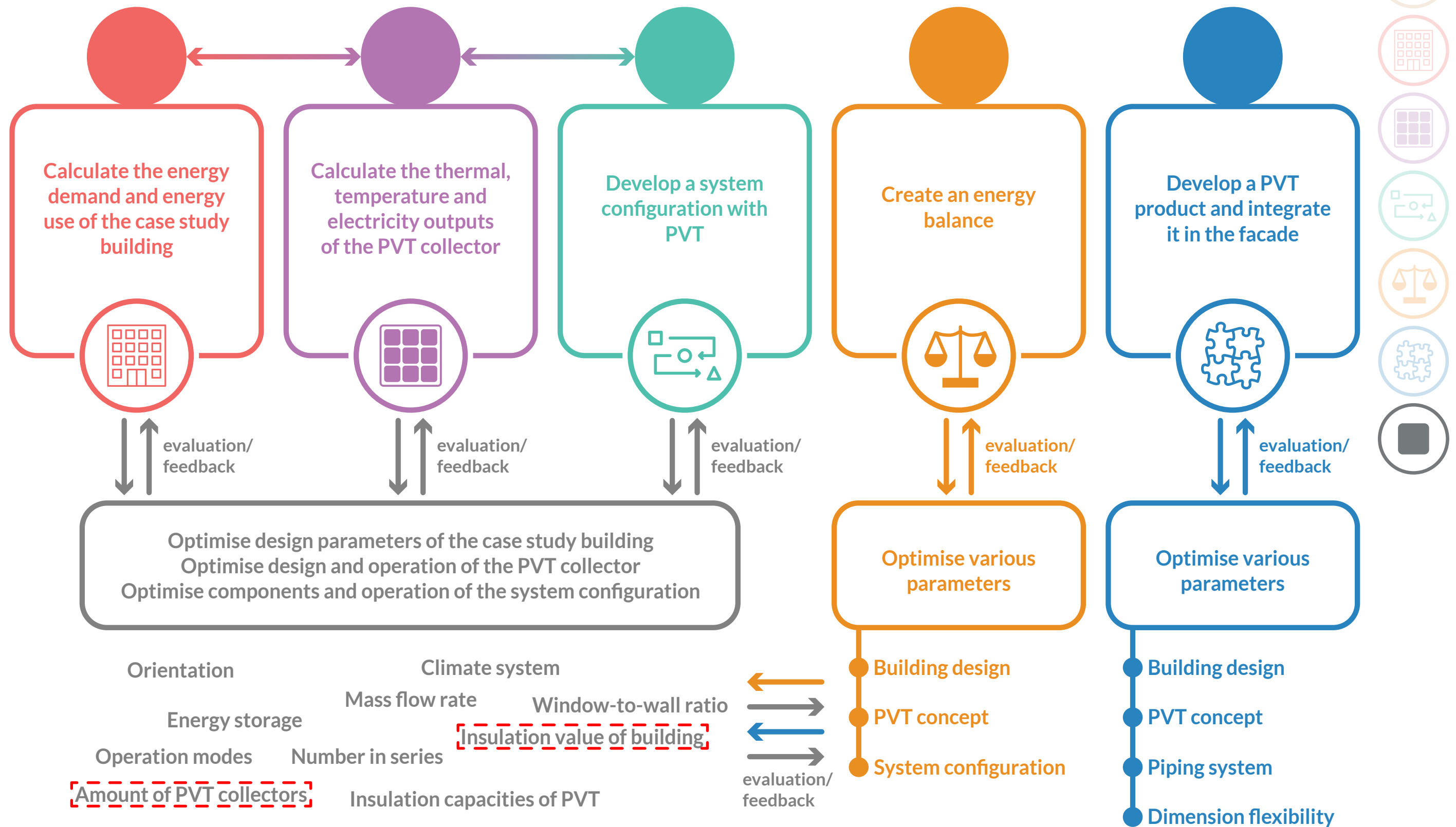
WIDER APPROACH FOR DEVELOPING AND INTEGRATING A PVT CONCEPT



EVALUATION & CONCLUSION

