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Thermofluid Systems Modelling

Prof Pieter Rousseau
Prof Ryno Laubscher
Prof Johan van der Spuy
Rashid Haffejee

Mechanical and Mechatronic Engineering

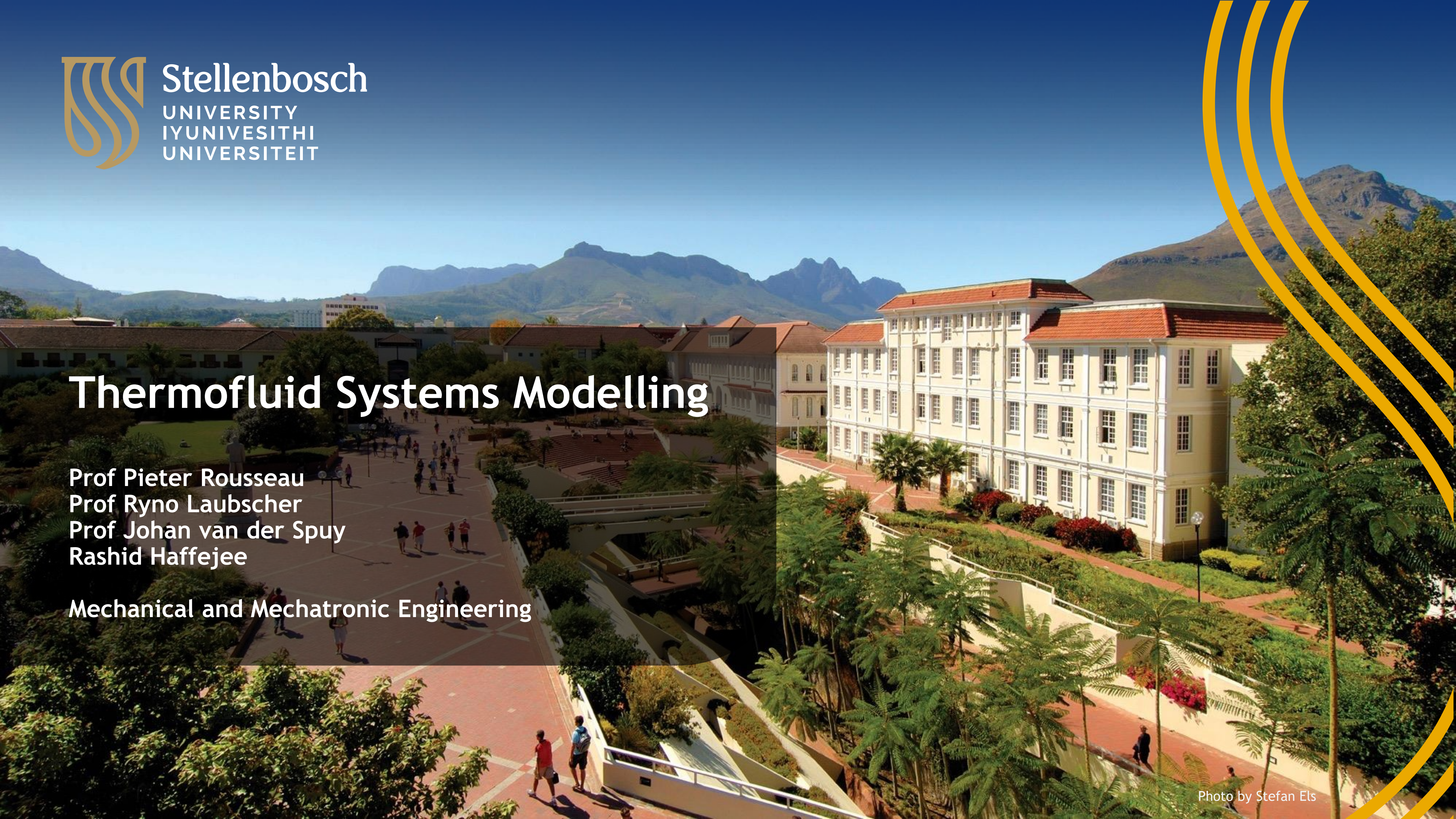
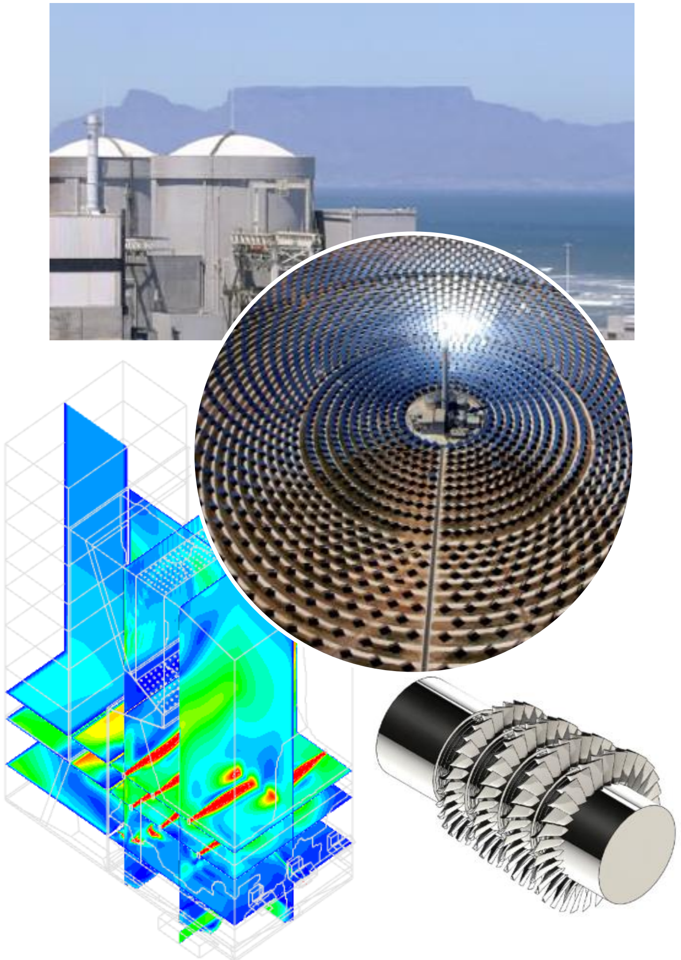


