Heat transfer interactions in the structural optimization of energy systems

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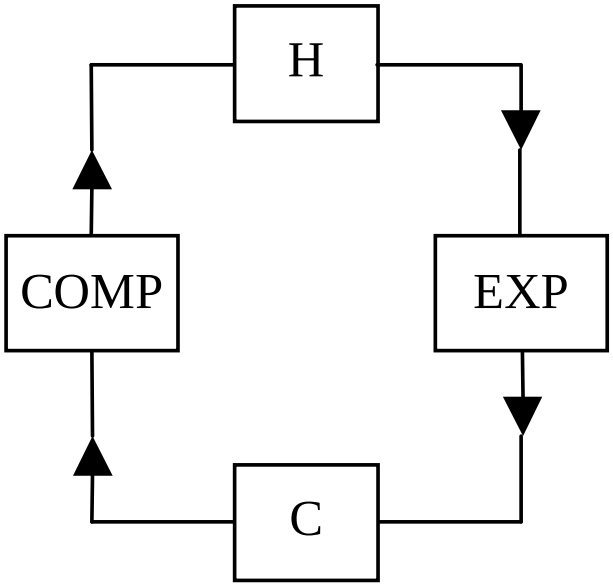
The framework

- The problem of representing the possible configurations is faced starting from the analysis of thermodynamic cycles involved in energy conversion systems

- Synthesis of thermal system components: *operation by which one or more thermodynamic cycles are composed into a single system*

Basic unit of system structure: the thermodynamic cycle



COMP: compressor
EXP: expander
H: hot source
C: cold source

- **Characteristics**:

  each cycle is made up of the four fundamental transformations

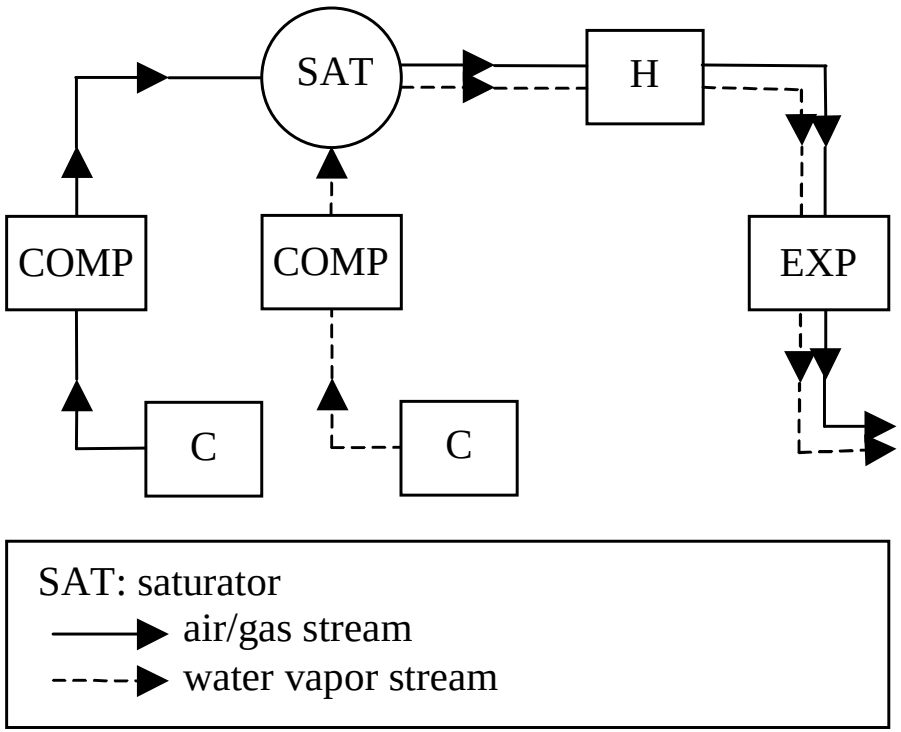
  - compression
  - heat exchange with the HT source
  - expansion
  - heat exchange with the LT source

---> four fundamental components

- **Variables**:

