Dynamic analysis and control of an air-cooled heat exchanger system for a 50 MWe sCO2 CSP Plant

Presented by Colin Francois du Sart (Colin.duSart@uct.ac.za), University of Cape Town
Co-authored by Pieter Rousseau, Stellenbosch University

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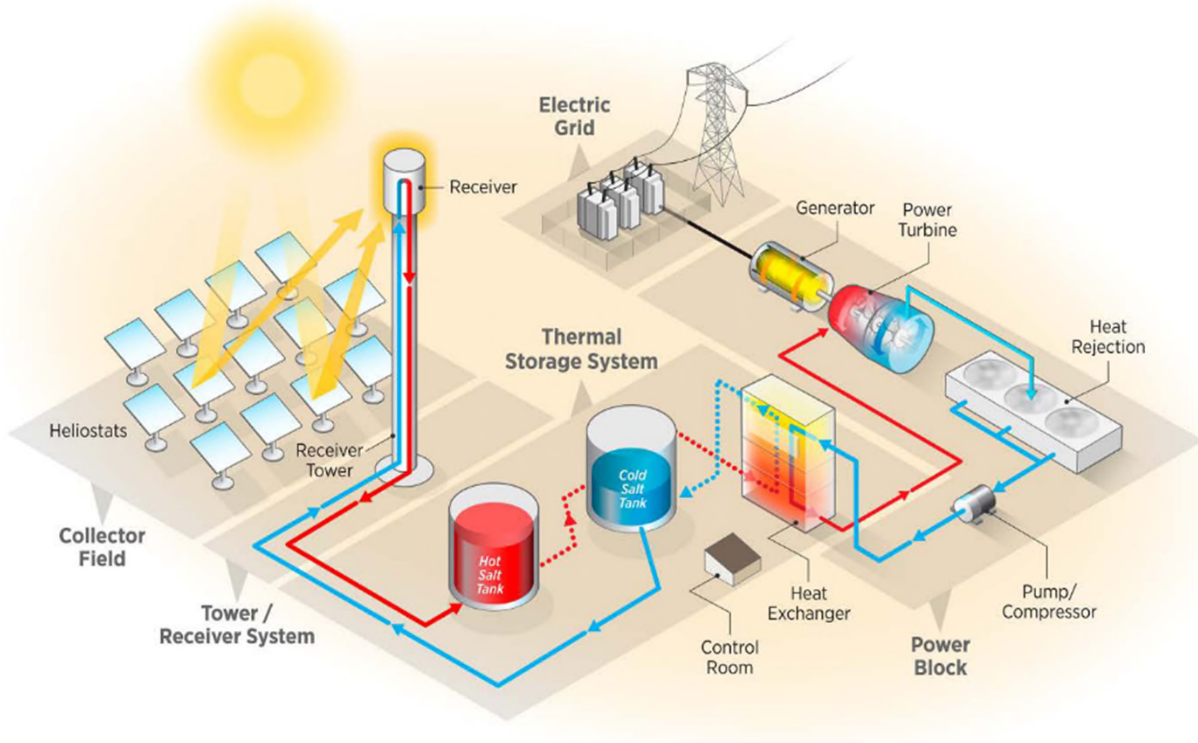
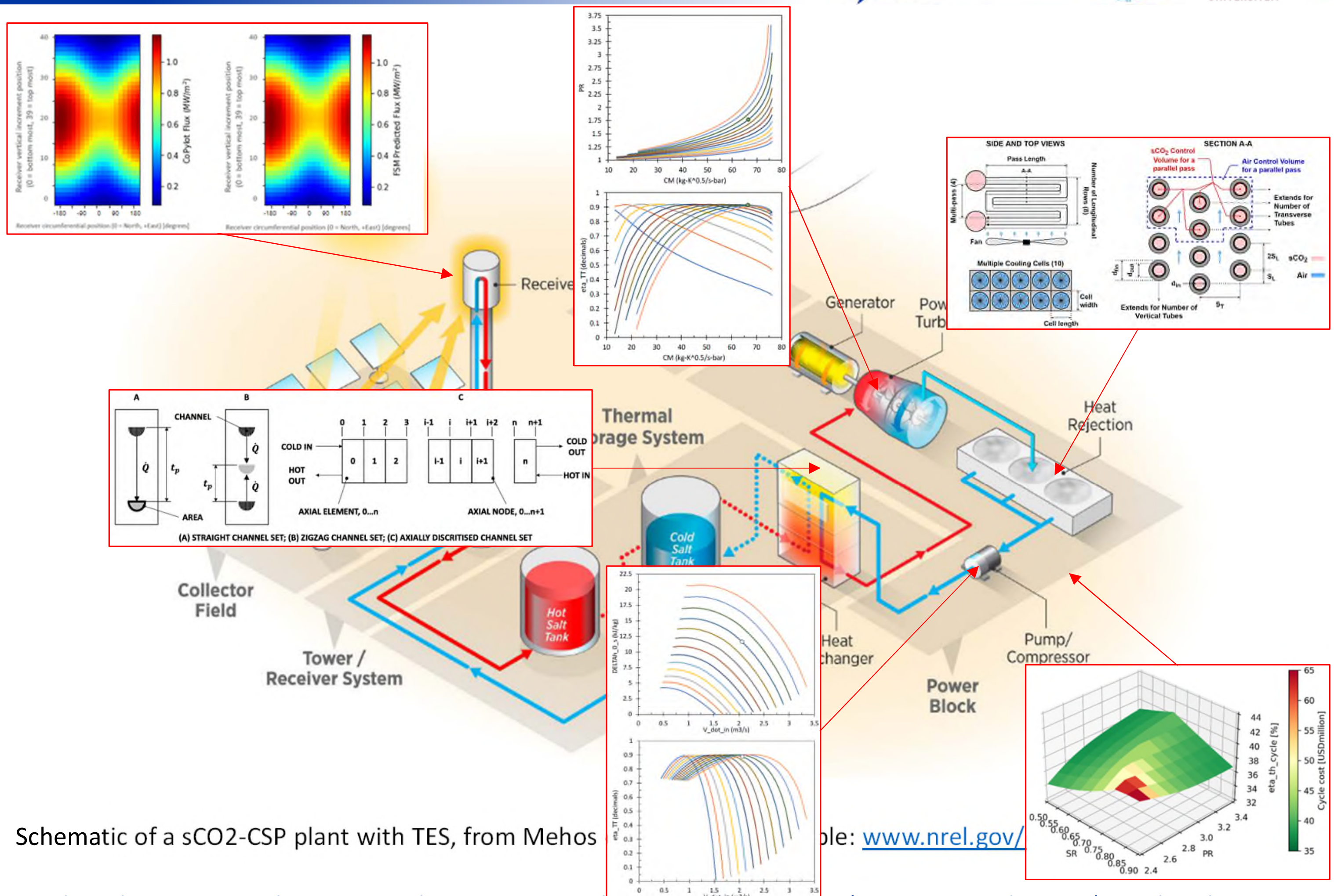
Introduction



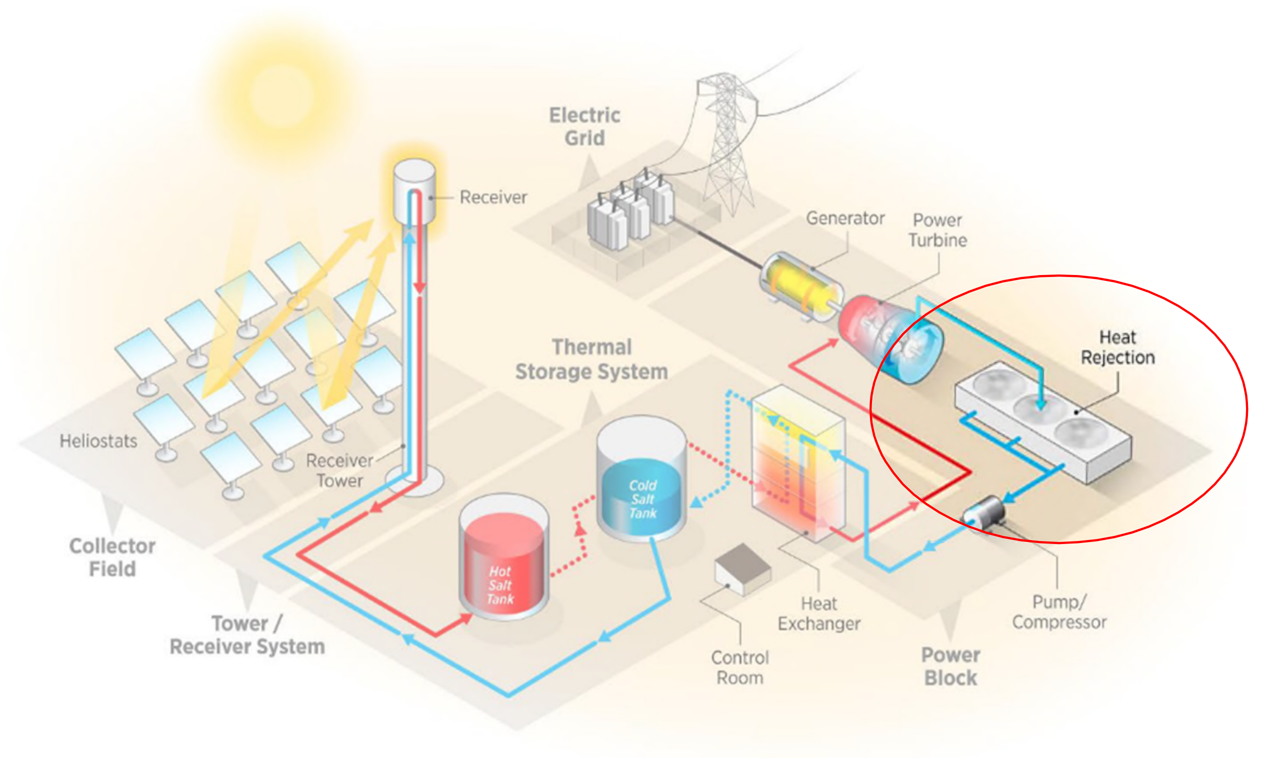
Schematic of a sCO2-CSP plant with TES, from Mehos et al. (2017). Available: www.nrel.gov/docs/fy17osti/67464.pdf

Introduction



Schematic of a sCO2-CSP plant with TES, from Mehos ... ple: www.nrel.gov/

Introduction



Schematic of a sCO2-CSP plant with TES, from Mehos et al. (2017). Available: www.nrel.gov/docs/fy17osti/67464.pdf

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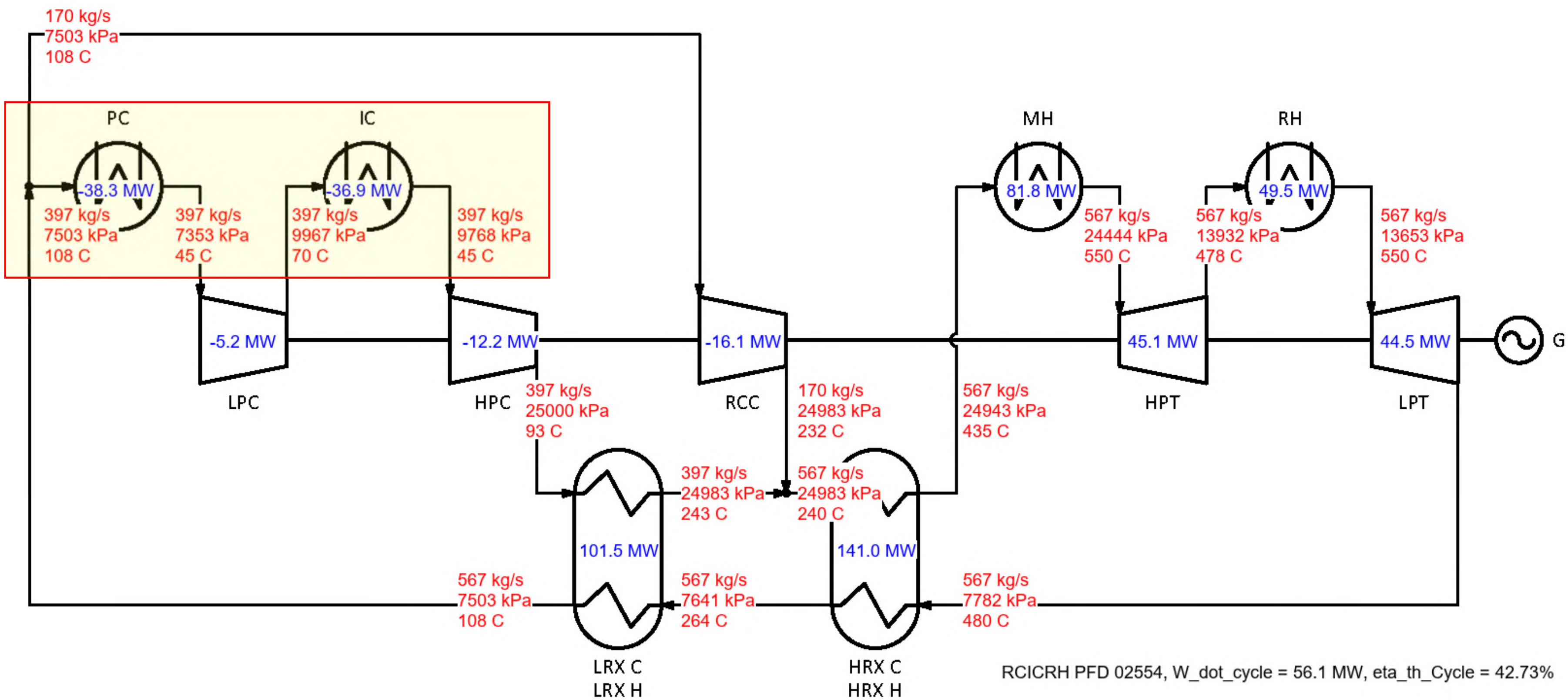
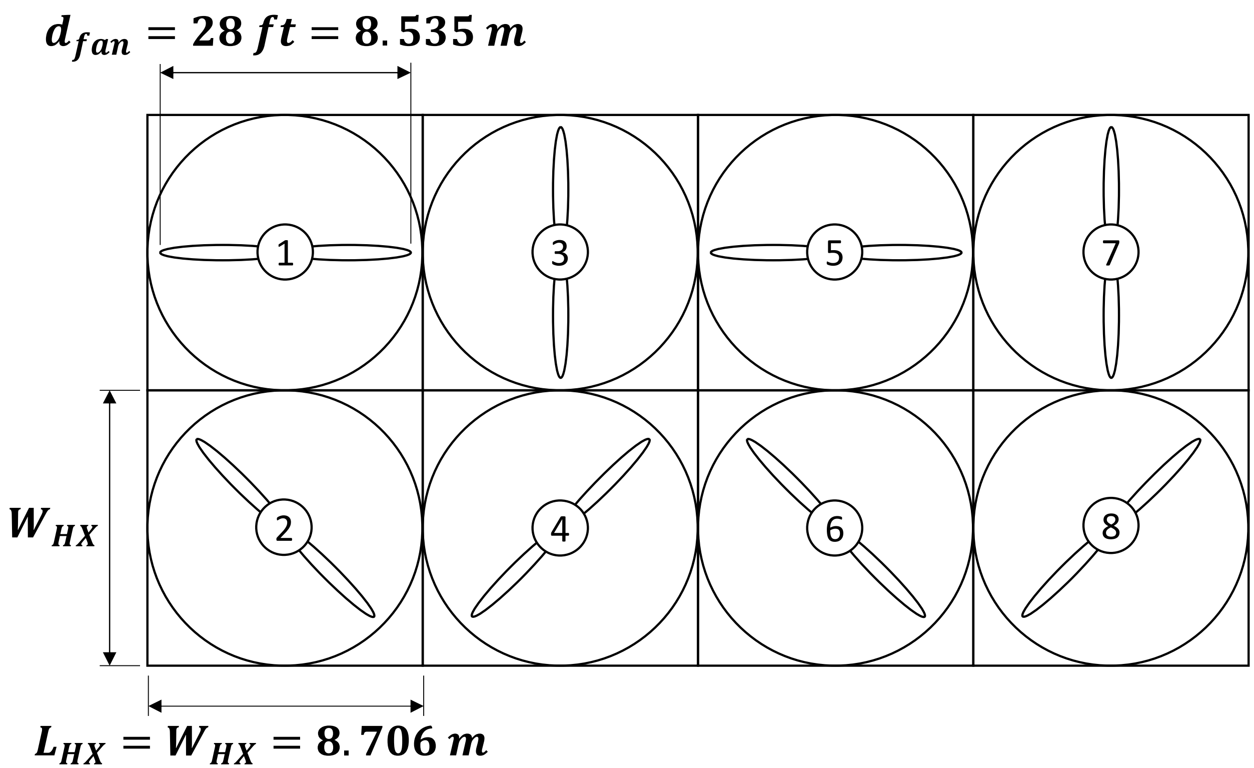


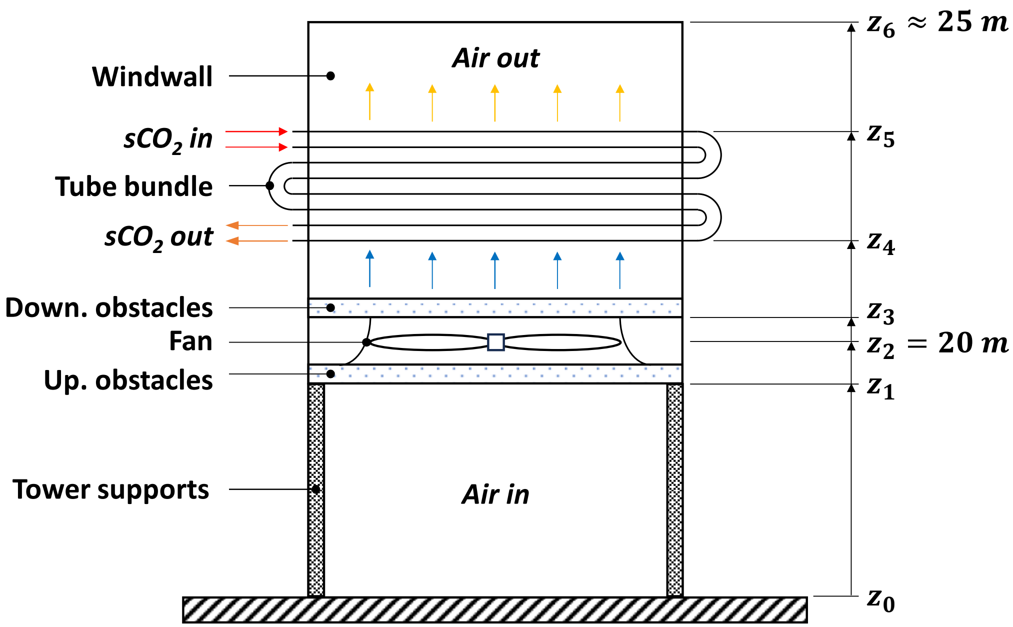
Power cycle design presented in Renewable Energy Journal (du Sart, et al., 2024)