Photo by Stefan Els

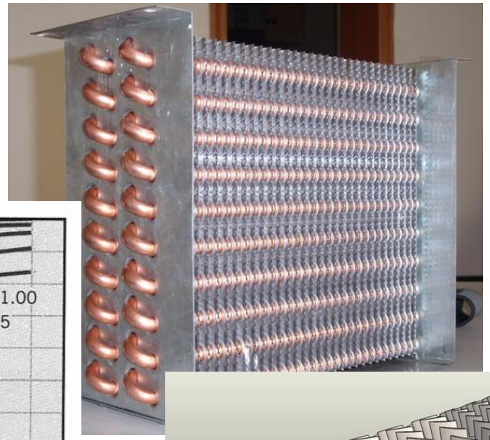
What are thermofluid systems?

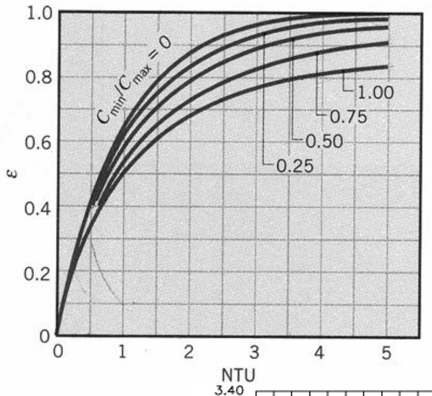
- Thermofluid systems provide the backbone of all industrial processes:
  - Power generation systems.
  - Heating and cooling systems.
  - Water and gas reticulation systems.
- Thermofluid systems include:
  - Biomass, coal, and gas-turbine power plants.
  - Concentrated solar, nuclear, and pumped storage power plants.
  - Heat pumps and refrigeration cycles.
  - Large water distribution networks.
- Components include:
  - Pipes, ducts, valves, nozzles, orifices.
  - Pumps, blowers, compressors, turbines.
  - Heat exchangers, evaporators/condensers, cooling towers.
  - Solar receivers, boilers, furnaces, reactors.

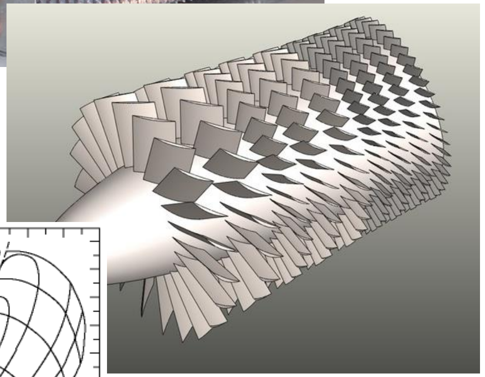


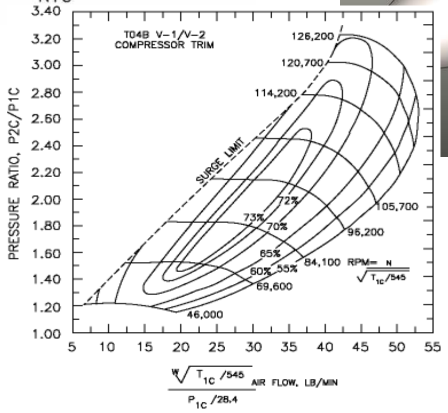
Modelling - why and how?