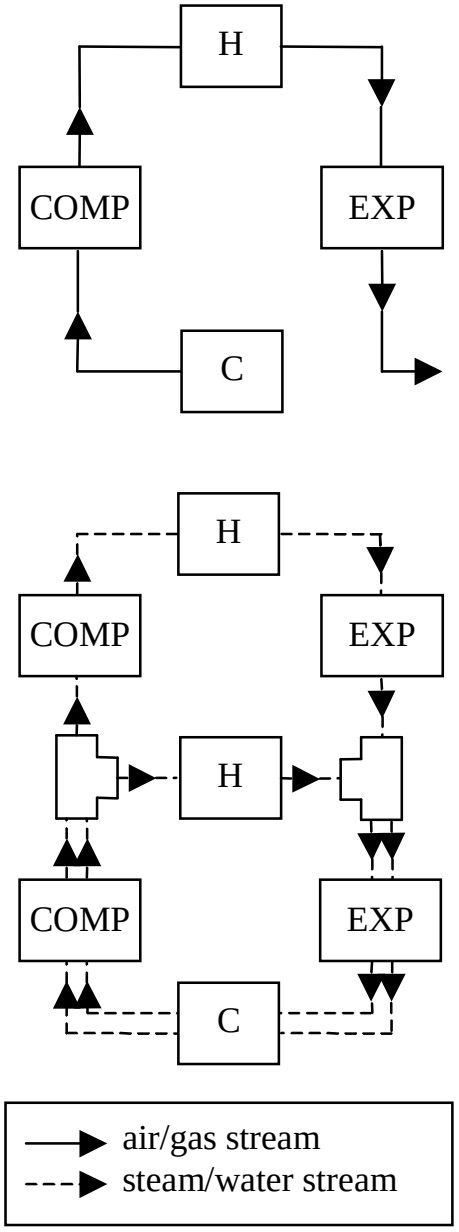
- kind of the operating fluid
- extreme p and T of the cycle

Combining the thermodynamic cycles



- Cycles of the same or different substances may share common transformations. This requires the inclusion of other secondary components (e.g. saturators, mixers) when different streams join in a single stream

- The common paths of the cycles end when the streams are separated in other components (e.g. separators, condensers, splitters)

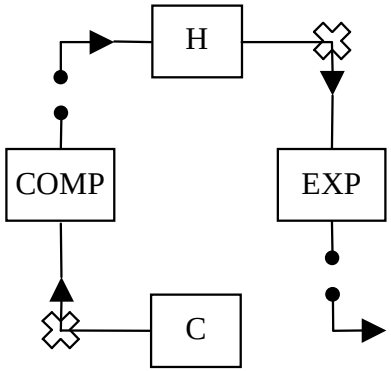


The "basic" system configuration

• The basic system configuration is defined by:
- operating fluids
- extreme values of p and T
- common transformations
of the cycles

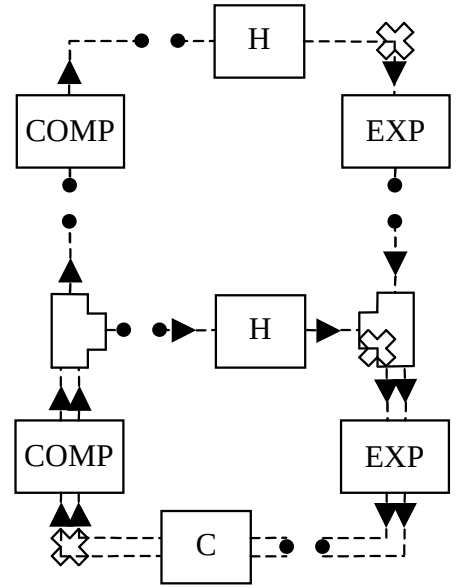
• Two pressure levels CC: The steam section is represented using two cycles sharing three transformations. The pressure extremes of the cycles determine the compression/expansion stages

• Internal heat transfer is now to be introduced considering that the heat from hot and cold sources, if needed, is transferred externally only



Representation of heat transfer interactions

• Addition of secondary heat exchangers between any couple of subsequent components



• Cycles paths are considered as "interrupted" to allow for the inclusion of heat transfer devices which may alter in any direction the temperature of the streams of the working fluids

→ expected increases or decreases in temperature correspond to cold flows that need to be heated or to hot flows that need to be cooled, respectively