System description

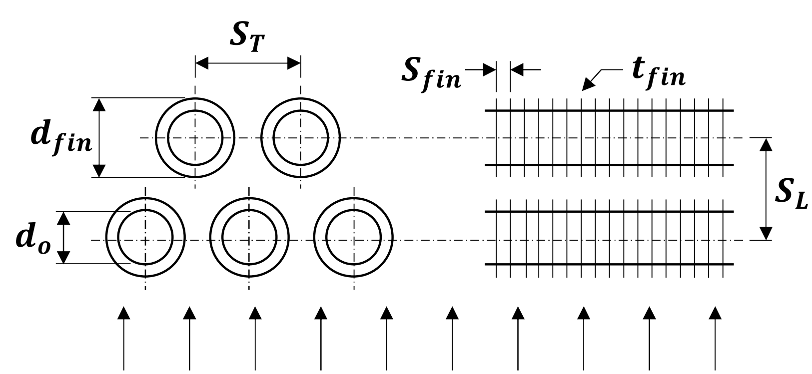


ACHE system design presented in sCO2 Europe Proceedings (du Sart, et al., 2025)

System description



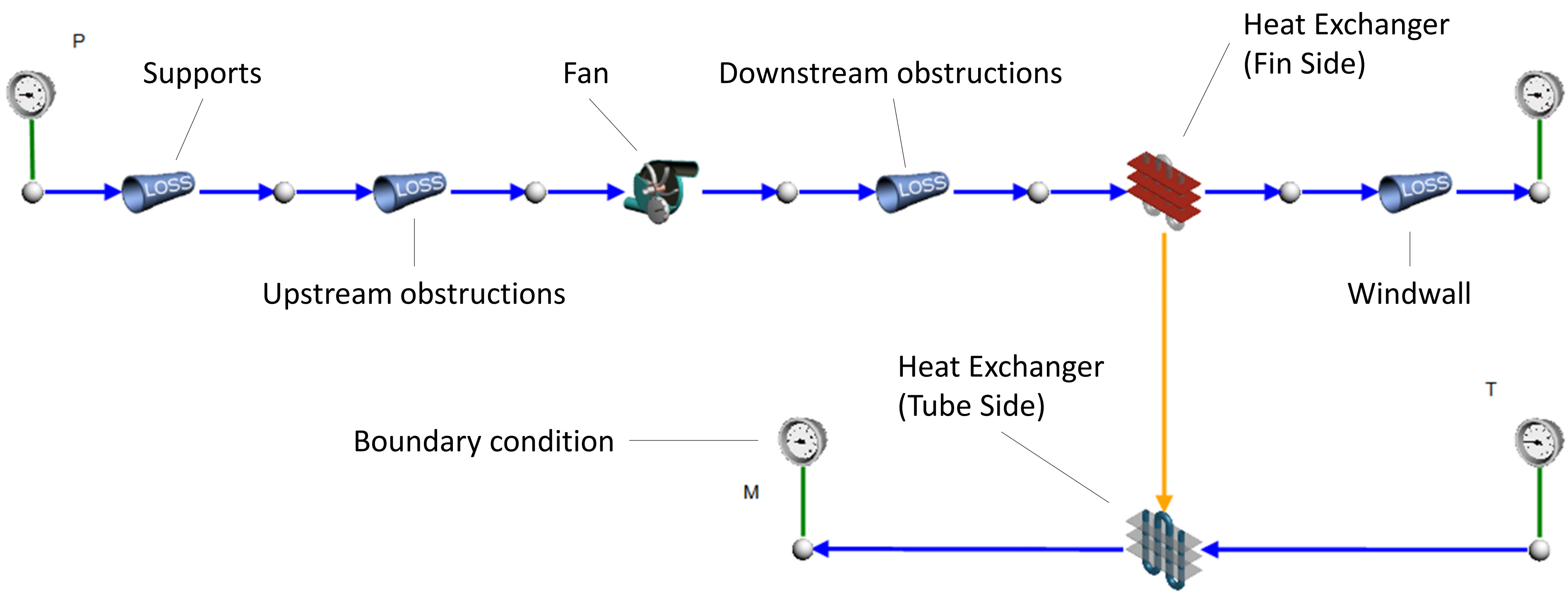
CF-8.8-1.0J A/B
Kays & London (2018)



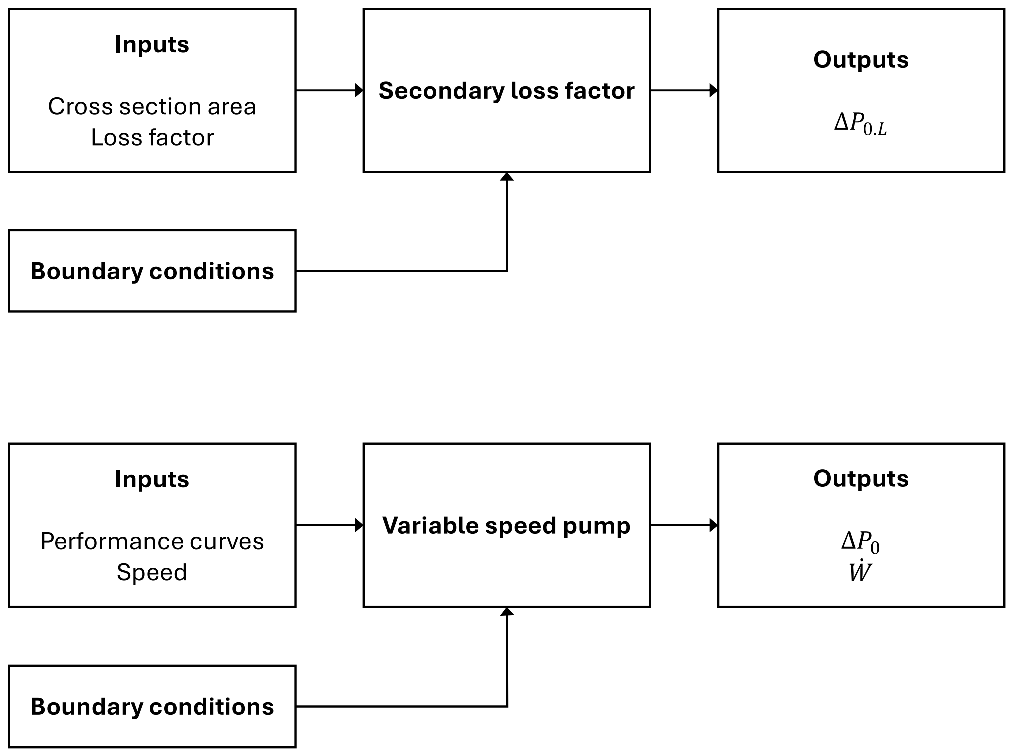
Schedule 10 ASTM A106 Grade B piping
OD = 26.7 mm
wt = 2.11 mm

ACHE system design presented in sCO2 Europe Proceedings (du Sart, et al., 2025)

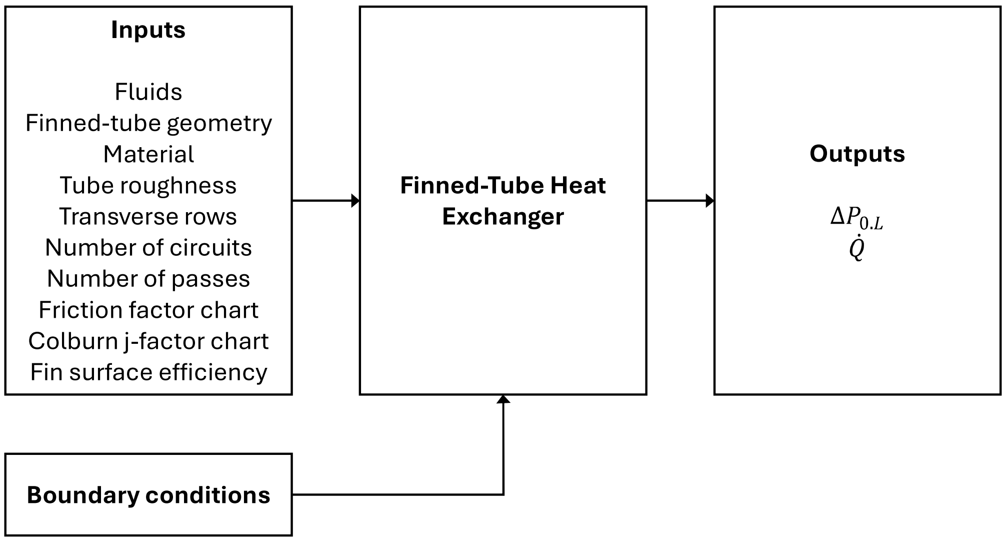
Flownex model



Flownex model



Flownex model



Flownex model

$$\frac{\partial \rho}{\partial t} = \frac{1}{V}\left(\sum \dot{m}_{in} - \sum \dot{m}_{out}\right)$$

$$\frac{\partial \dot{m}}{\partial t} = \frac{A}{L}\left[P_{0.in} - P_{0.out} - \frac{\rho^2 v^2 A^2 (\rho_{in} - \rho_{out})}{2\rho_{in}\rho_{out}A_{in}A_{out}} + \rho g (z_{in} - z_{out}) + \Delta P_{0.W} - \Delta P_{0.L}\right]$$

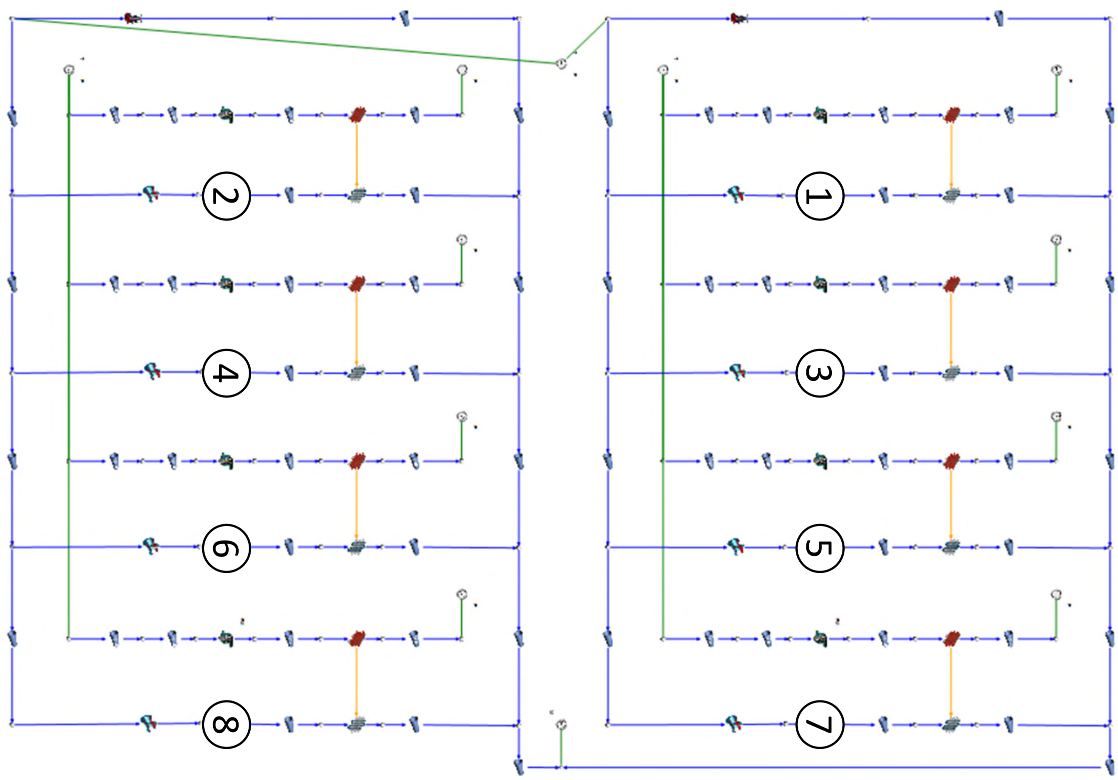
$$\frac{\partial h_0}{\partial t} = \frac{1}{\rho V}\left[\sum \dot{m}_{in}(h_{0.in} - h_0 + g z_{in}) - \sum \dot{m}_{out}(h_{0.out} - h_0 + g z_{out}) + \dot{Q} - \dot{W} + V\frac{\partial P}{\partial t}\right]$$

Verification

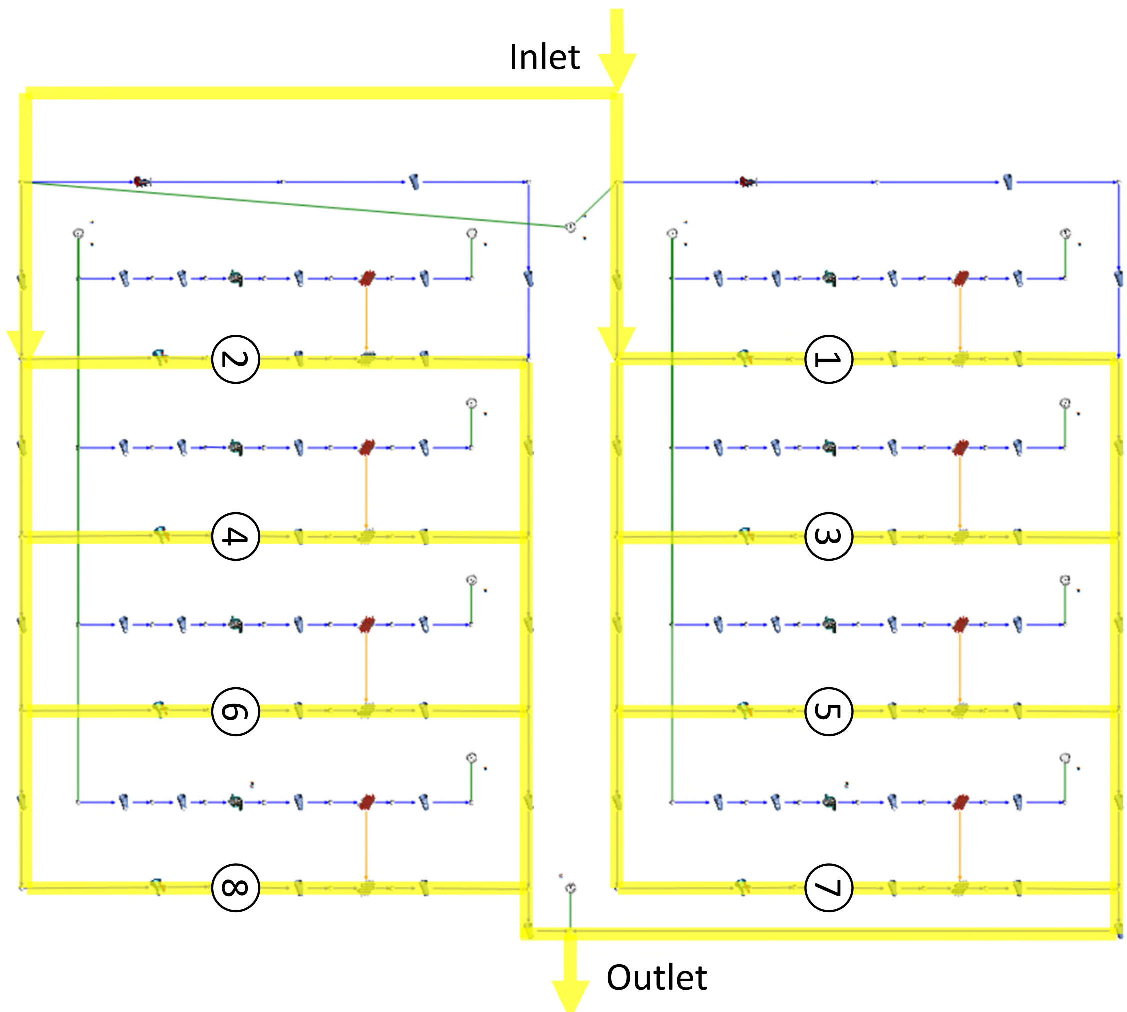
Results, Python model relative to Flownex model

Error in %	Precooler	Intercooler
$\dot{Q}$	-0.528	0.992
ΔP_c	10^{-6}	10^{-5}
ΔP_h	3.256	8.472
$T_{c.out}$ ($°C$)	-0.150	0.581
$T_{h.out}$ ($°C$)	0.333	-0.349
$P_{h.out}$	-0.040	-0.022
$P_{c.out}$	-0.007	-0.028