- Modelling is applied to:
  - Evaluate novel technologies.
  - Perform parametric and what-if analysis.
  - Optimize system designs.
  - Improve efficiency and control of processes.
  - Detect anomalies for condition monitoring.
- Processes are governed by the principles of:
  - Thermodynamics.
  - Fluid mechanics.
  - Combustion, heat transfer, work/power.









Modelling - why and how?

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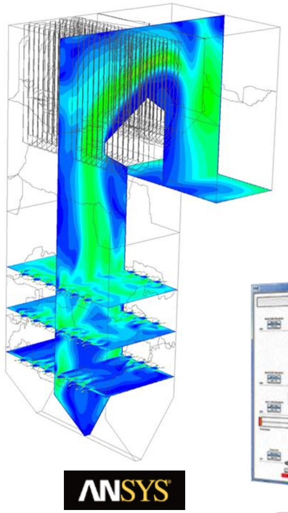
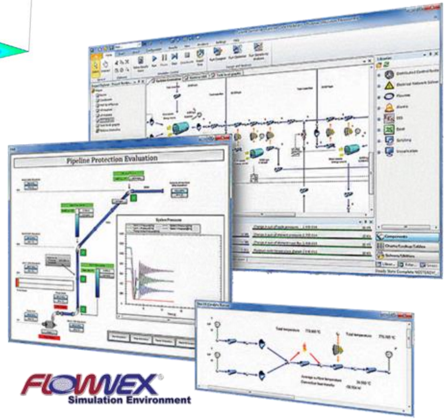
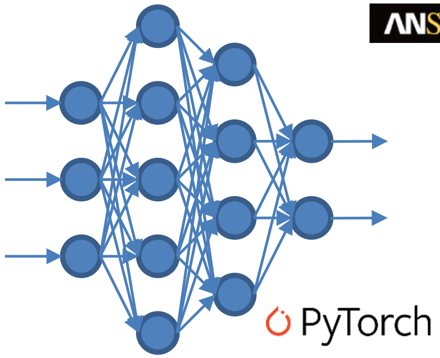
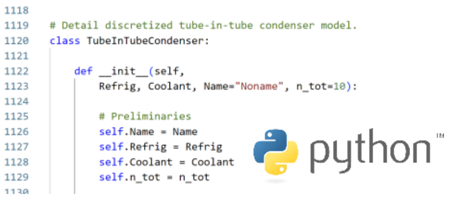
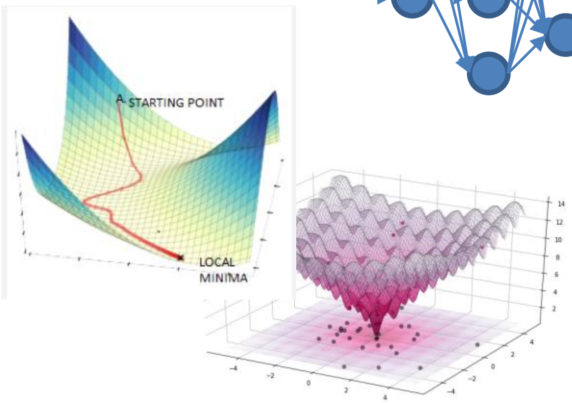
- Fundamental physics-based models:
  - Computational Fluid Dynamics (CFD).
  - Integrated Process Modelling (Thermofluid networks).
  - Custom-developed code.
- Machine Learning methods:
  - Surrogate models.
    - Deep Neural Networks (DNN).
    - Scientific machine learning.
  - Optimization techniques.
    - Gradient-based algorithms.
    - Evolutionary algorithms.