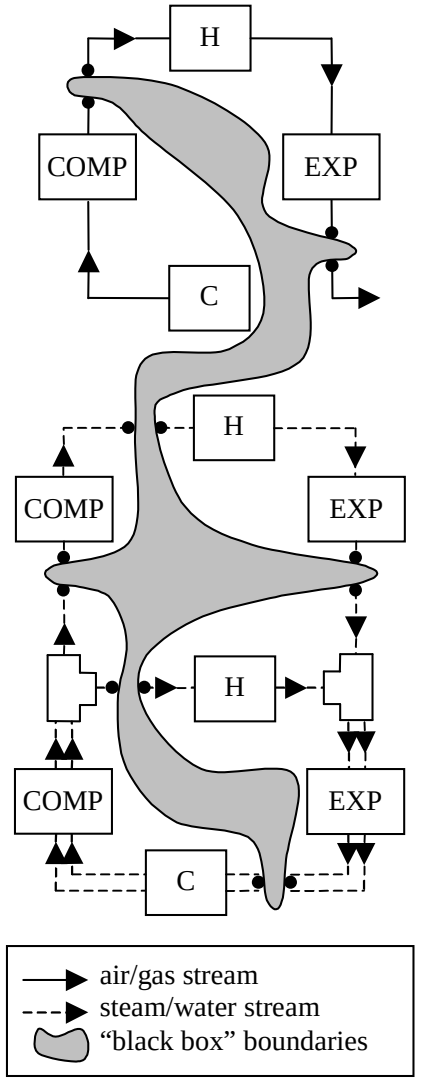
• Direct link between C and COMP and between H and EXP

Different levels in the definition of the structure

- Overall system configuration divided into two parts

- a part including the component of the basic plant configuration

- a part bounding the interruptions in the cycle paths and comprising all the hot and cold thermal flows generated by these interruptions; this part corresponds to the heat transfer section of the system (black-box) in which all heat transfers occur independently of the heat exchanger network that realizes them.

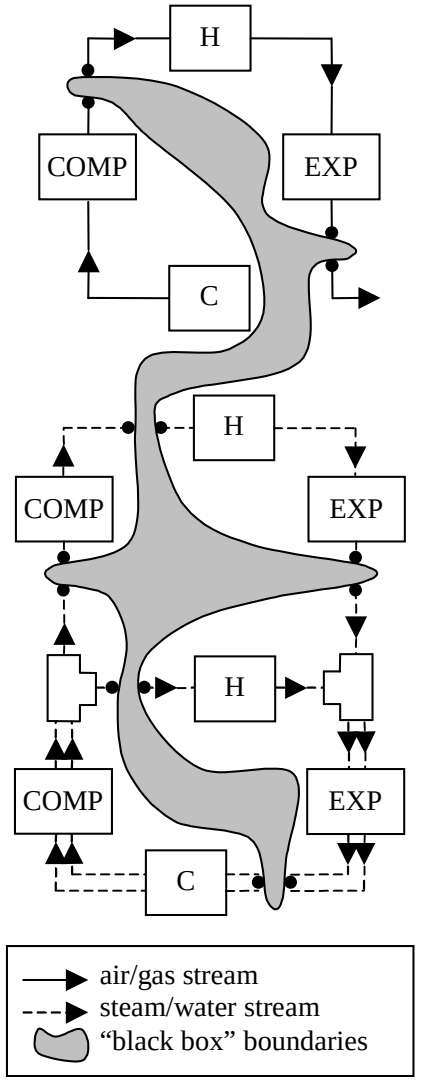


Separation of problems in the synthesis of thermal system components

1) Generate and organize cycles and related components into a basic structure

2) Assign the parameters of the basic structure components and those at the interface between basic structure and heat transfer black-box (i.e. temperatures at black-box boundaries)