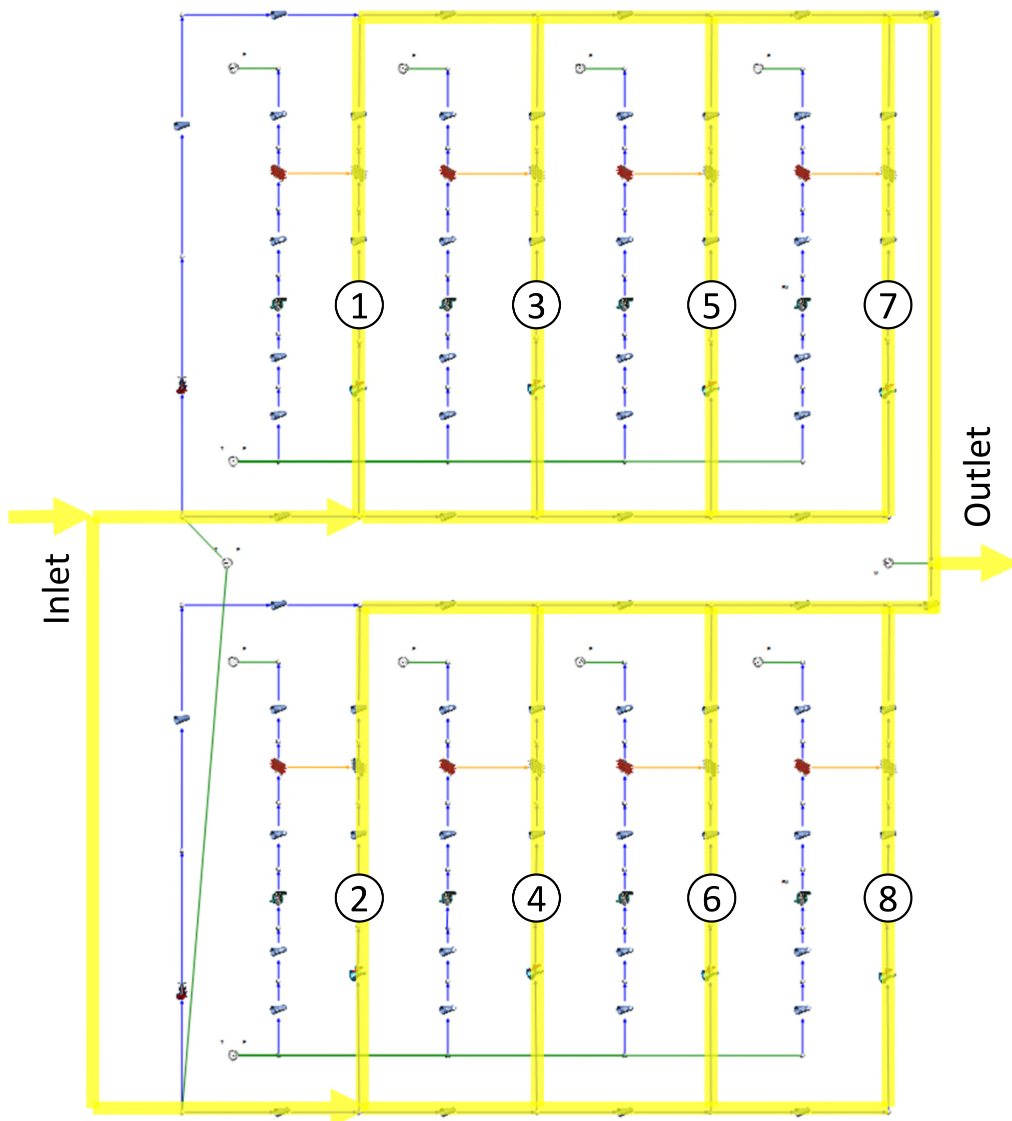
Complete ACHE model



Primary flow path



Primary flow path

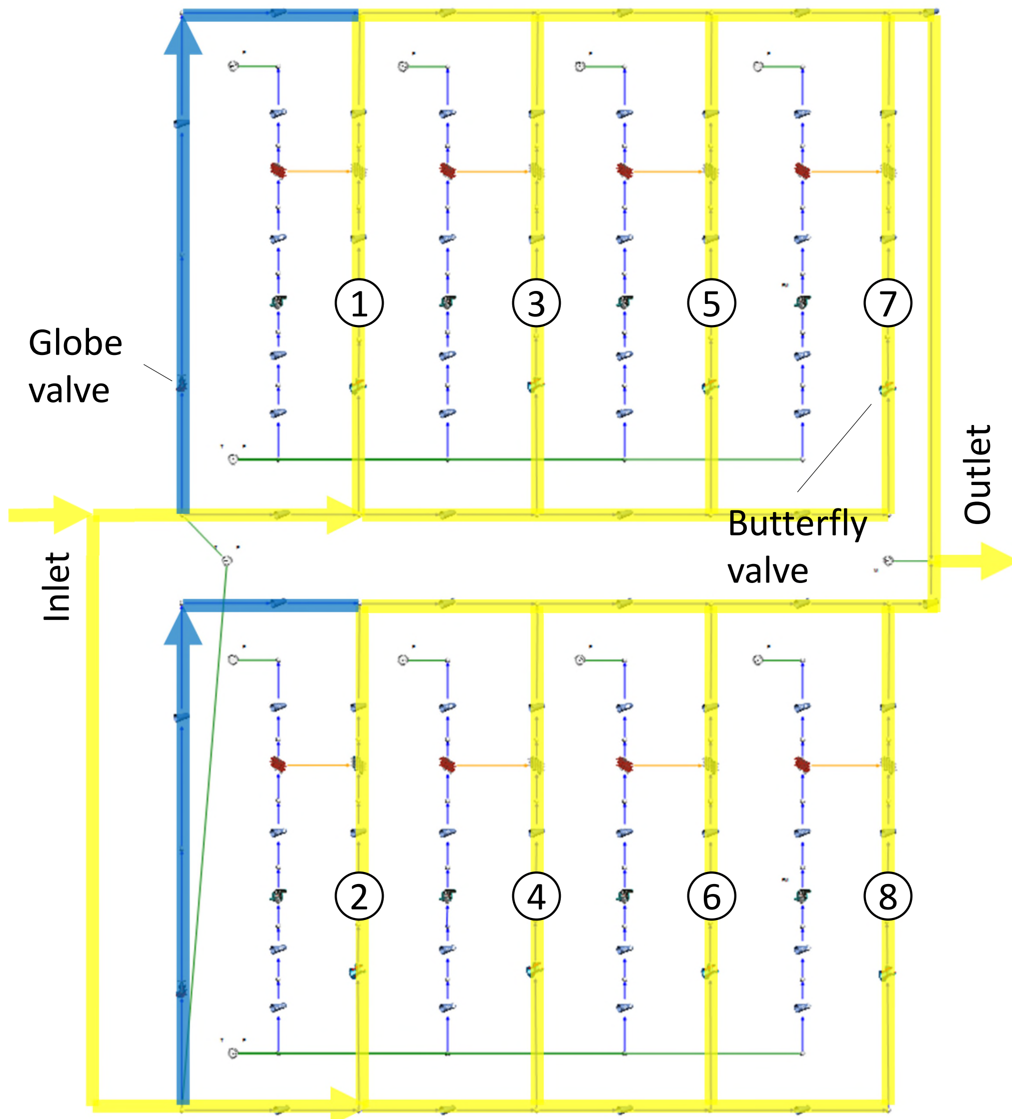


Maintain CIT at 45°C

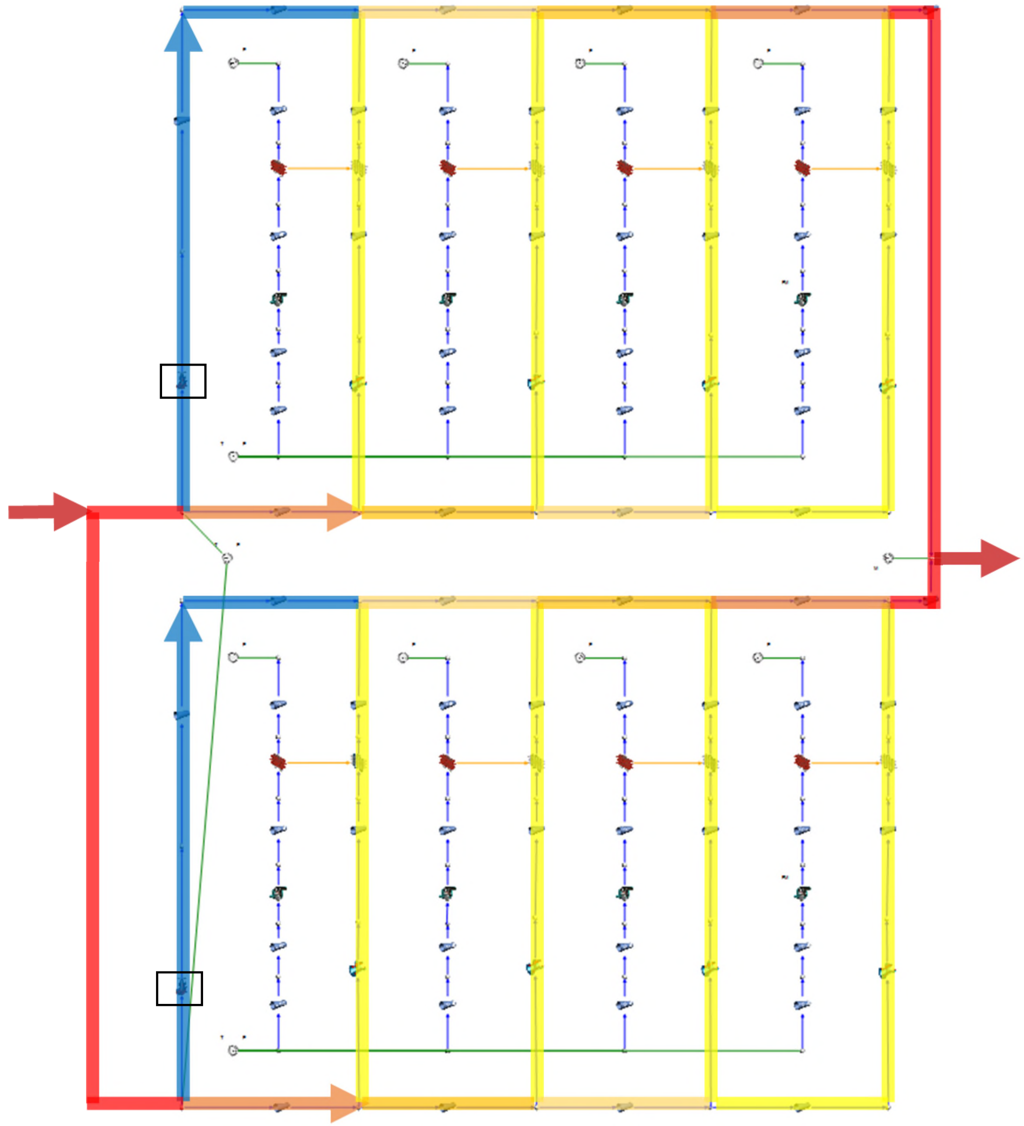
Mitigate two-phase Flow

Reduce fan power

Bypass flow path



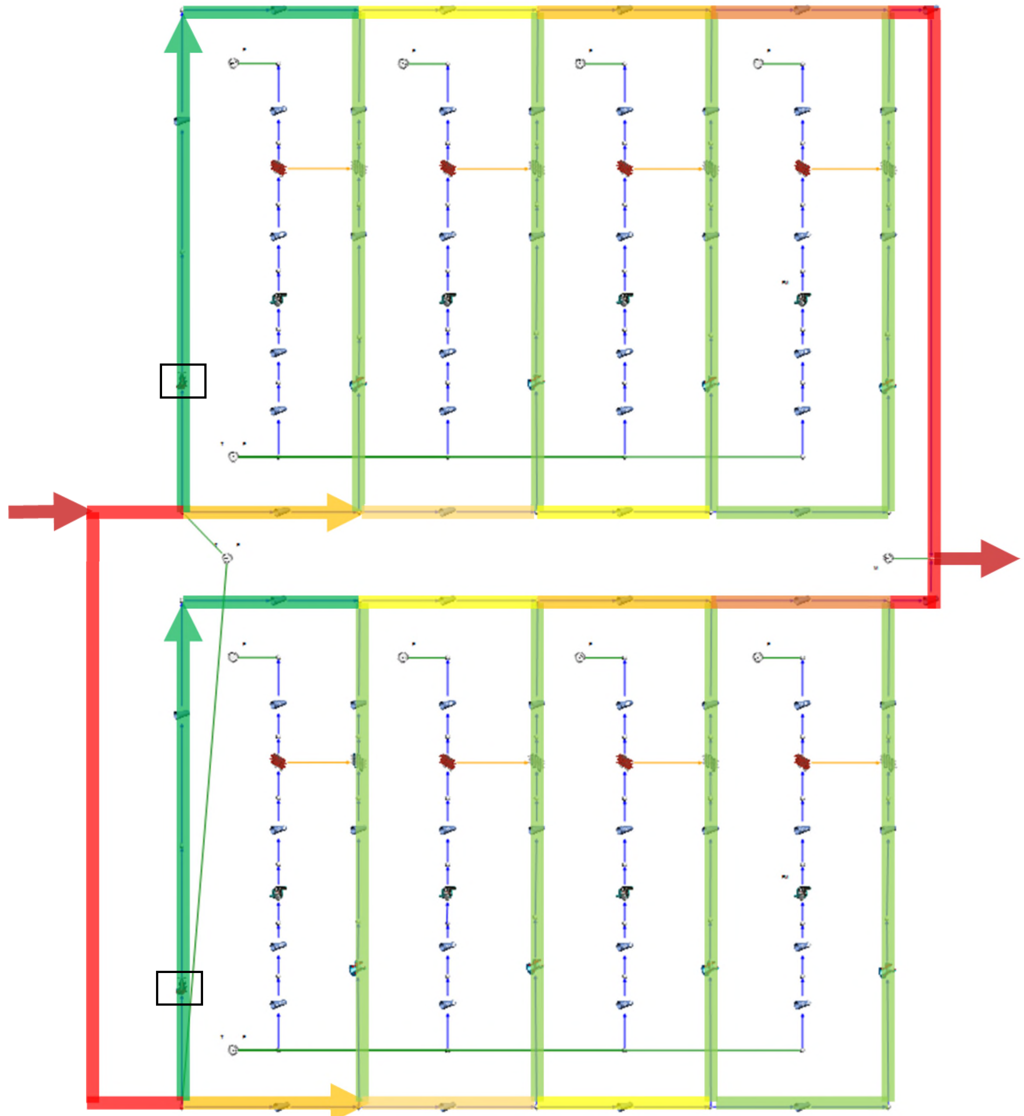
Mass flow rates (design)



$T_{cell} < 45°C$
$T_{bypass} \gg 45°C$
$T_{out} = 45°C$

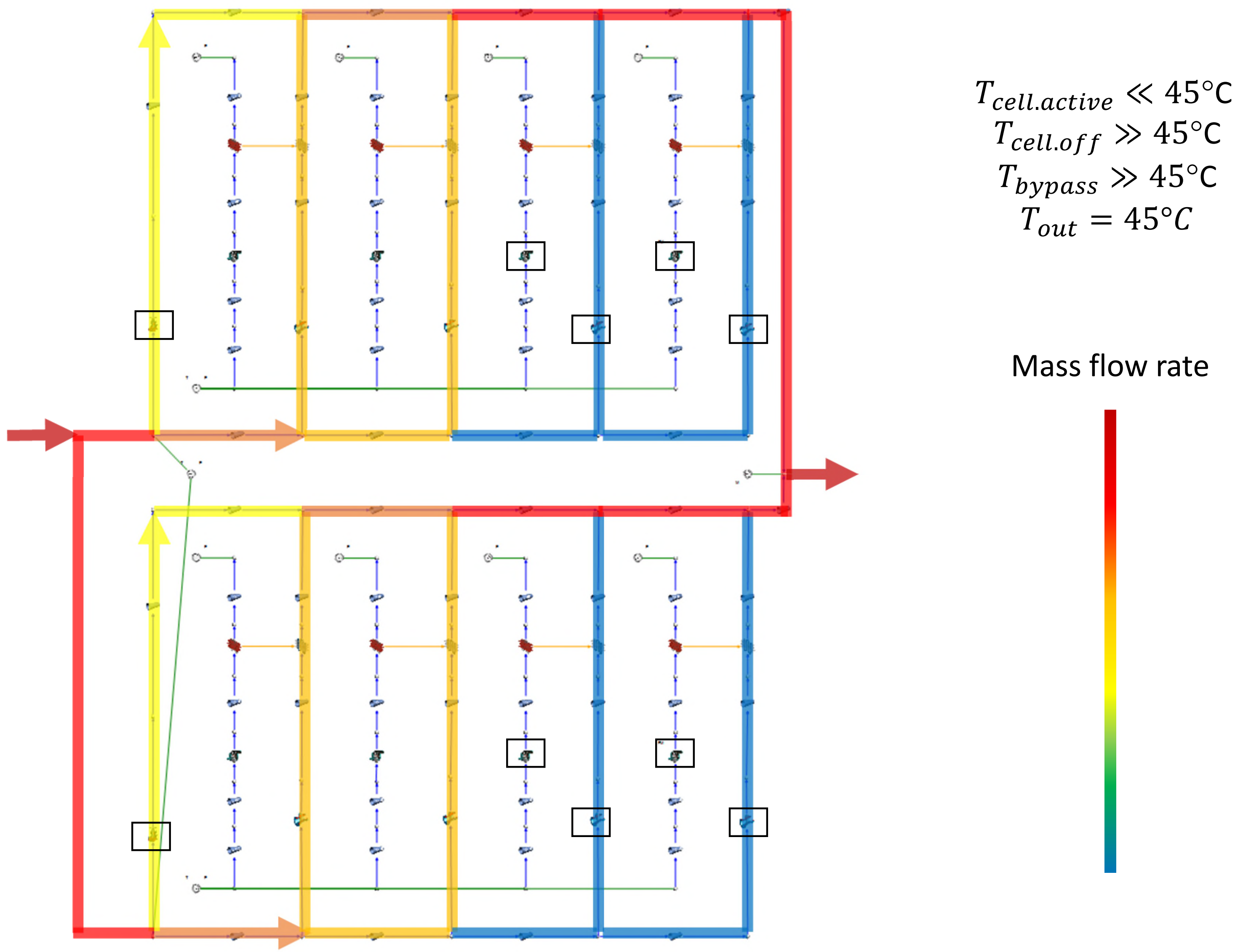
Mass flow rate

Mass flow rates (reduced duty)