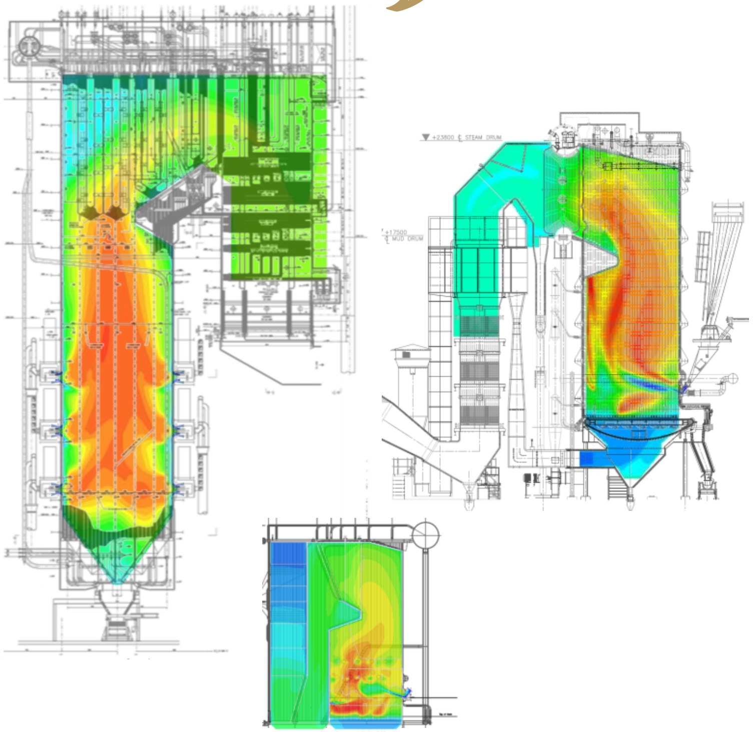


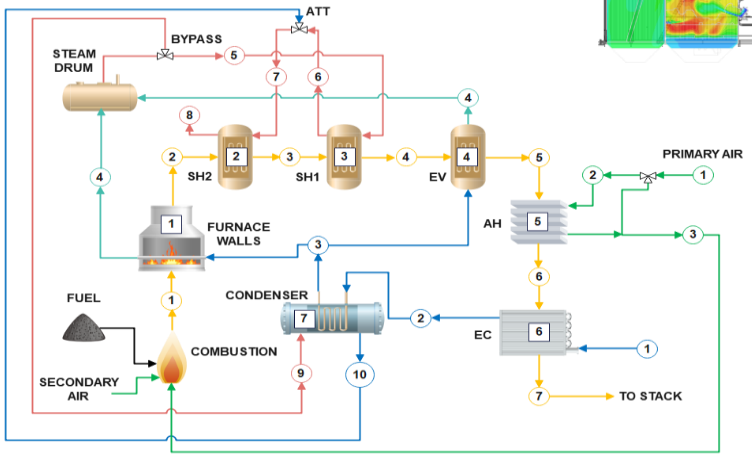




Application: Biomass and coal-fired boilers

- Detail 3D CFD models:
  - Utility-scale coal-fired boilers.
  - Industrial-scale and compact biomass-fired boilers.
- Integrated process models:
  - Complete biomass and coal-fired boilers.
  - Coal- and biomass co-firing boilers.
- Value-addition:
  - Compare burner swirl configurations.
  - Optimize under grate air flow distribution.
  - Optimize overfire air nozzle layout.
  - Analyse part-load performance.





Application:
Gas-cooled nuclear reactors

- Integrated process models:
  - Helium gas turbine power cycles.
  - Reactor cavity cooling system (RCCS).
  - Specialised high pressure and temperature test facilities.
  - Steady-state and dynamic analysis.
- Value-addition:
  - Optimise plant and test facility designs.
  - Analyse part-load performance.
  - Develop control philosophy.
  - Identify potential anomalies.

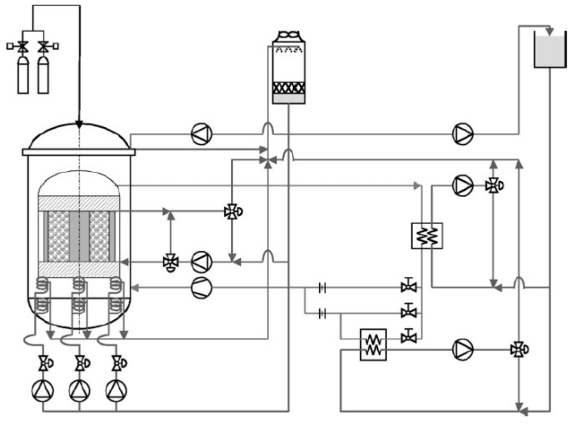


Fig. 20. Schematic of the HTTU pant layout.