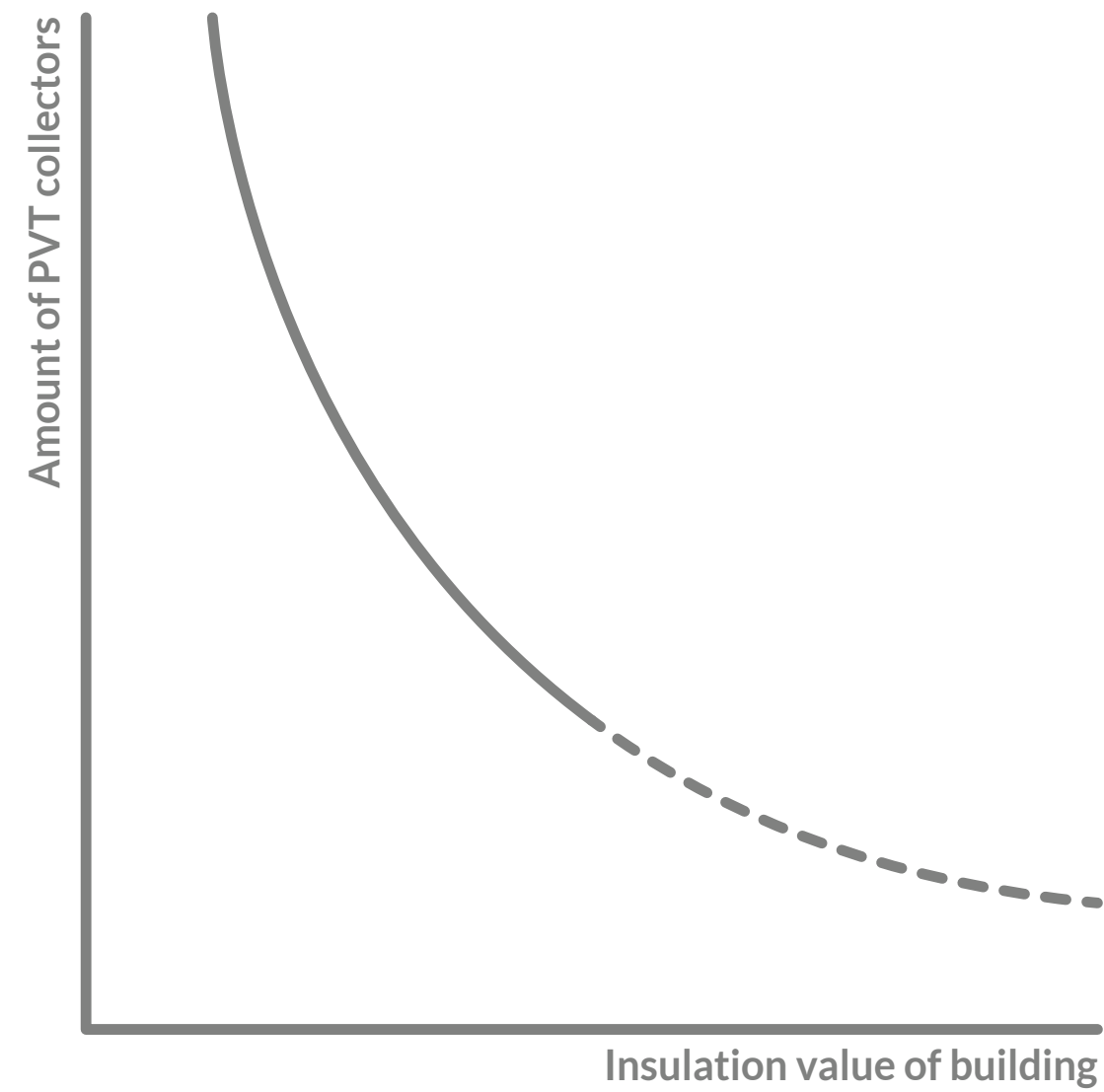
Design process

WIDER APPROACH FOR DEVELOPING AND INTEGRATING A PVT CONCEPT



EVALUATION & CONCLUSION