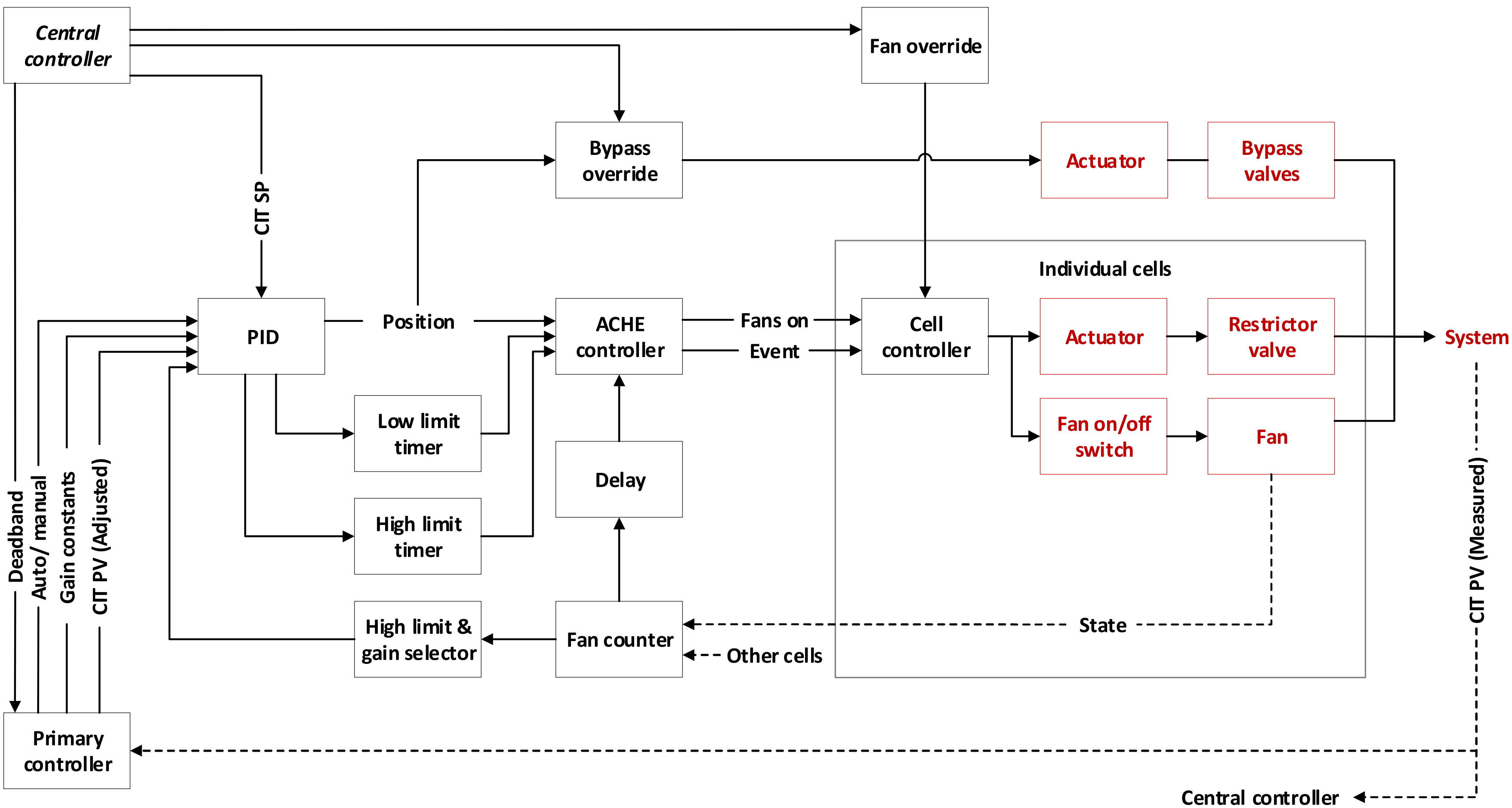


$T_{cell} \ll 45°C$
$T_{bypass} \gg 45°C$
$T_{out} = 45°C$

Mass flow rates (low duty)



Control system



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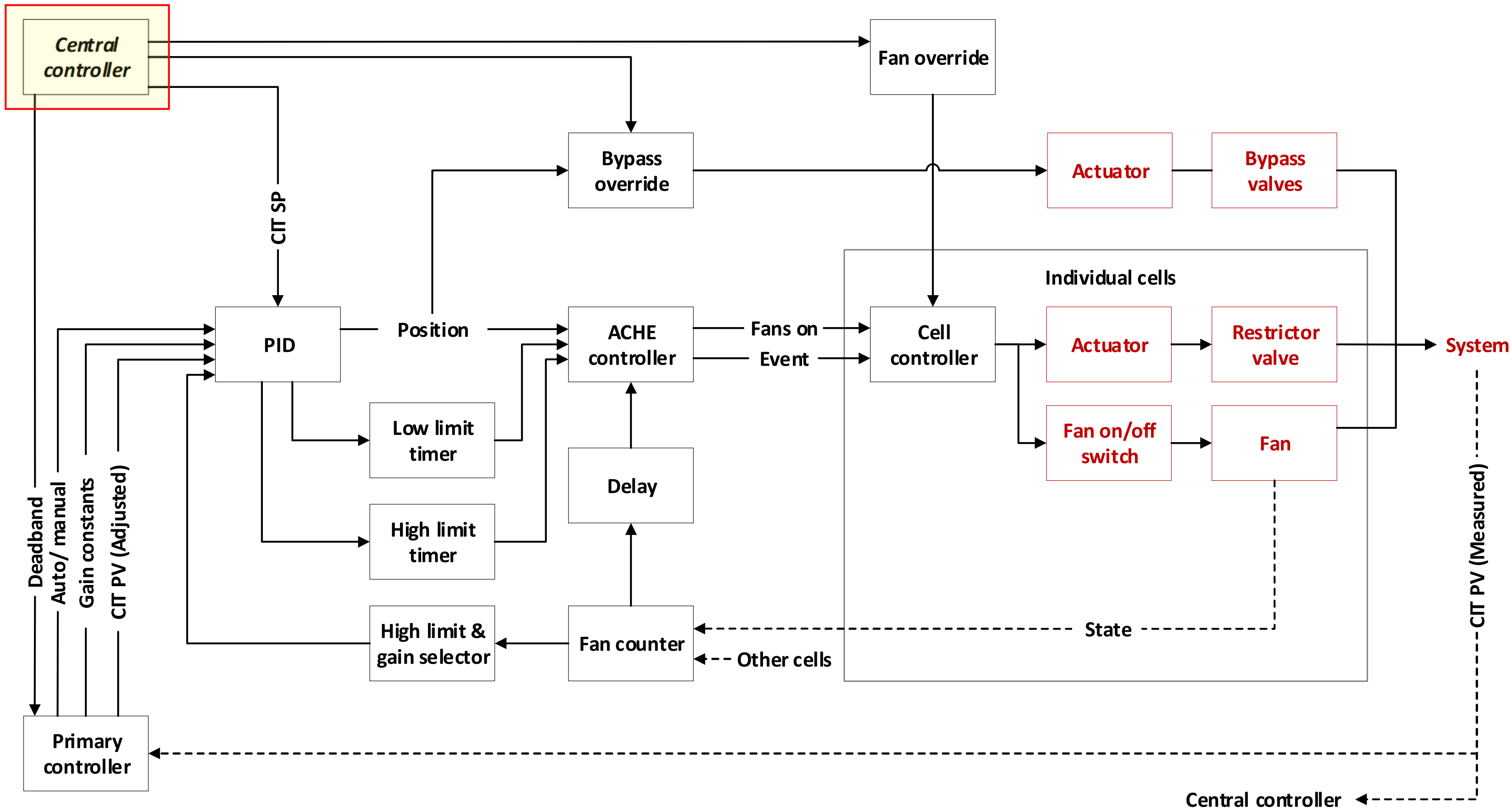

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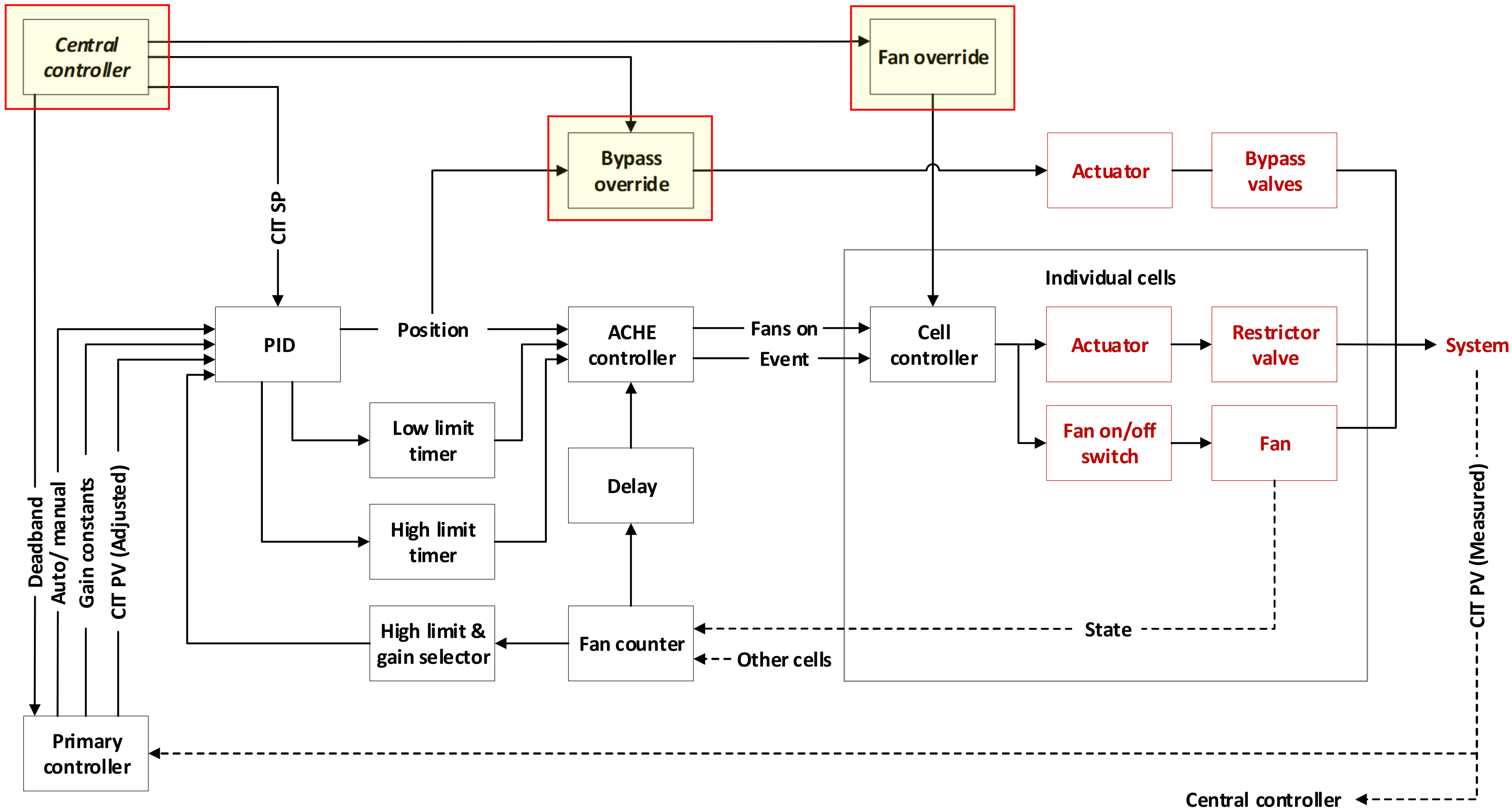

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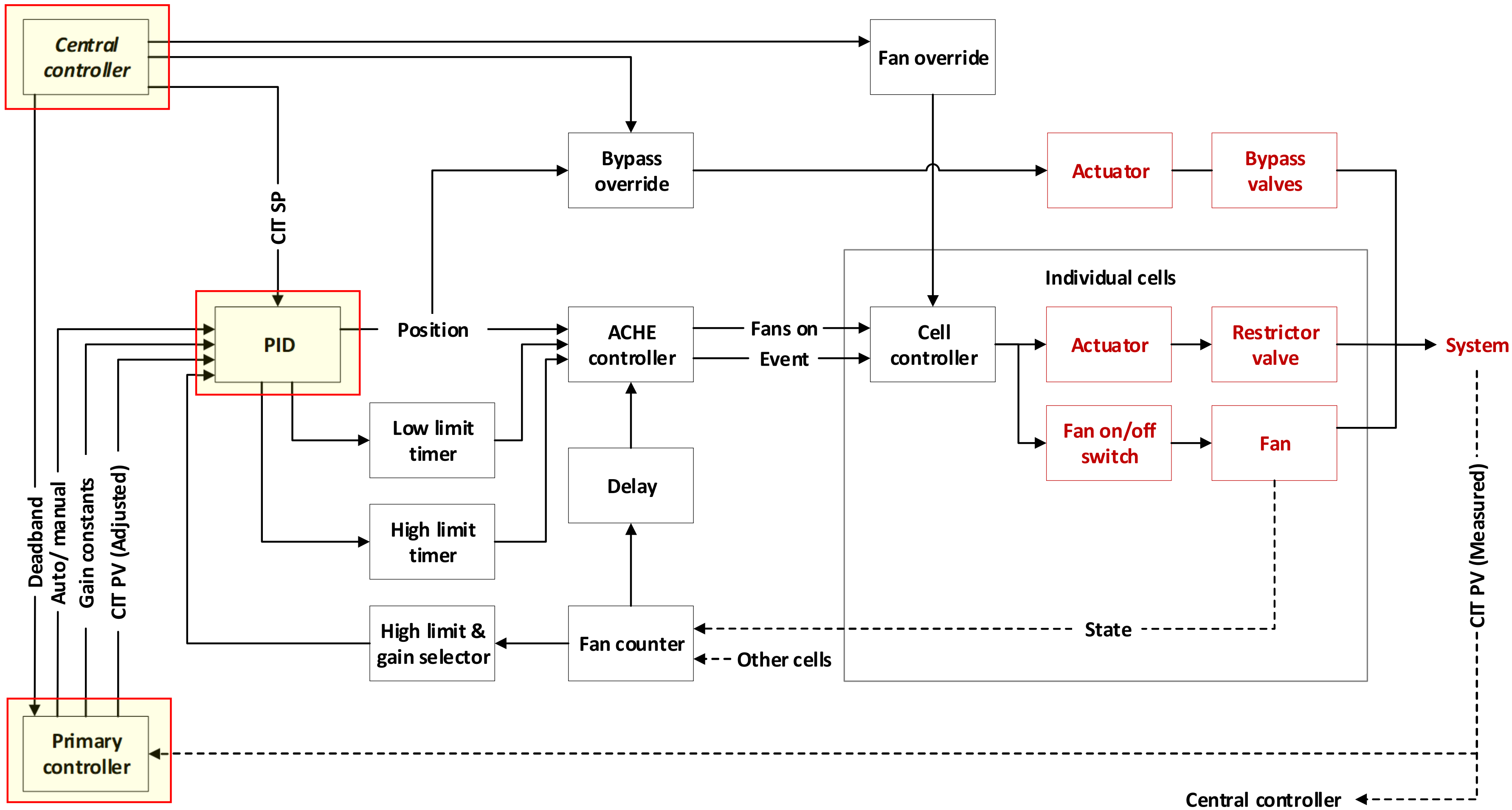

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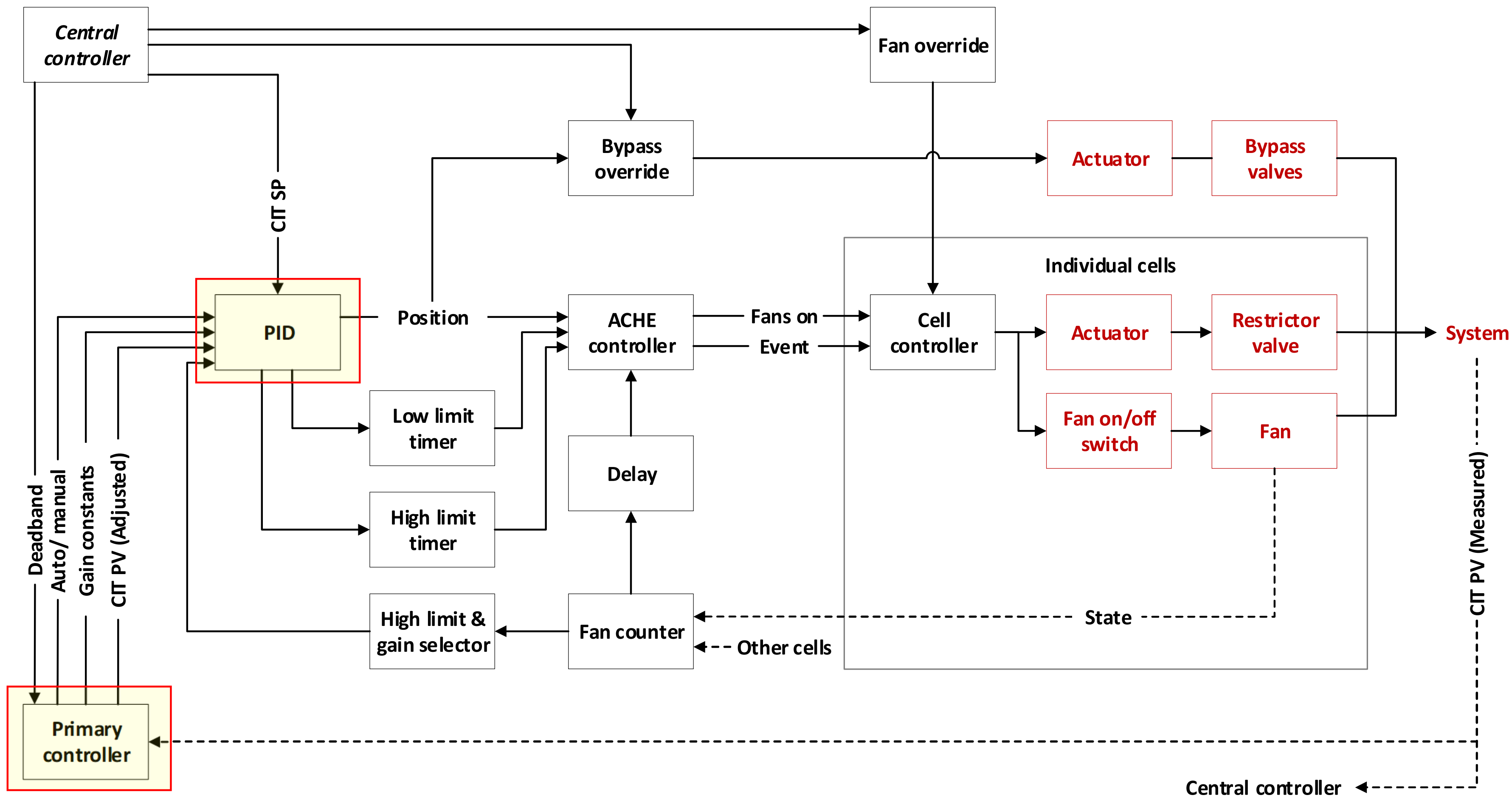