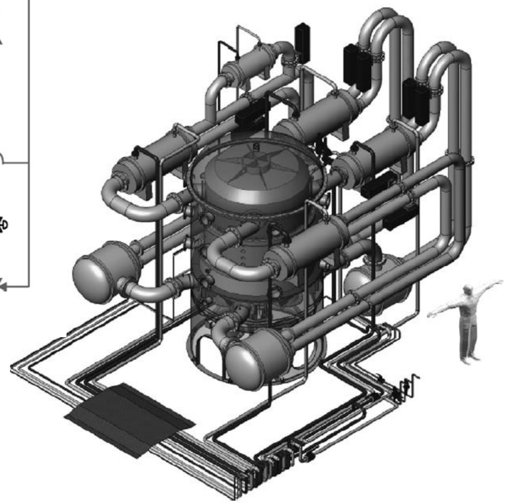


Fig. 21. Solid model of the HTTU plant.

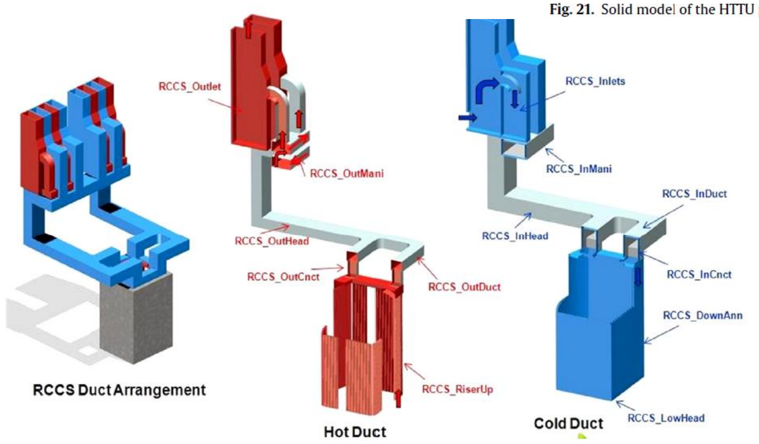
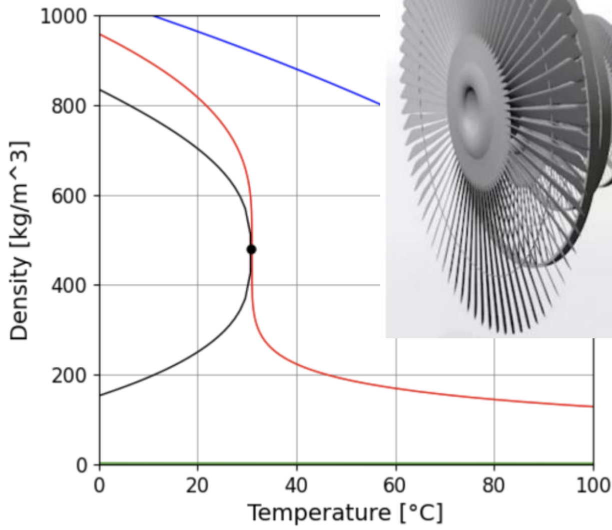


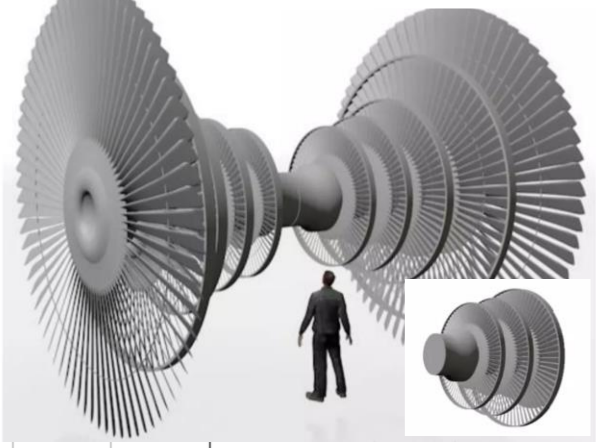
Fig. 7. Duct and chimney structure of the RCCS (Jun, 2012).