Design process



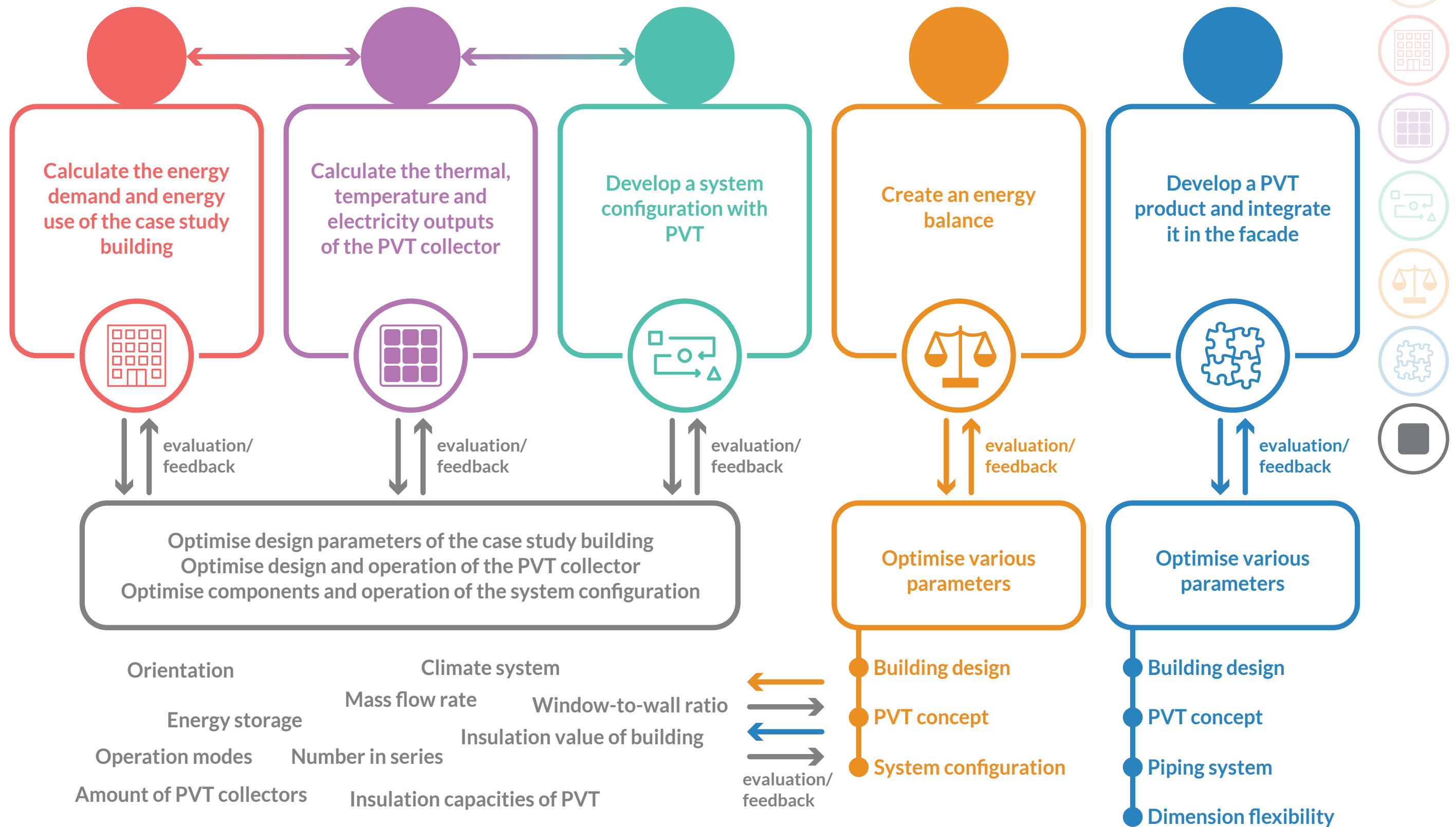
- Remaining energy provided by
i.e. ground source heat pump