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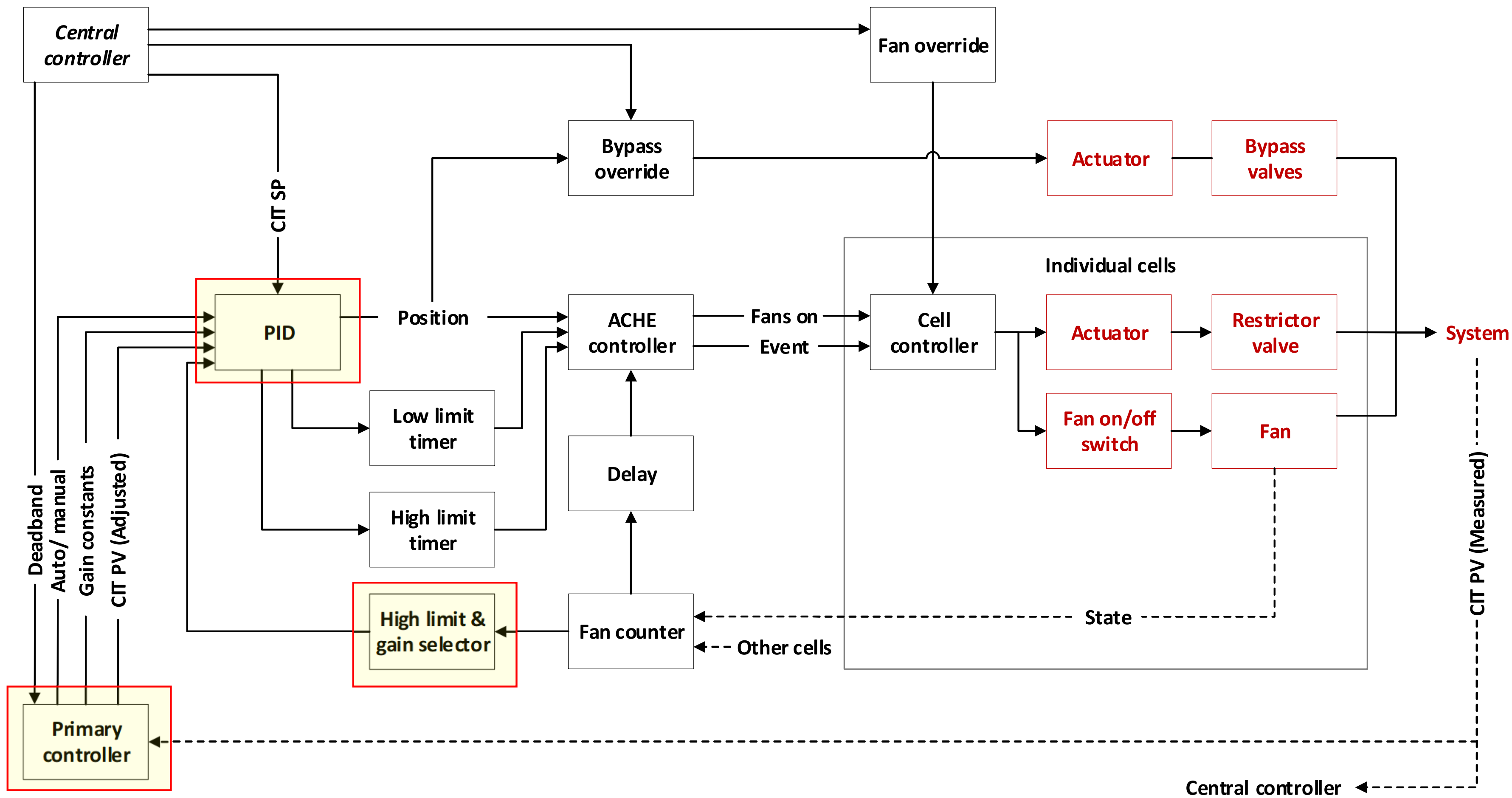

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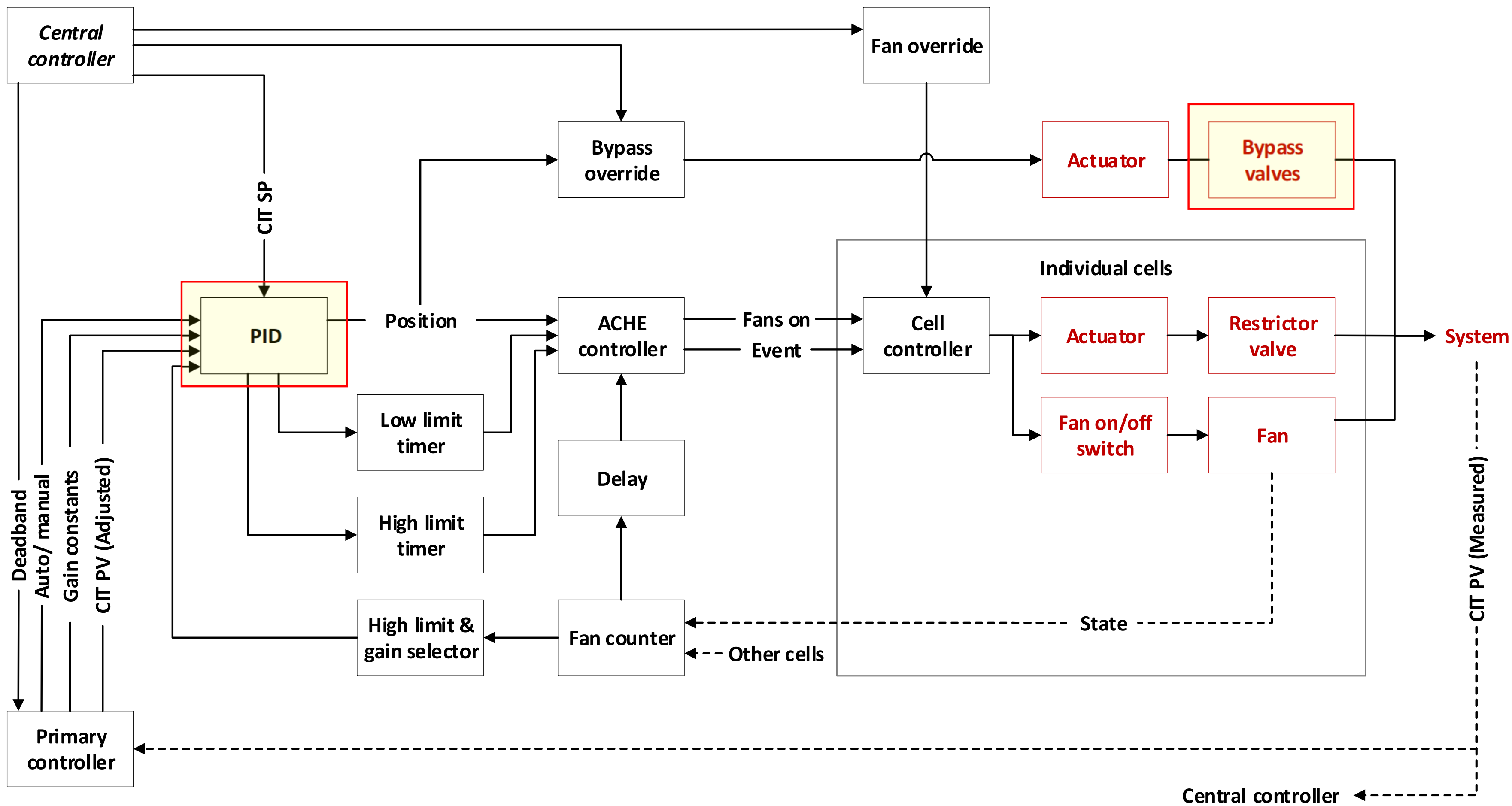

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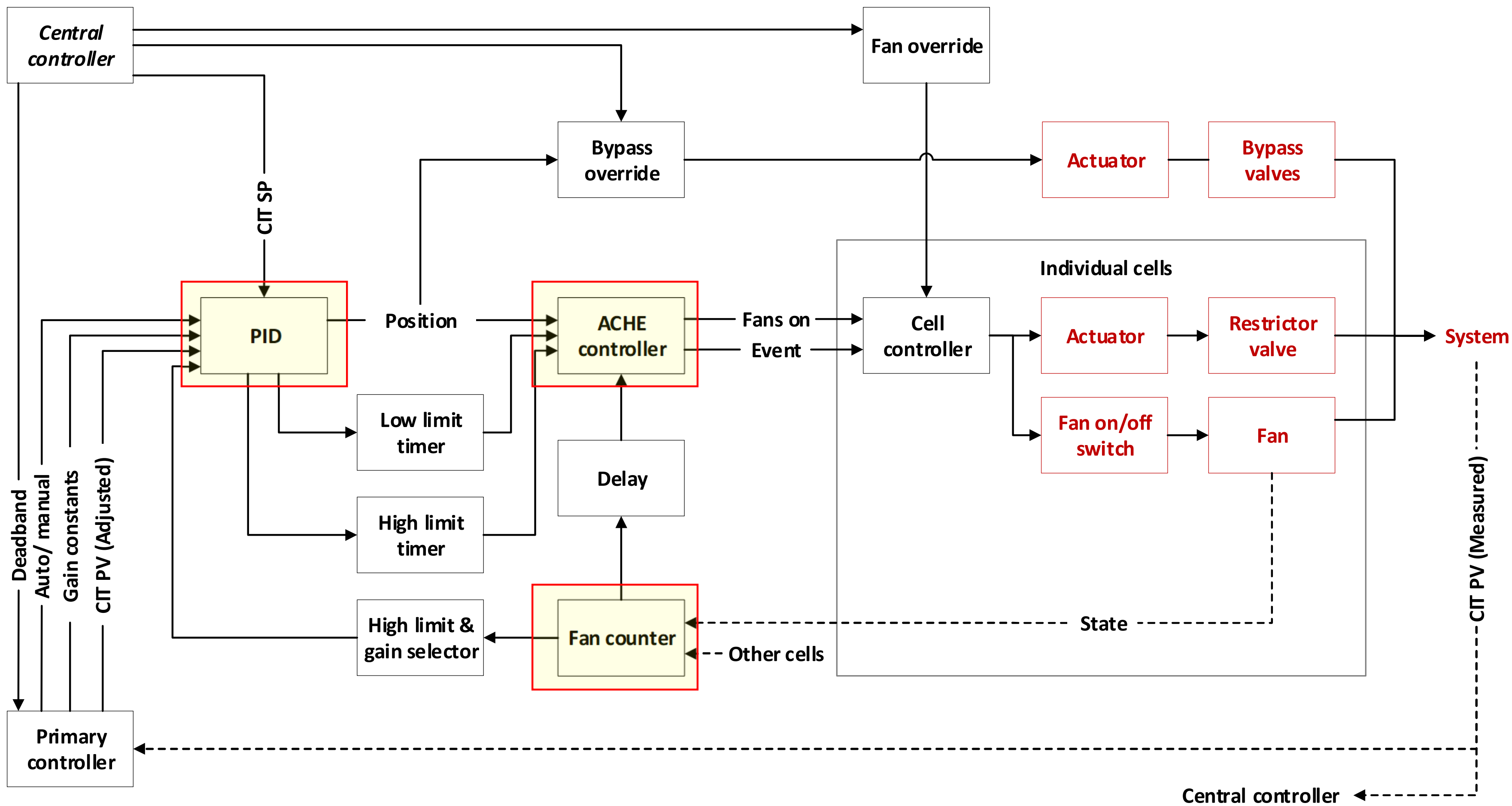
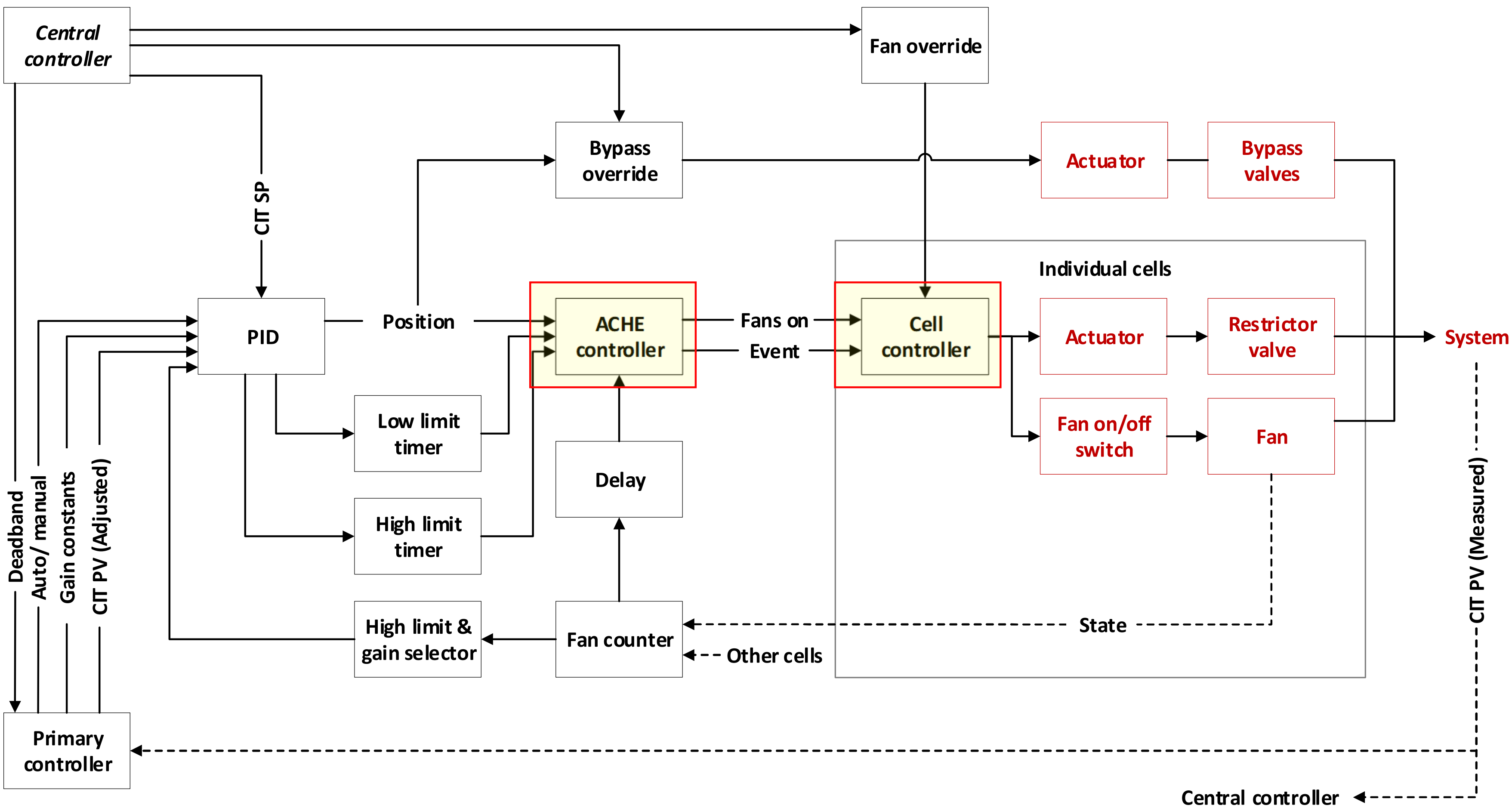