Application: Supercritical CO_2 power cycles

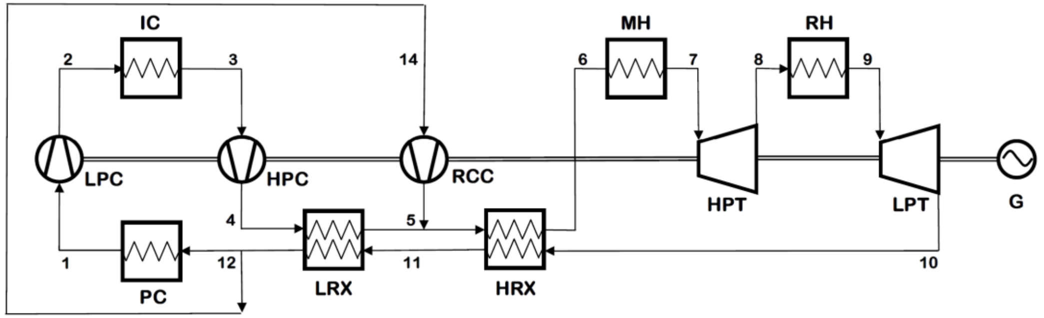
- CO_2 at supercritical pressure ≥75 x atm:
  - No phase separation between liquid and vapor.
  - Sudden expansion from liquid to vapour ≈31°C.
- Gas turbine power cycles:
  - Higher cycle efficiency.
  - Compact turbomachinery.
  - Solar power plants with dry cooling.



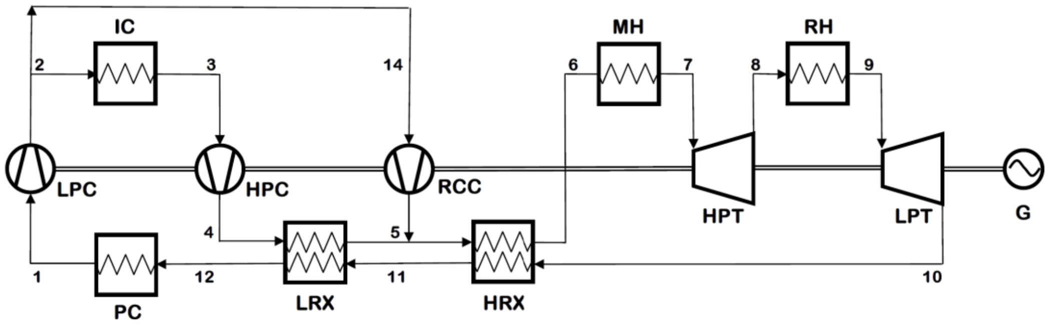
Adapted from: US DOE - Quadrennial Technology Review 2015



Intercooled recompression reheat (ICRCRH)

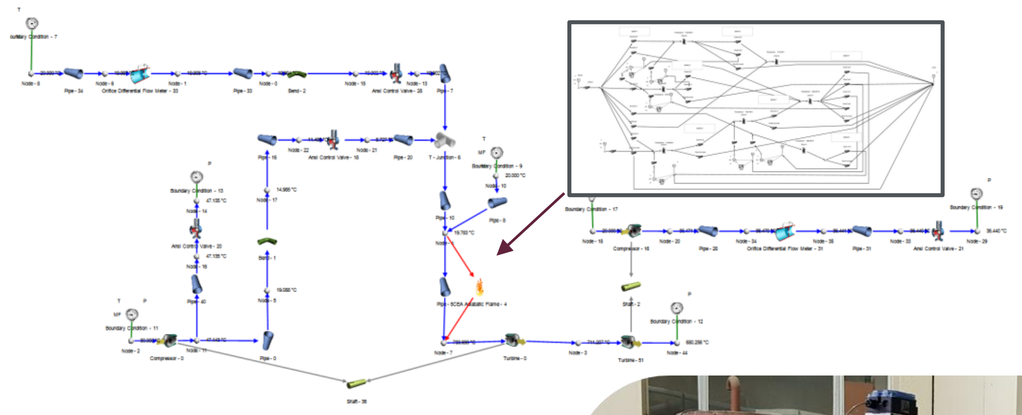


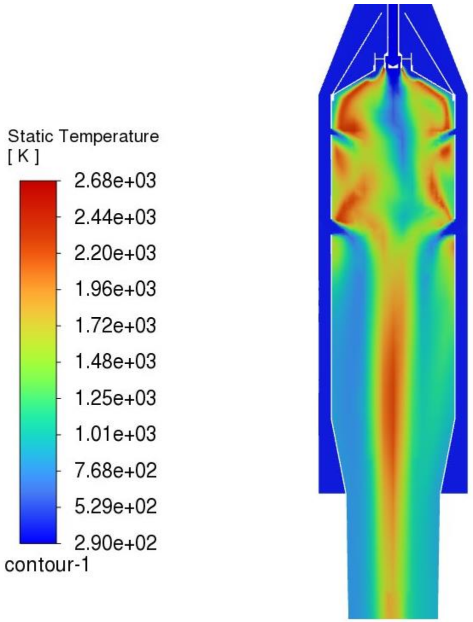
Partial cooled recompression reheat (PCRCRH)