3) Define the structure of the heat exchanger network inside the black-box

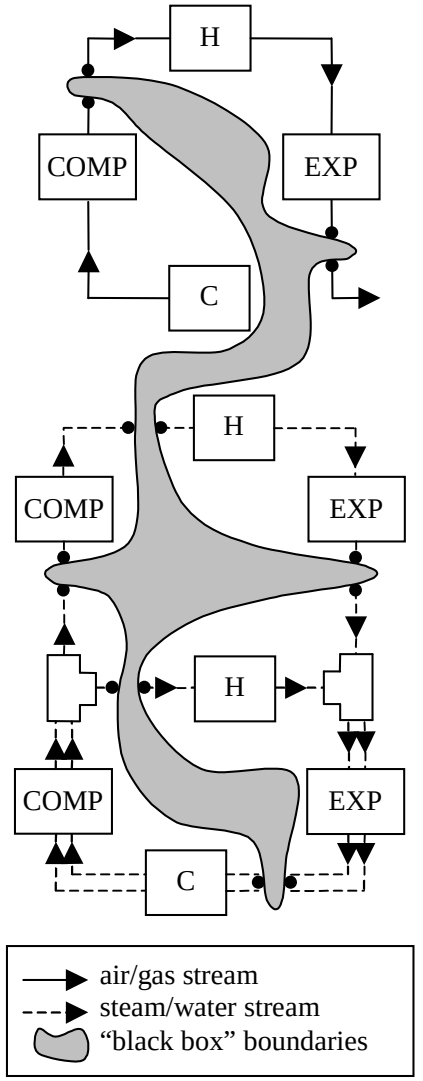


Advantages

All three steps are needed to evaluate the objective function(s), but….

The structure of the system is represented by a limited number of fundamental decision variables

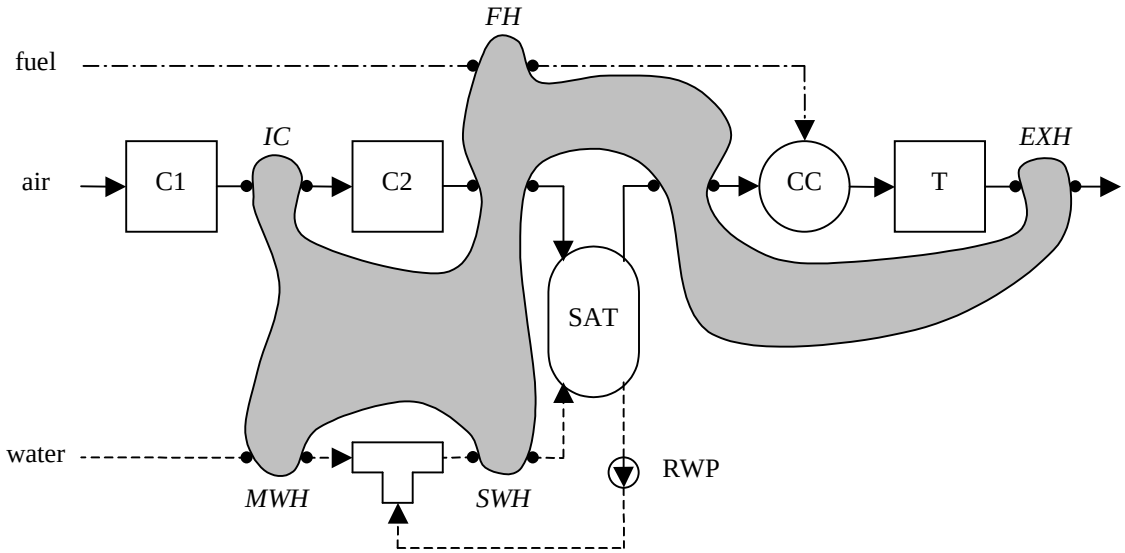
→ points of insertion of secondary heat exchangers follow automatically, therefore they do not need to be considered as decision variables