Control system



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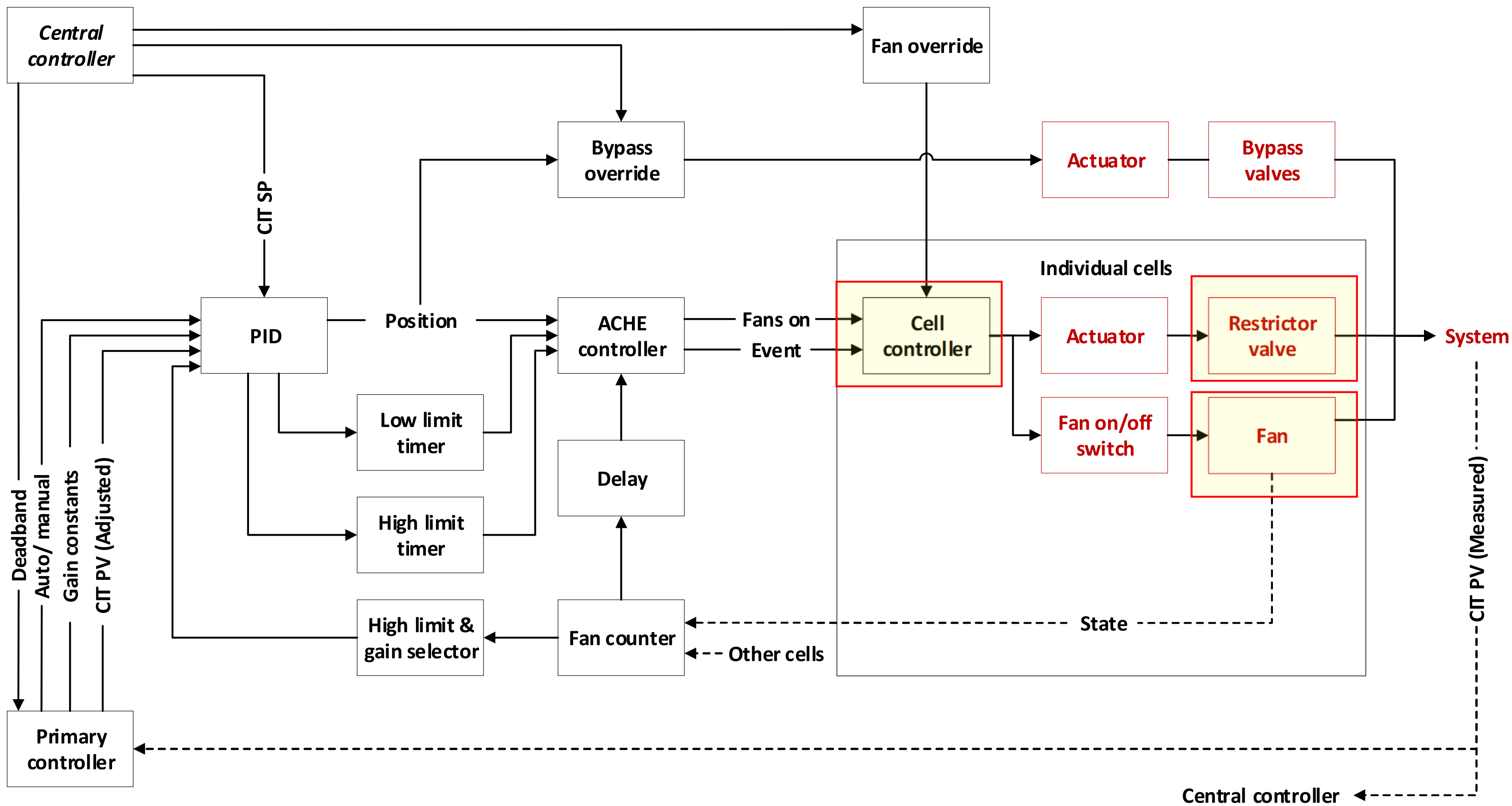
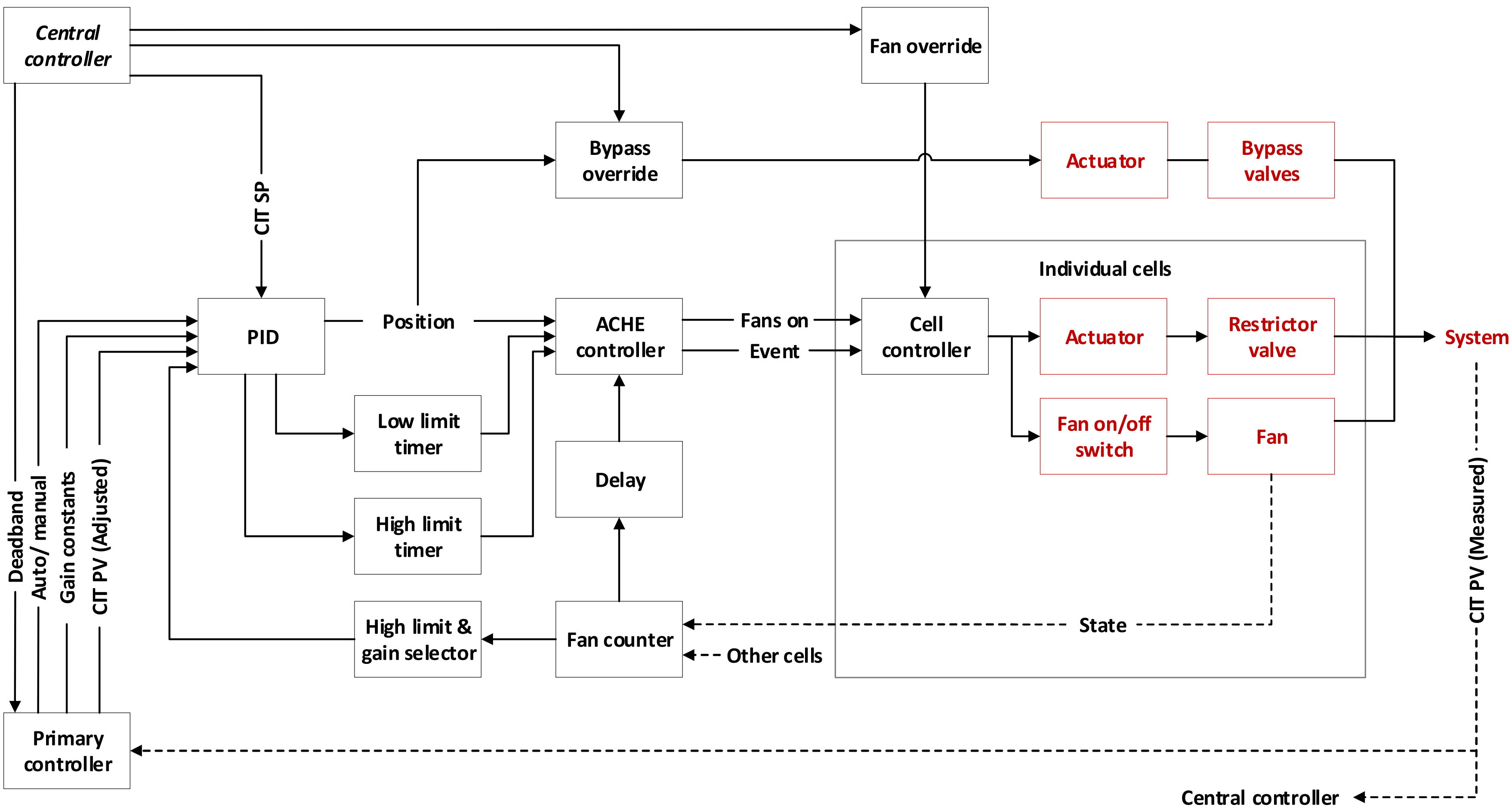
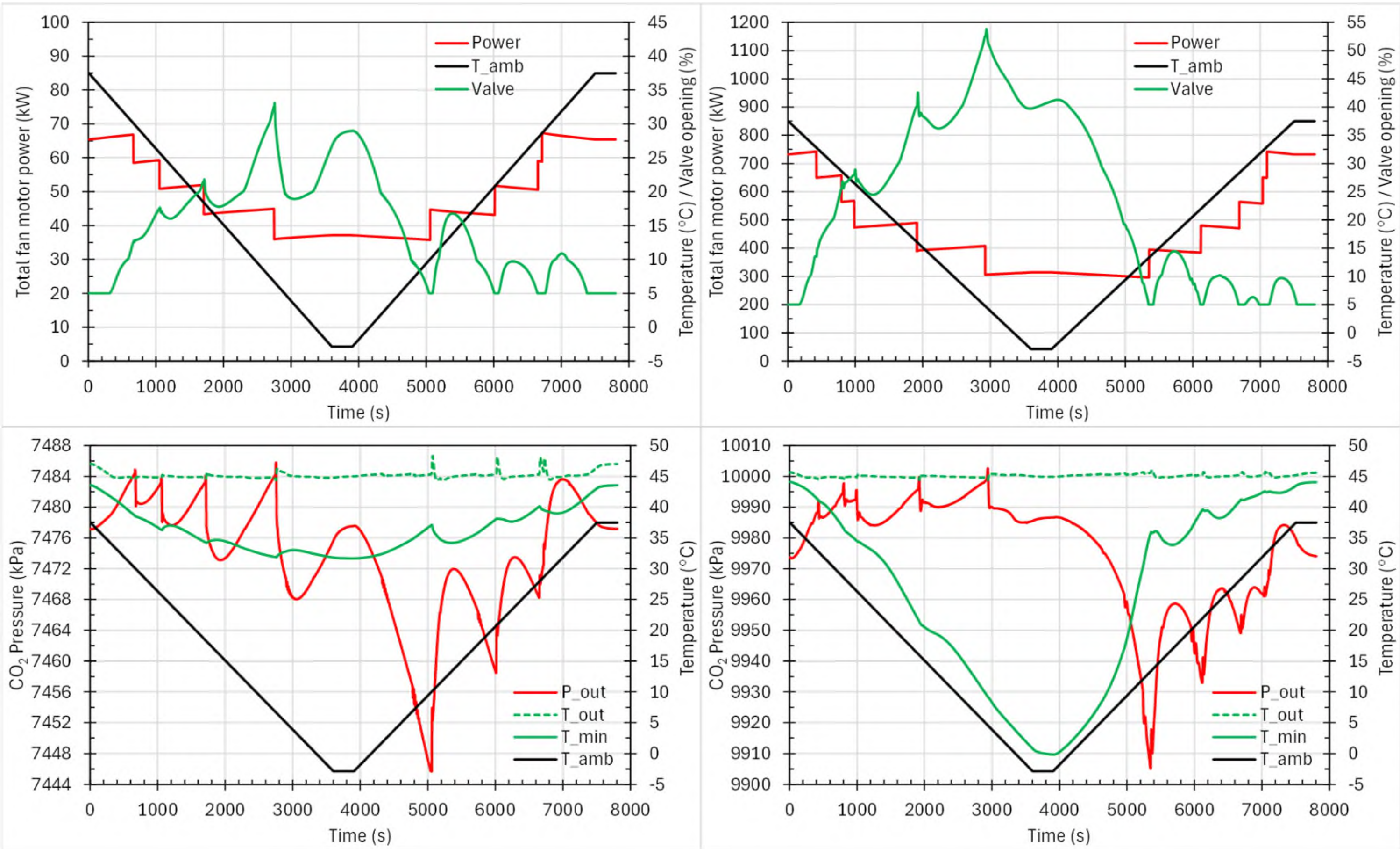


Control system



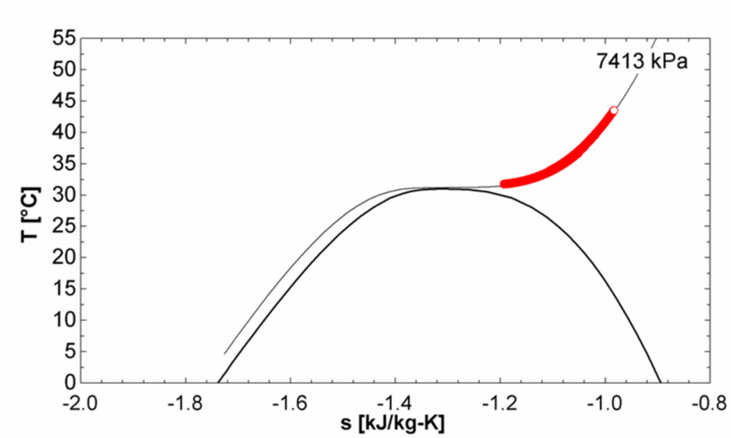
Stress test results

Precooler | Intercooler

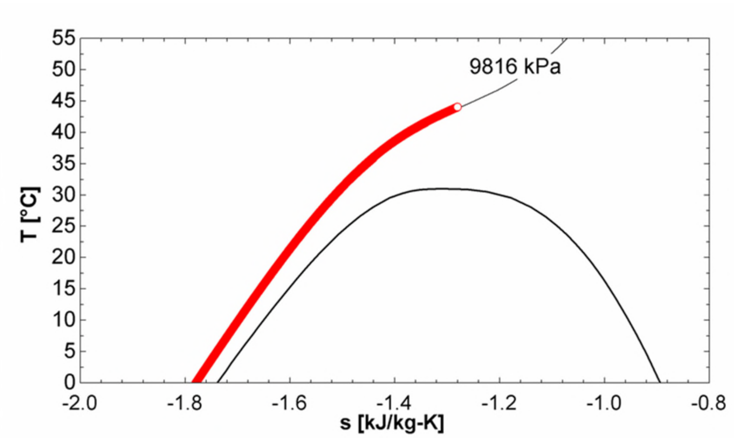


T-s diagrams

Precooler



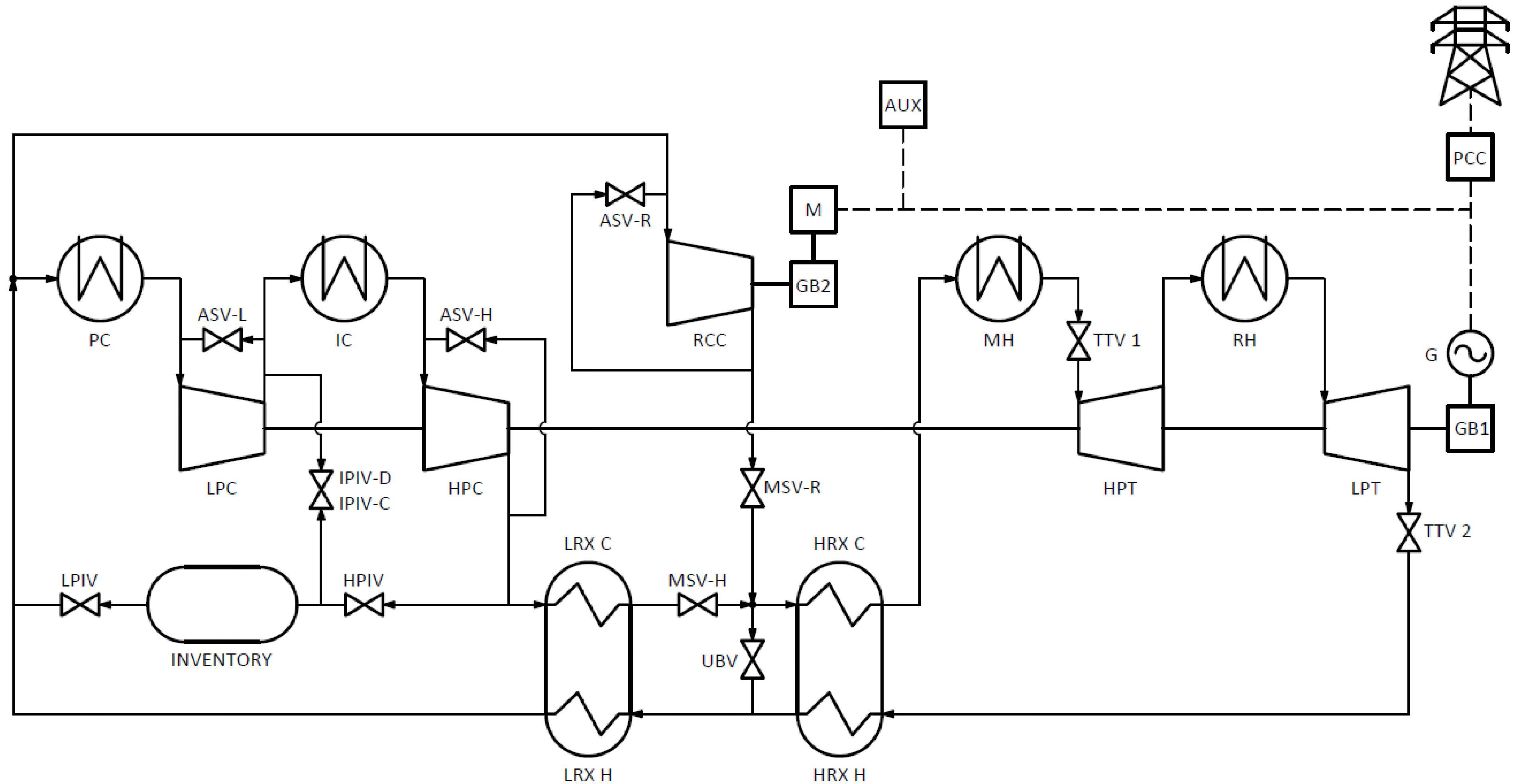
Intercooler



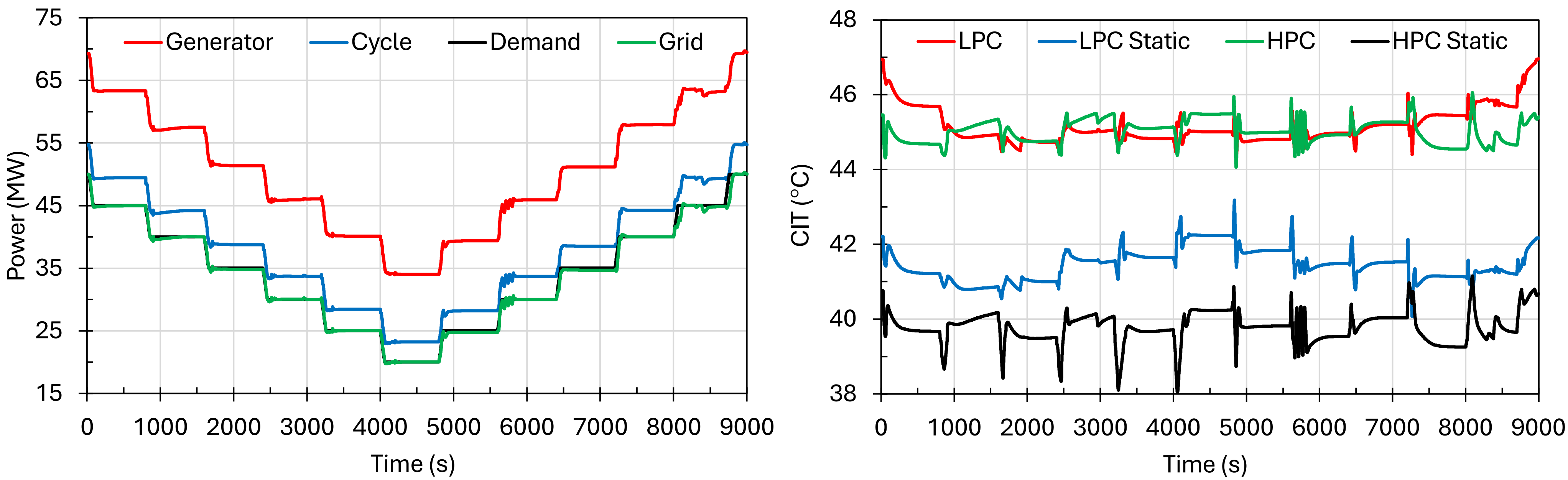
Two-phase flow mitigation

	$T_{ambient}$	CIT Target	Valve Pos.	Fans Off	$T_{0.IC.out}$	$P_{0.IC.out}$	$T_{IC.min}$	P_{IC} at $T_{IC.min}$	$T_{HPC.in}$
Mode	**°C**	**°C**	**% Open**	**-**	**°C**	**kPa**	**°C**	**kPa**	**°C**
Control	-2.9	45	51	5	44.9	9984	0.1	9868	41.2
Tier 1	-2.9	45	25	5	43.3	9964	9.8	9837	40.4
Tier 1	-2.9	45	10	5	42.1	9908	26.9	9777	39.6
Tier 1/2	-2.9	45	5	5	41.5	9858	33.7	9727	39.1
Tier 2	-2.9	45	5	6	45.5	9678	40.2	9586	40.2