Application:
Gas turbines and compressors

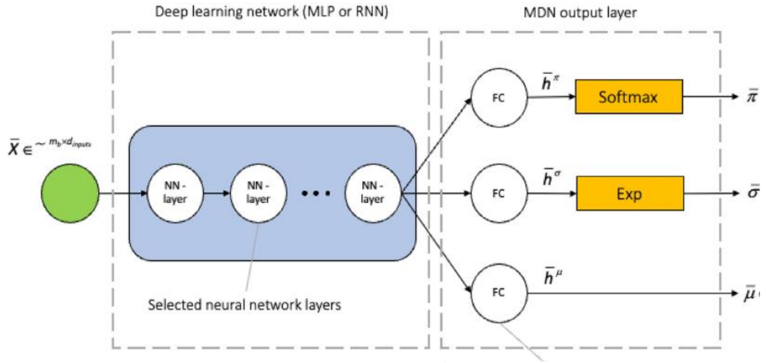
- Integrated gas turbine power cycle simulation:
  - Process models including complex turbomachinery performance.
  - Reactor network models capable of simulating emissions.
- Detail 3D CFD models:
  - Combustors.
  - Turbomachinery.
- Micro Gas Turbines (MGT) with sustainable fuels:
  - Hydrogen.
  - Ammonia.

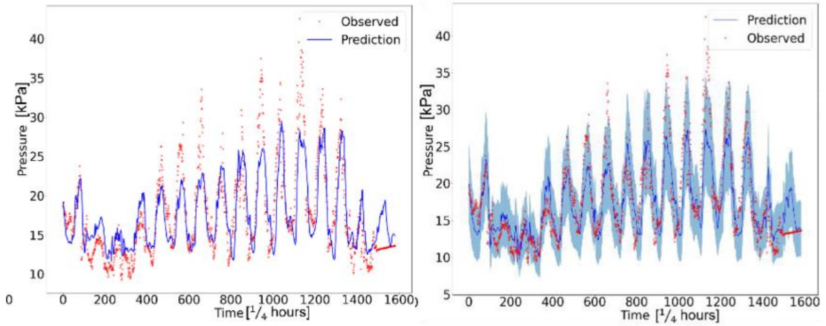


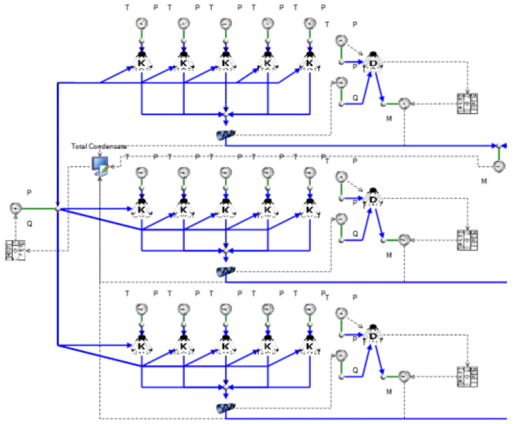


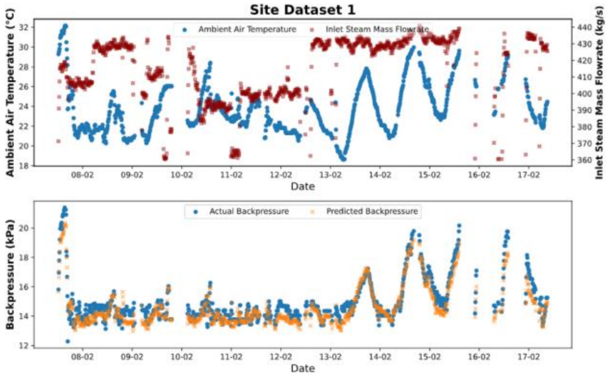
Application:
Air Cooled Condenser surrogate modelling

- Data-driven models:
  - Generated using deep learning and plant measurements.
- Physics-based surrogate models:
  - Generated using simulation data as opposed to sparse experimental data.
- Value addition:
  - Virtual sensors to perform condition monitoring.
  - Enhance control systems and optimise plant performance.