Example of Application - HAT cycle

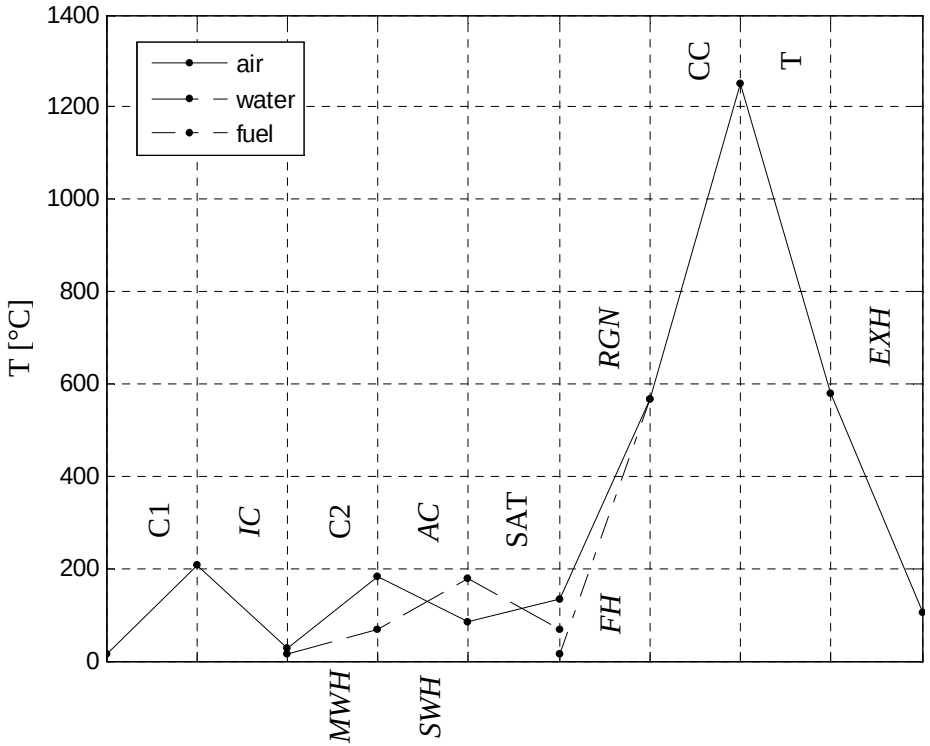
- Concept: increase the performance of a regenerative gas Brayton-Joule cycle by saturating the compressed air stream with water vapor.

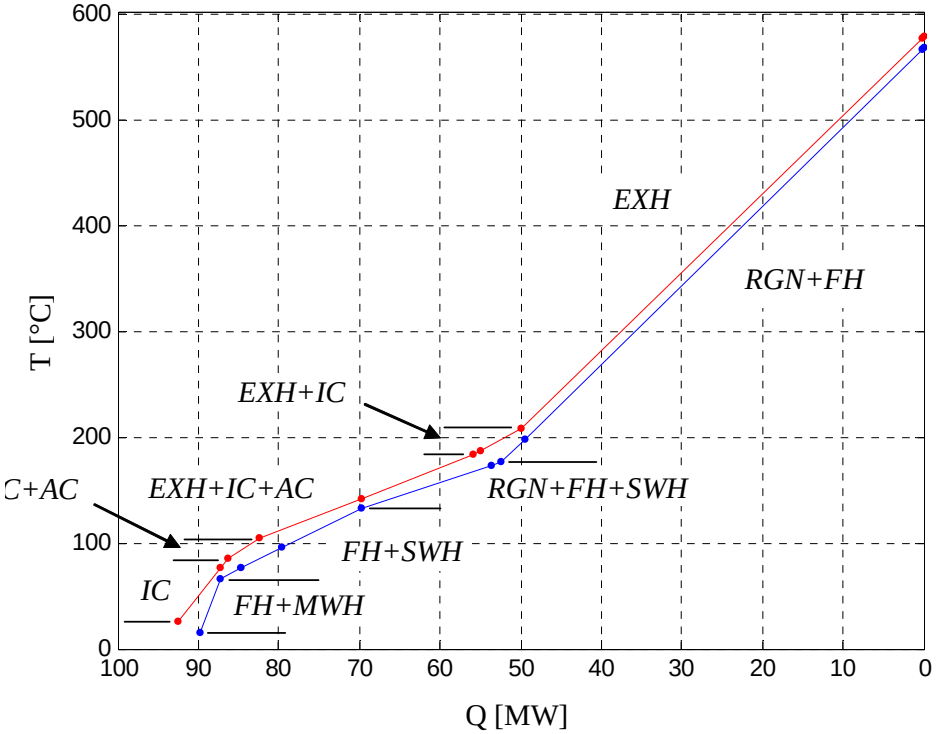
- The key system component is therefore the saturator that is added to the traditional architecture of the regenerative Brayton cycle.