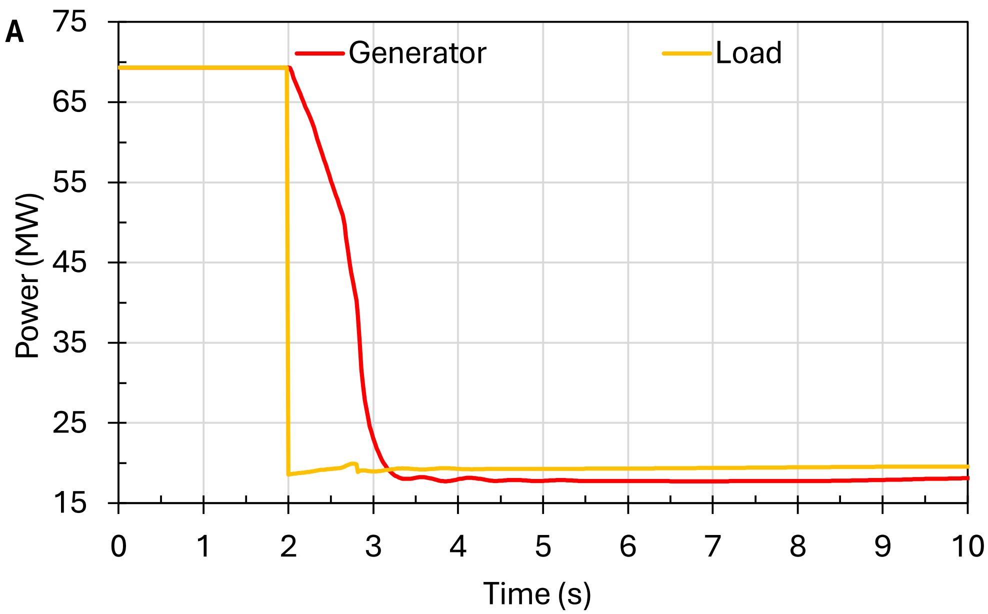
Additional results

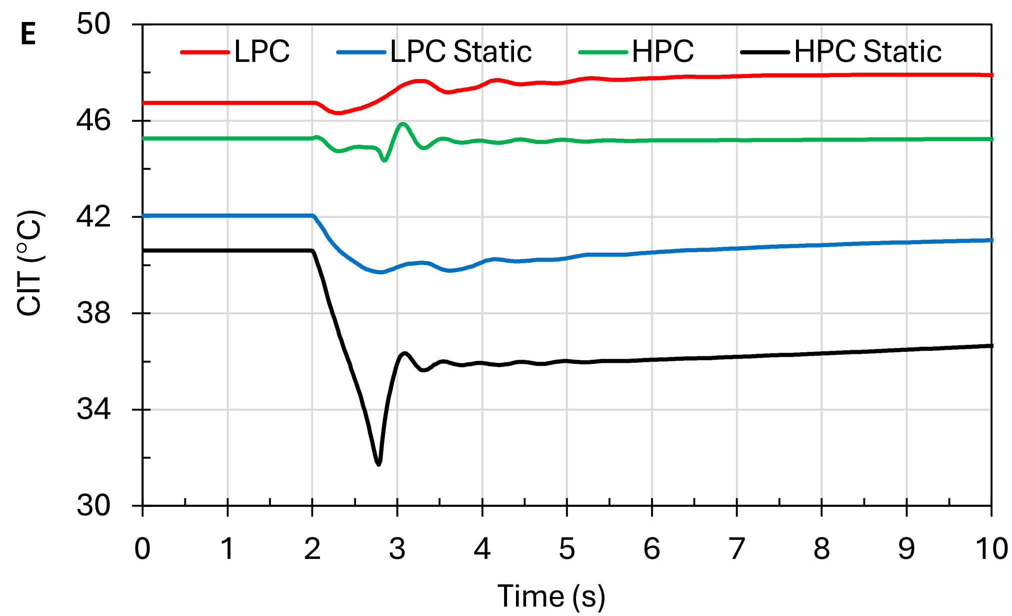


Additional results



Additional results



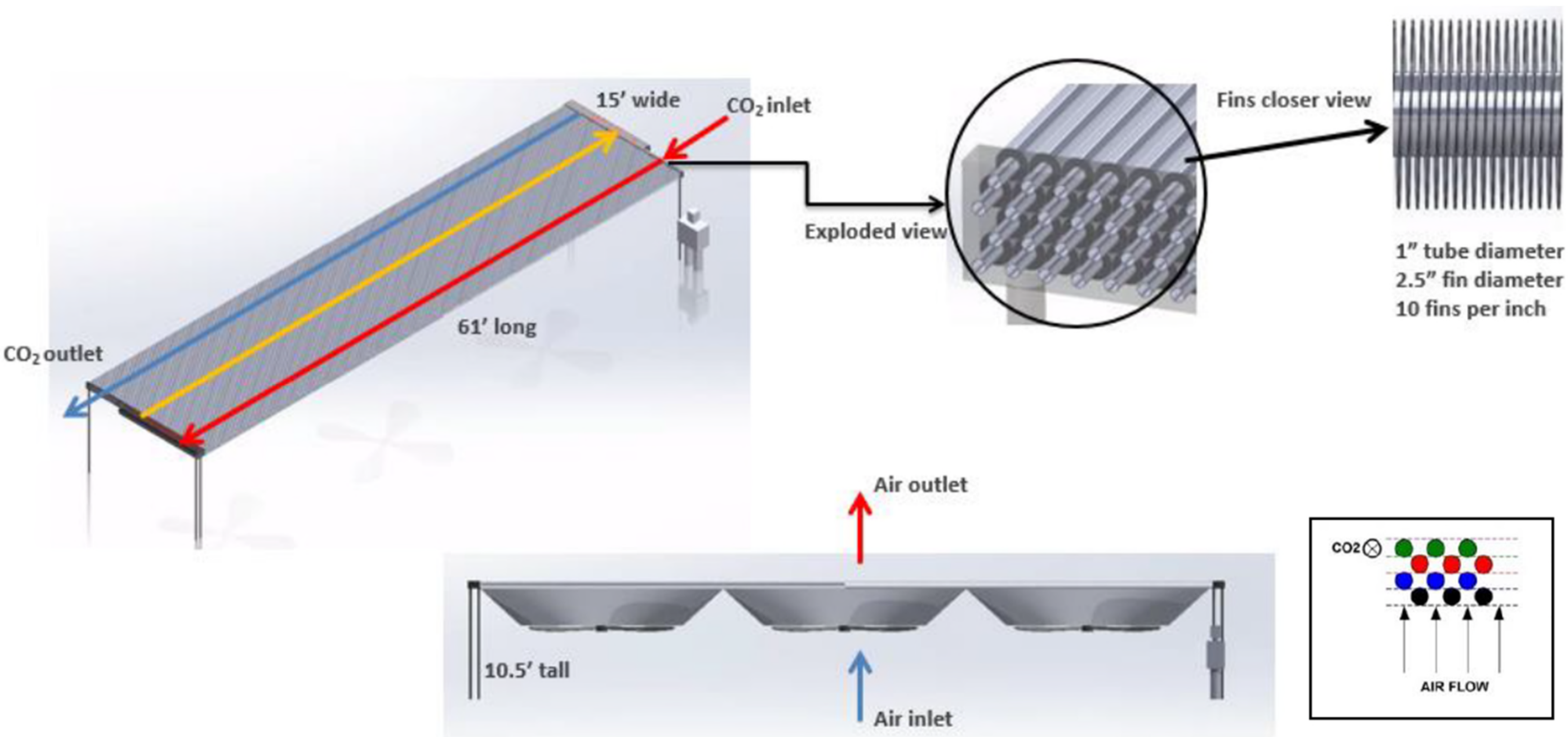


Summary and conclusions

- A dynamic model for multi-cell cooling systems that includes all the major components of forced draft ACHEs was developed.
- A bypass and fan on-off control system for such a cooling system was developed.
- The control system ensures a constant bulk outlet temperature (CIT) & prevents local two-phase flow within the funned-tube bundles.
- The results of dynamic simulations performed demonstrates the efficacy of the system.
- A classic PI controller can effectively be used to control such a cooling system.

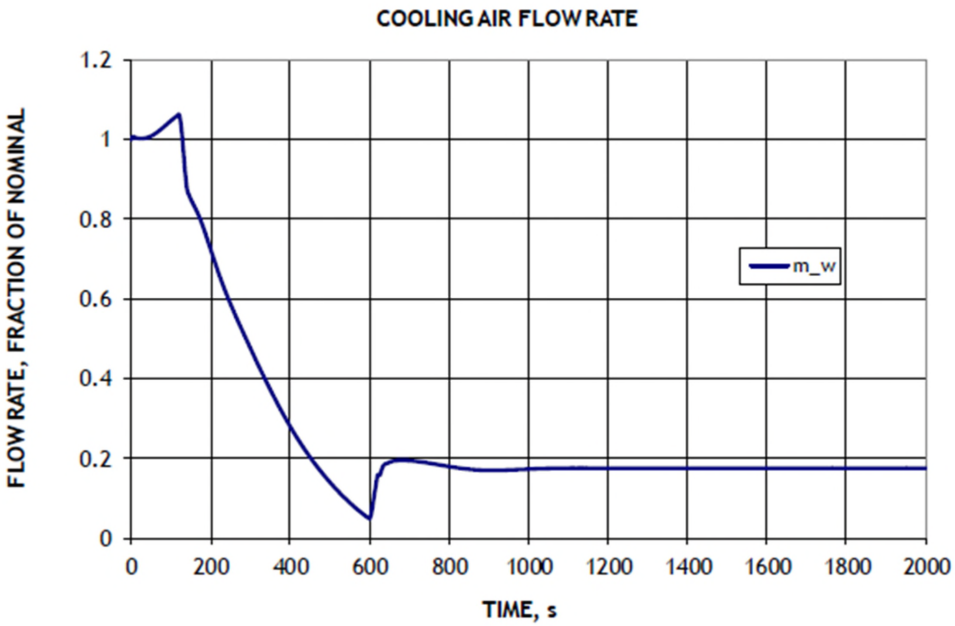
Q&A

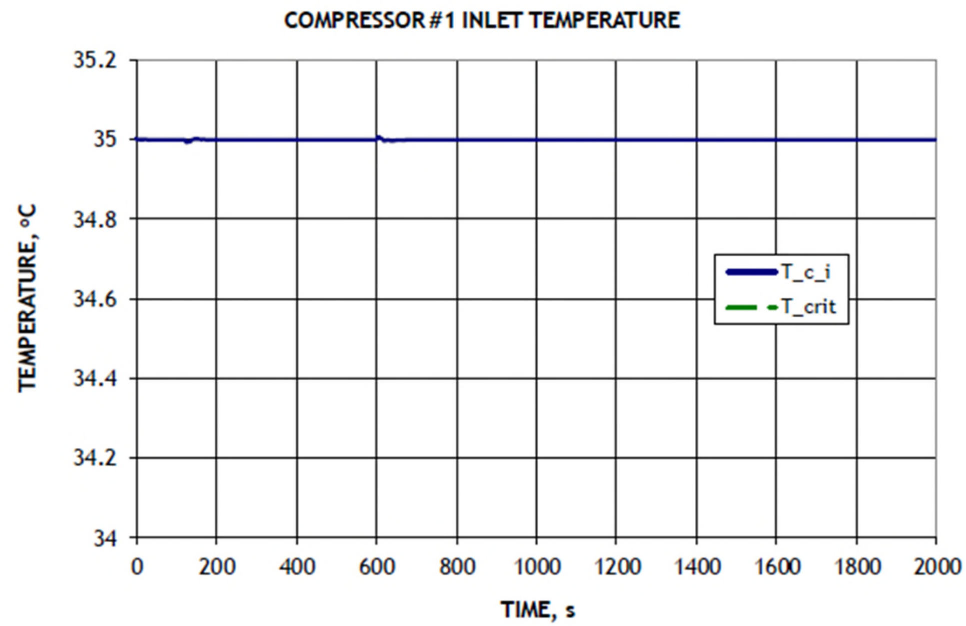
Literature review



Moisseytsev, Lv & Sienicki (2016)