EVALUATION & CONCLUSION

Design process

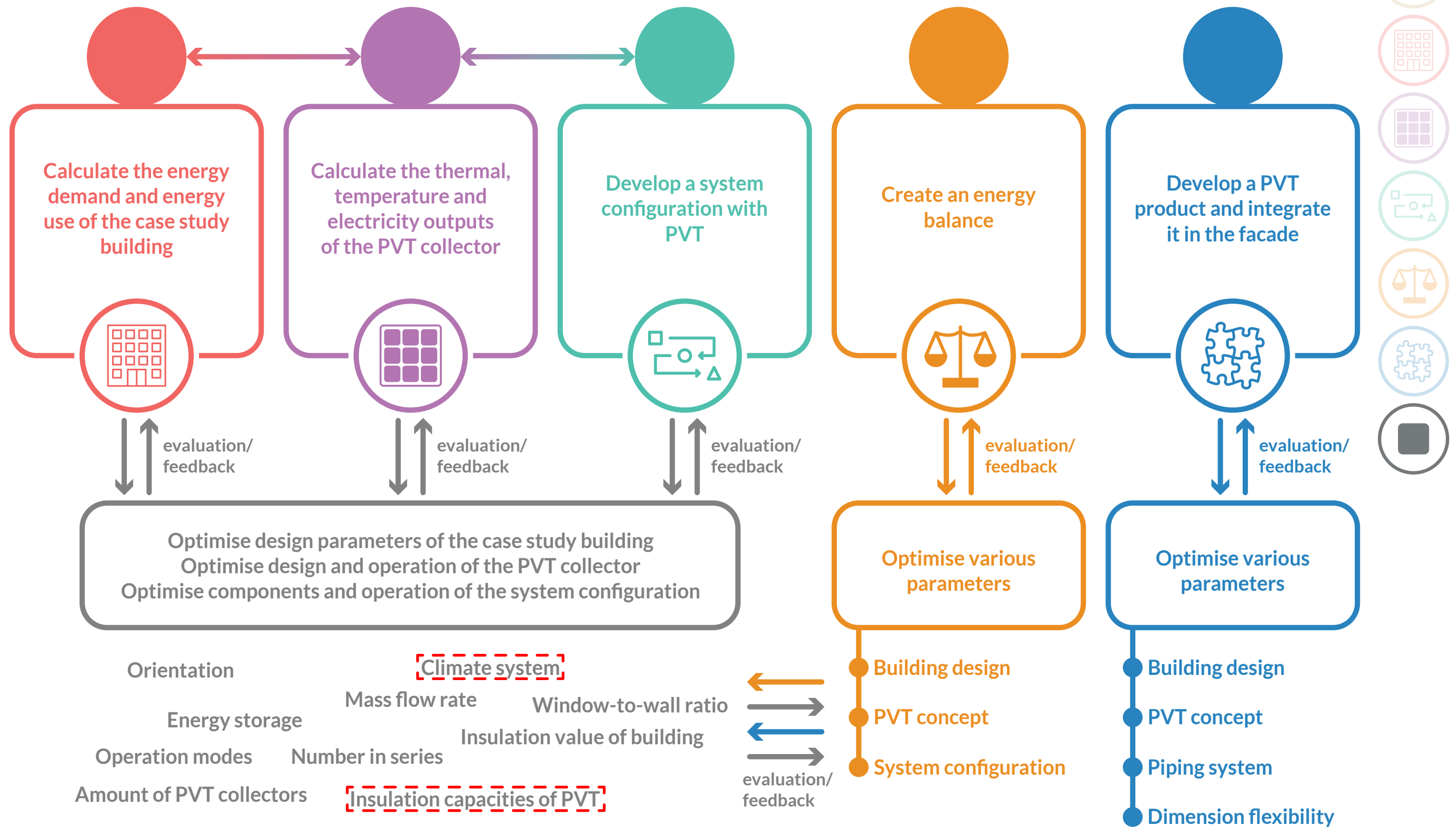
WIDER APPROACH FOR DEVELOPING AND INTEGRATING A PVT CONCEPT



EVALUATION & CONCLUSION

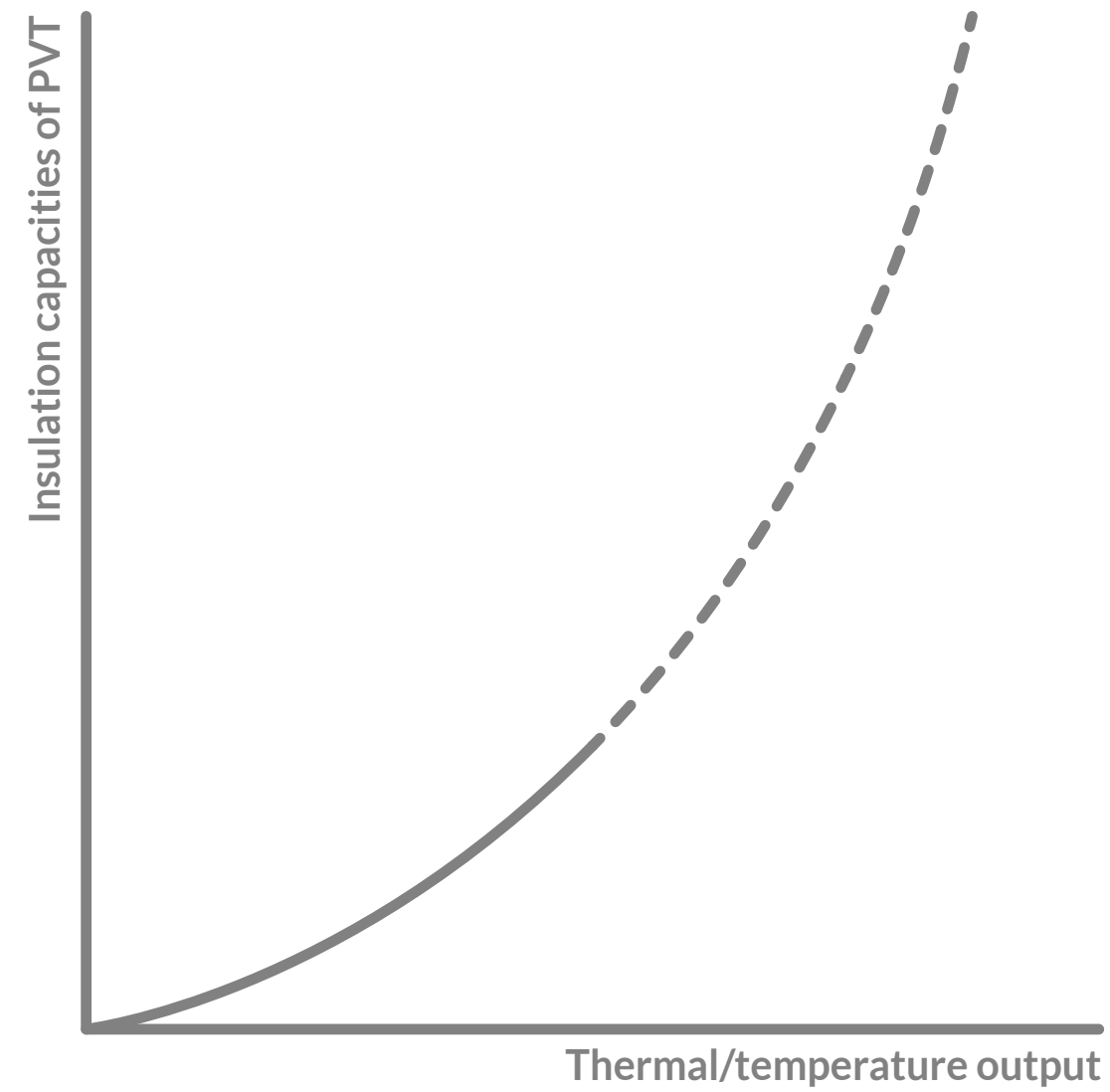
Design process

WIDER APPROACH FOR DEVELOPING AND INTEGRATING A PVT CONCEPT



EVALUATION & CONCLUSION

Design process



- Remaining energy upgraded by heat pump



EVALUATION & CONCLUSION

Answer to the research question

How can an energy concept with PVT be optimised or maximised in terms of renewable energy and be integrated in the envelope of a multi-family building?



EVALUATION & CONCLUSION

Answer to the research question

- Low-temperature heating
- Optimise or maximise various parameters
- Renewable energy systems
- Piping system
- Dimension flexibility

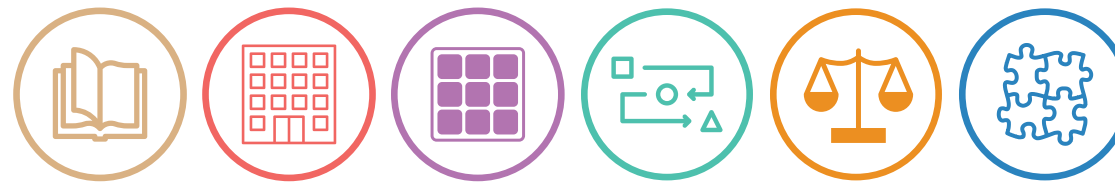


EVALUATION & CONCLUSION

Recommendations

- Effects in practice
- Dimension flexibility and its effect on the output and configuration
- Facade-integration aspects





THANK YOU