C1:	1st compression stage	*IC*:	intercooler
C2:	2nd compression stage	*AC*:	aftercooler
CC:	combustion chamber	*MWH*:	make-up water heater
SAT:	saturator	*SWH*:	saturator water heater
T:	turbine	*RGN*:	regenerator
RWP:	recuperated water pump	*FH*:	fuel heater
		EXH:	exhaust gas cooler

Results





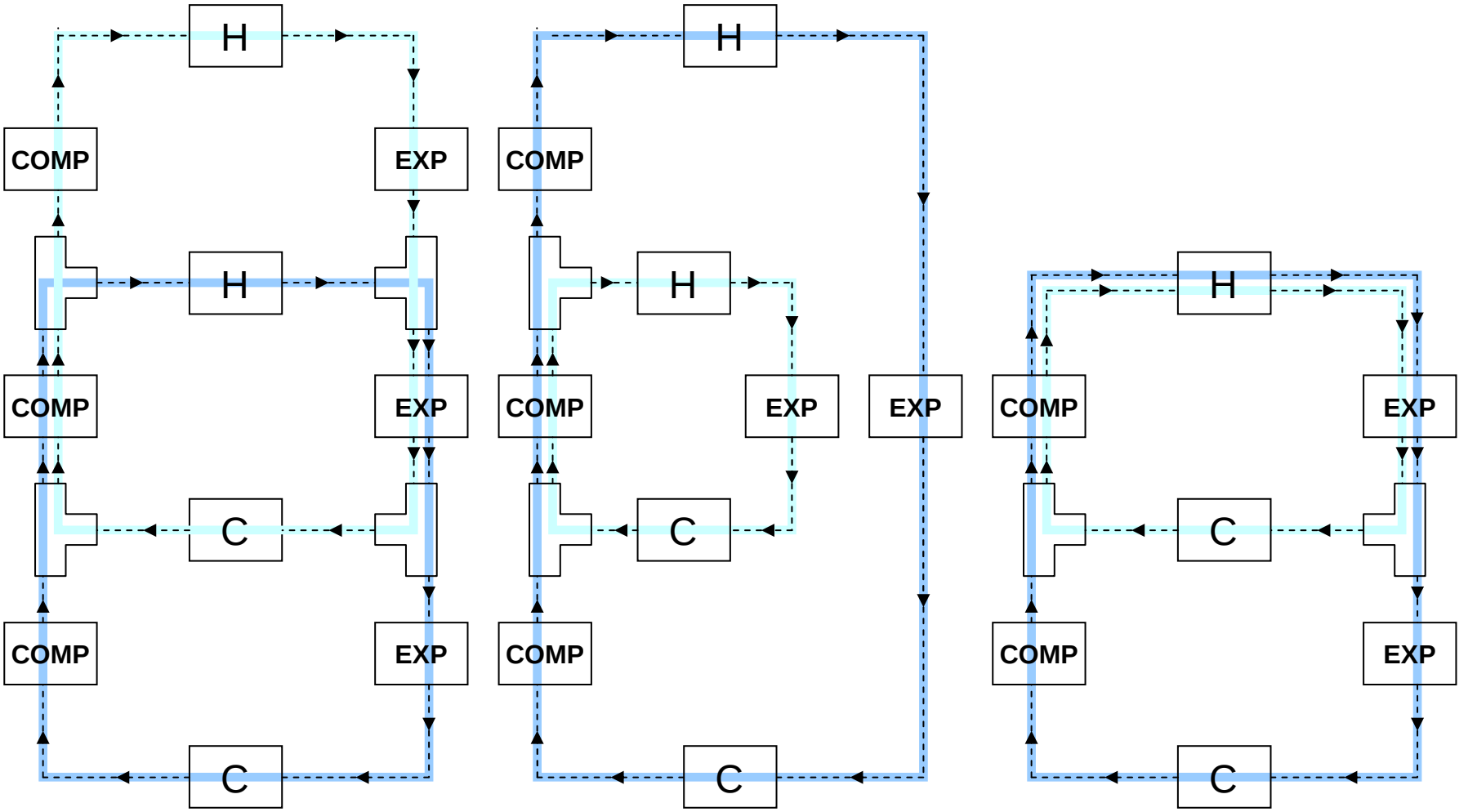
- Hot flows match almost ideally with the cold ones
- Deviations at low temperatures are due to the different heat capacities on the two sides (the decision variables that would maximizes heat recovery may adversely affect the contribution to overall exergetic efficiency)

Conclusions

• The heat transfer section can be separated from the synthesis of the other "basic" components, which instead define the main system characteristics.

• So, the variables associated with the position and number of heat exchangers can be excluded by the set of free variables in the general problem of defining the system structure, which is limited to the definition of basic system structure, i.e. to the interactions among thermodynamic cycles

• The procedure can be applied to any kind of plant including one or more thermodynamic cycles, and it is intended to be a part of a wider approach dealing with the definition of the basic system configuration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