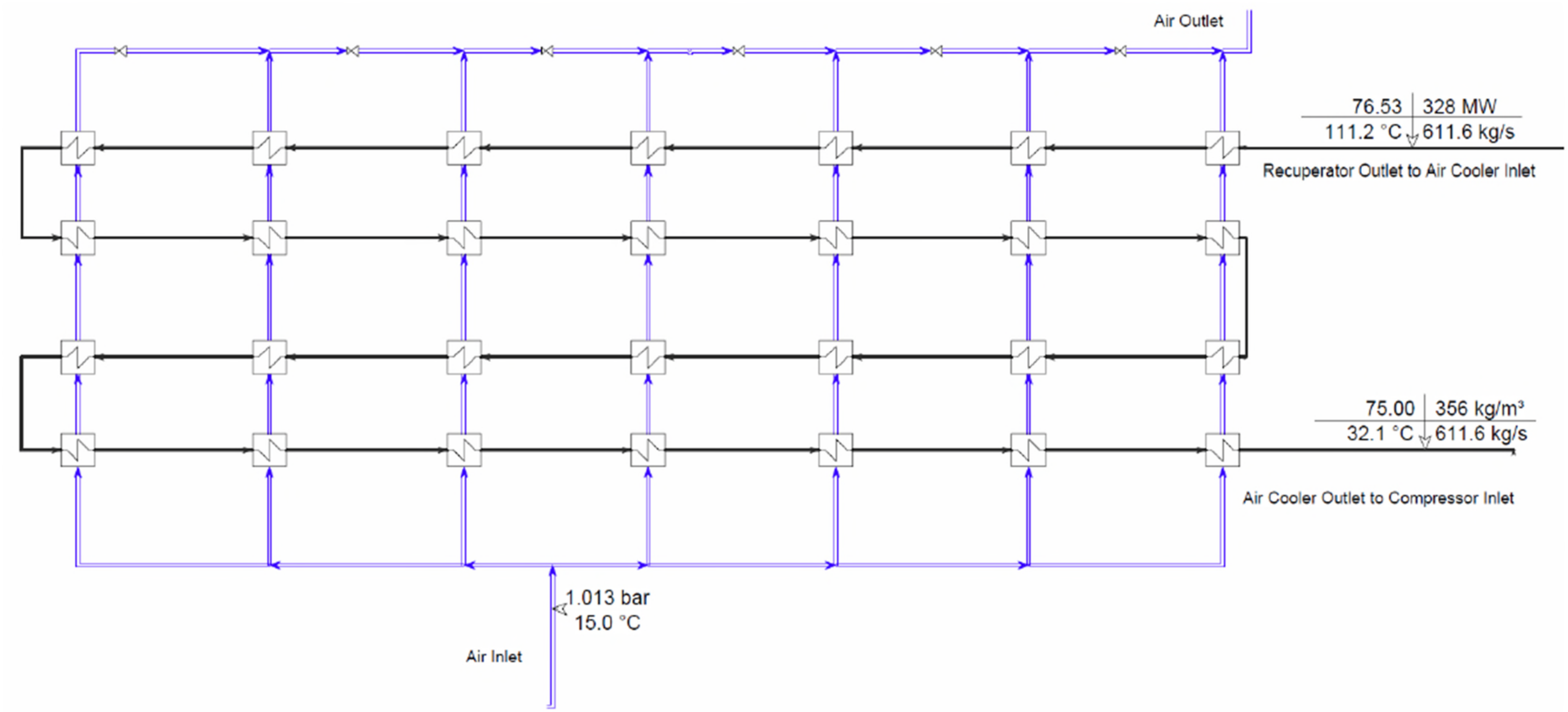
Literature review





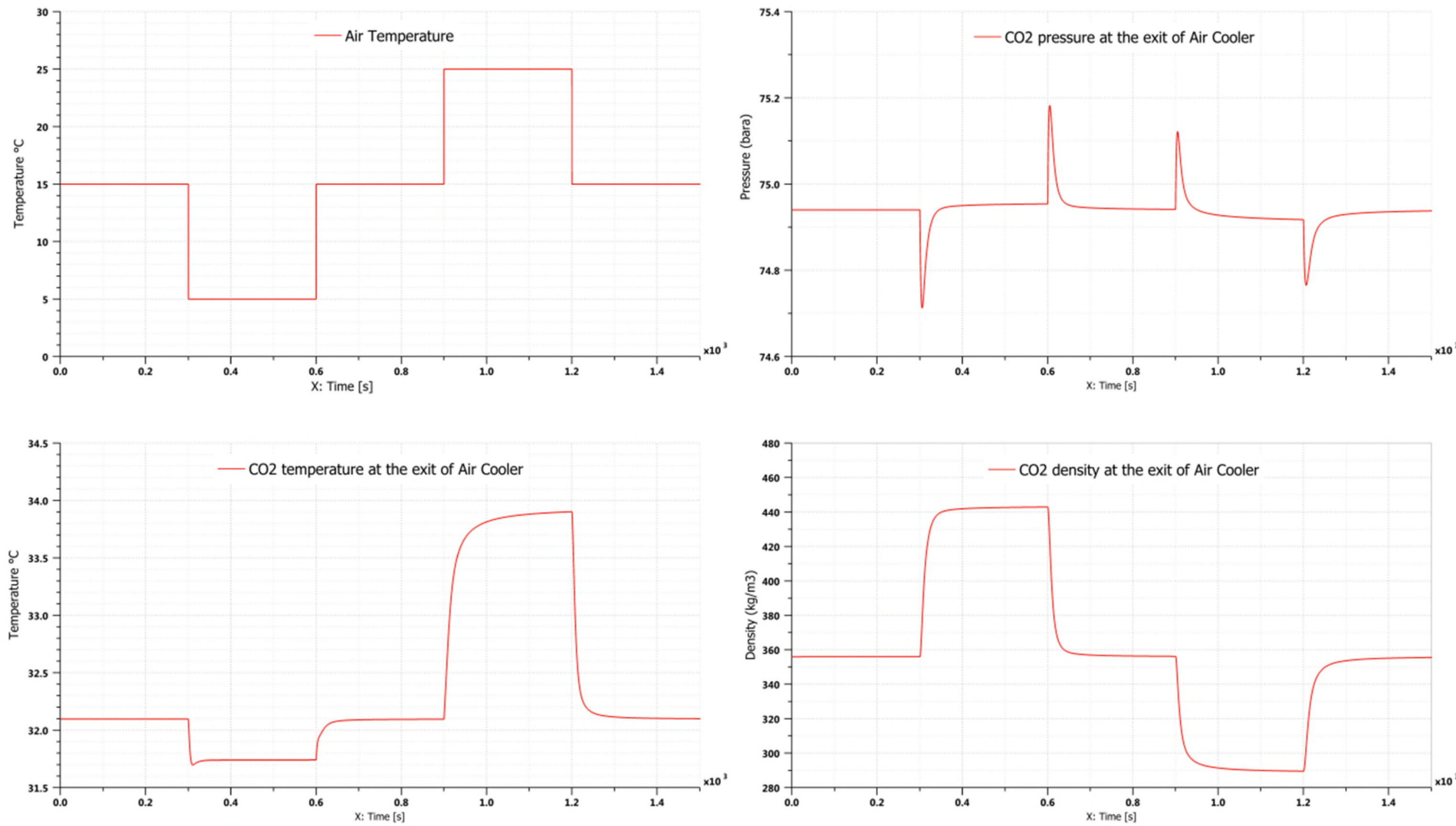
Moisseytsev & Sienicki (2018)

Literature review



Deshmukh, Kapat & Khadse (2019)

Literature review



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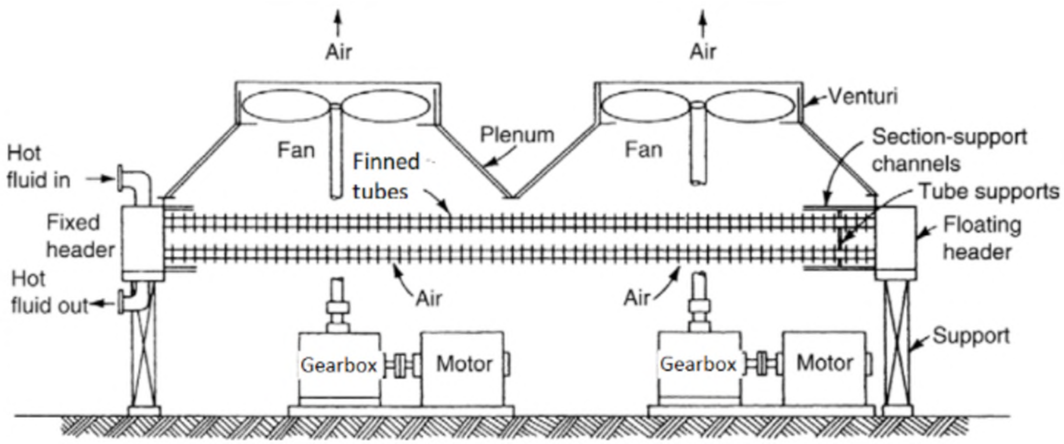
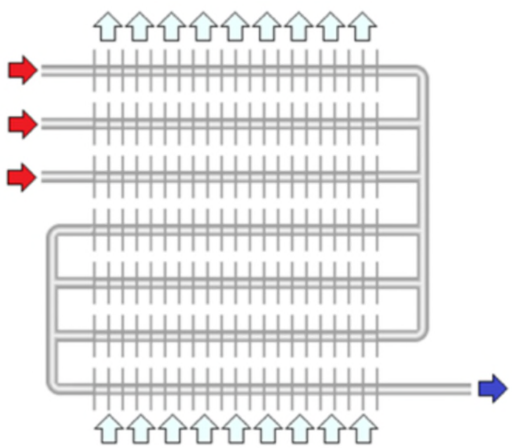
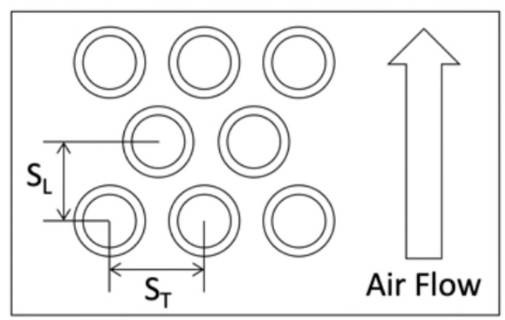
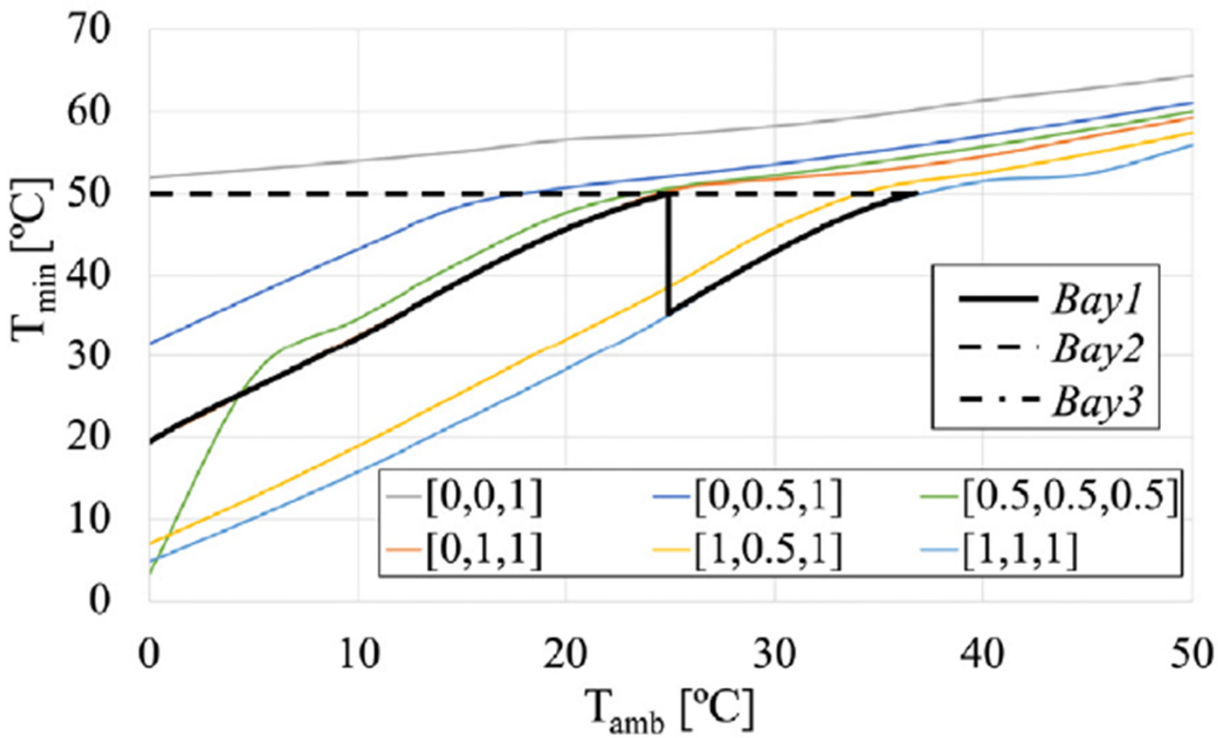






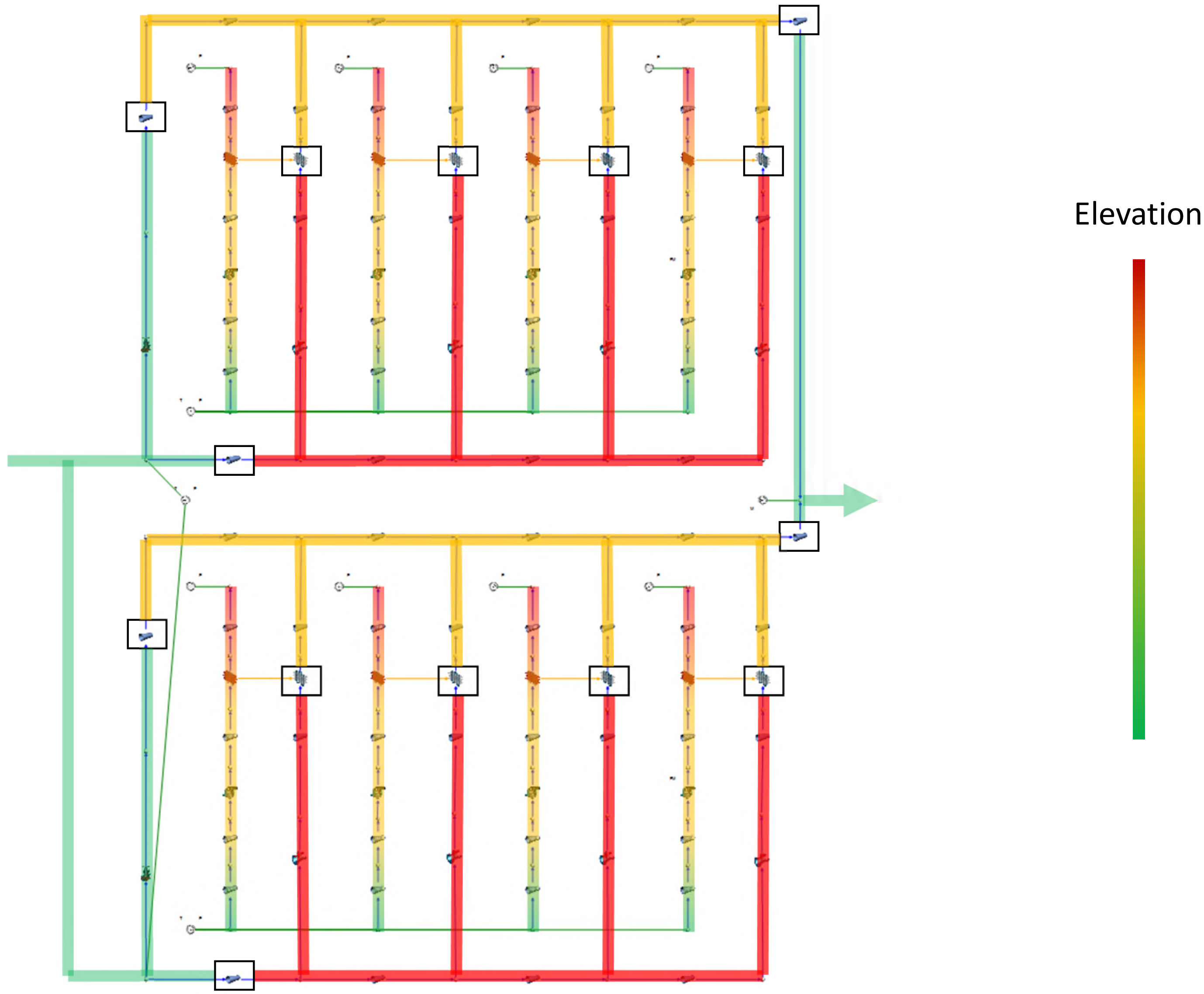
Rodríguez-De Arriba et al. (2023)

Literature review



Crespi et al. (2025)

Elevations



Related work

- Steady state cycle study:
  - du Sart, C.F., Rousseau, P. & Laubscher, R. 2024. Comparing the partial cooling and recompression cycles for a 50 MWe sCO2 CSP plant using detailed recuperator models. Renewable Energy 222. DOI: 10.1016/j.renene.2024.119980.
- Solar field and receiver studies:
  - Heydenrych, J.M., Rousseau, P.G. & du Sart, C.F. 2022. Reduced-order modelling of central solar tower receivers using an equivalent thermal resistance network. In Proceedings of the 16th international conference on heat transfer, fluid mechanics and thermodynamics (HEFAT-16). Virtual: HEFAT. 911–916. Available: https://www.researchgate.net/publication/363173202.
  - Heydenrych, J.M., Rousseau, P.G. & du Sart, C.F. 2023. A reduced order modelling methodology for concentrated solar power external cylindrical receivers. In Proceedings of the 17th international heat transfer conference (IHTC-17). Cape Town: Begell House. Available: https://ihtcdigitallibrary.com/conferences/ihtc17,7188217e24389634,15e3d1eb26dcb54a.html.
- Heat rejection system studies:
  - Abrahams, L., du Sart, C. & Laubscher, R. 2022. Design of an air-cooled heat rejection system for a SCO2 concentrated solar power plant. In 16th international conference on heat transfer, fluid mechanics and thermodynamics (HEFAT-16). Virtual: HEFAT. 288–293.
  - du Sart, C. & Rousseau, P. 2025. Thermofluid design and off design performance of an air-cooled heat exchanger system for a 50 MWe sCO2 CSP Plant. In The 6th European sCO2 Conference for Energy Systems. Delft. DOI: 10.17185/duepublico/83292.

Related work

- Turbomachinery studies:
  - du Sart, C.F., Rousseau, P. & Laubscher, R. 2024. A method to develop centrifugal compressor performance maps for off-design and dynamic simulation studies of sCO2 cycles. In Proceedings of the 8th International Supercritical CO2 Power Cycles Symposium.
  - du Sart, C., Rousseau, P. & Laubscher, R. 2024. A method to develop radial inflow turbine performance maps for off-design and dynamic simulation studies of sCO2 cycles. In Proceedings of ASME Turbo Expo 2024. ASME. DOI: https://doi.org/10.1115/GT2024-127958.
  - Laubscher, R., Rousseau, P., Van Der Spuy, J., du Sart, C. & Johannes, P. 2024. Development of a 1D network-based momentum equation incorporating pseudo advection terms for real gas sCO2 centrifugal compressors which addresses the influence of the polytropic path shape. Thermal Science and Engineering Progress 55. DOI: https://doi.org/10.1016/j.tsep.2024.102921
  - Laubscher, R., Rousseau, P., Johannes, P., du Sart, C. & Van Der Spuy, J. 2025. Design analysis of high and low loaded high- and low-pressure axial-flow turbines for a single shaft 50 MWe supercritical carbon dioxide Brayton power cycle. Applied Thermal Engineering 274. DOI: 10.1016/j.applthermaleng.2025.126781
- PhD:
  - du Sart, C.F., 2025. Thermofluid design and dynamic simulation of an sCO2 power cycle for a 50 MWe concentrated solar thermal tower plant in Southern Africa. University of Cape Town, Faculty of Engineering and the Built Environment, Department of Mechanical Engineering

References

Crespi, F., Rodríguez-De Arriba, P., Sánchez, D. & García-Rodríguez, L. 2025. Principles of operational optimization of CSP plants based on carbon dioxide mixtures. *Applied Thermal Engineering*. 260:124871. DOI: 10.1016/j.applthermaleng.2024.124871.

Deshmukh, A., Kapat, J. & Khadse, A. 2019. Transient thermodynamic modeling of air cooler in supercritical CO2 Brayton cycle for solar molten salt application. Proceedings of the ASME Turbo Expo. 9(June). DOI: 10.1115/GT2019-91409.

Kays, W.M. & London, A.L. 2018. Compact heat exchangers. In Compact heat exchangers. 3rd ed. New Delhi: Scientific International.

Mehos, M., Turchi, C., Vidal, J., Wagner, M., Ma, Z., Ho, C., Kolb, W., Andraka, C., et al. 2017. Concentrating Solar Power Gen3 Demonstration Roadmap. Available: https://www.nrel.gov/docs/fy17osti/67464.pdf.

Moisseytsev, A., Lv, Q. & Sienicki, J.J. 2016. Dry Air Cooler Modeling for Supercritical Carbon Dioxide Brayton Cycle Analysis, ANL-ART-50.

Moisseytsev, A. & Sienicki, J.J. 2018a. Dynamic Control Analysis of the AFR-100 SMR SFR With a Supercritical CO2 Cycle and Dry Air Cooling Part 1: Plant Control Optimization. In *Proceedings of the 2018 26th International Conference on Nuclear Engineering (ICONE26)*. London: ASME. DOI: 10.1115/ICONE26-82292.

Rodríguez-De Arriba, P., Crespi, F., Sánchez, D. & Muñoz, A. 2023. A Methodology To Design Air-Cooled Condensers for Supercritical Power Cycles Using Carbon Dioxide and Carbon Dioxide Mixtures. In The 5th European sCO2 Conference for Energy Systems. Prague. 283–293. DOI: 10.17185/duepublico/77329.

du Sart, C. & Rousseau, P. 2025. Thermofluid design and off design performance of an air-cooled heat exchanger system for a 50 MWe sCO2 CSP Plant. In *The 6th European sCO2 Conference for Energy Systems*. Delft. DOI: 10.17185/duepublico/83292.