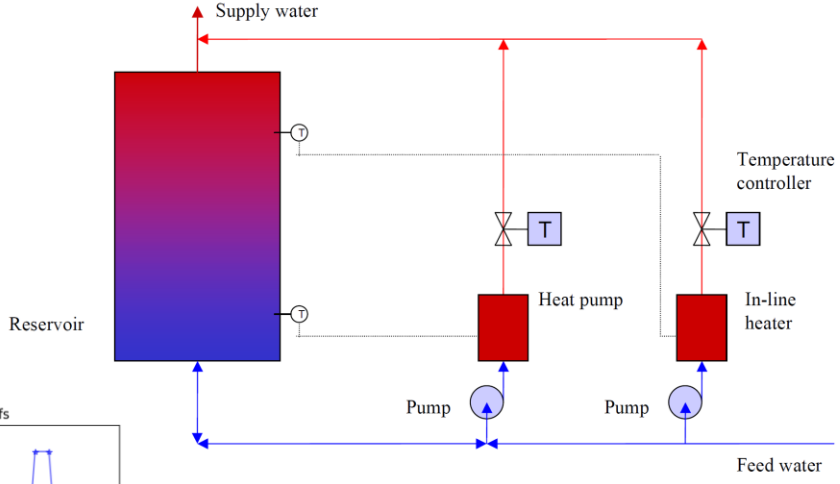


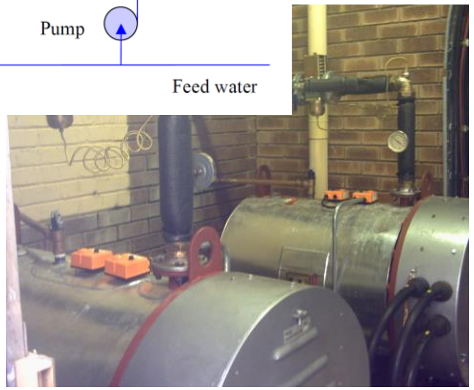


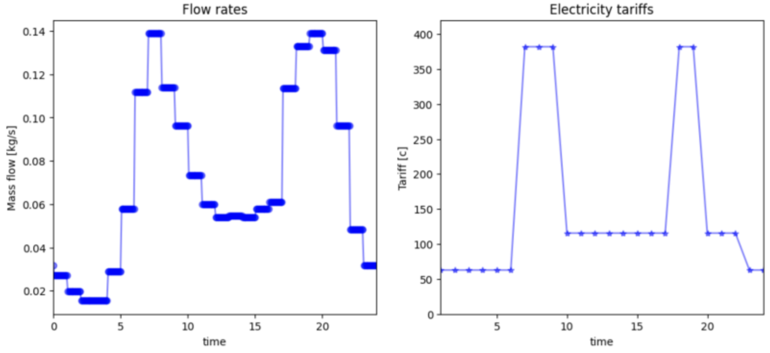


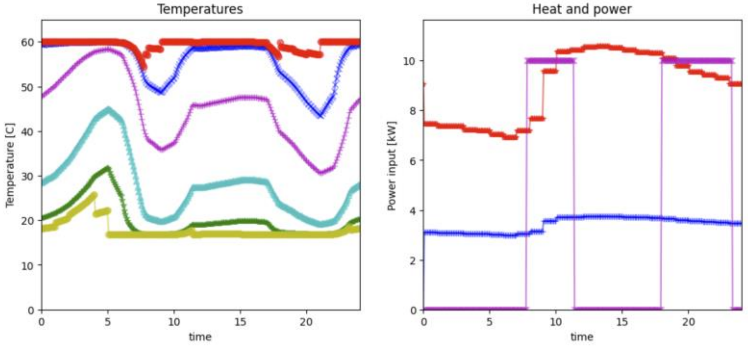
Application:
Water heating system optimization

- Heat pump + backup heater + thermal storage:
  - Ensure adequate supply water temperature.
  - Minimize daily electricity cost.
- Genetic optimization:
  - Variable consumption.
  - Variable price.
  - Continuous and discrete heating modes.
  - Thermal storage.
  - Analogue override.

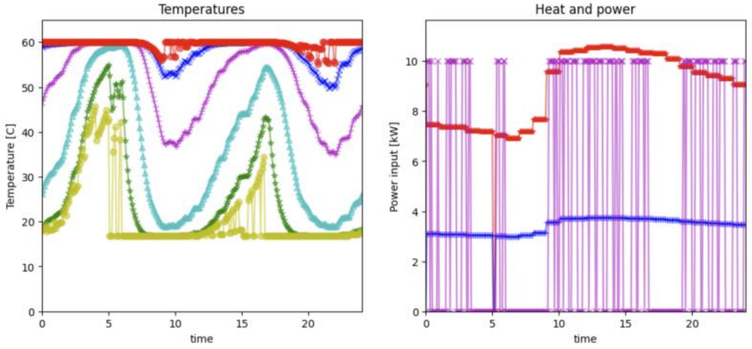








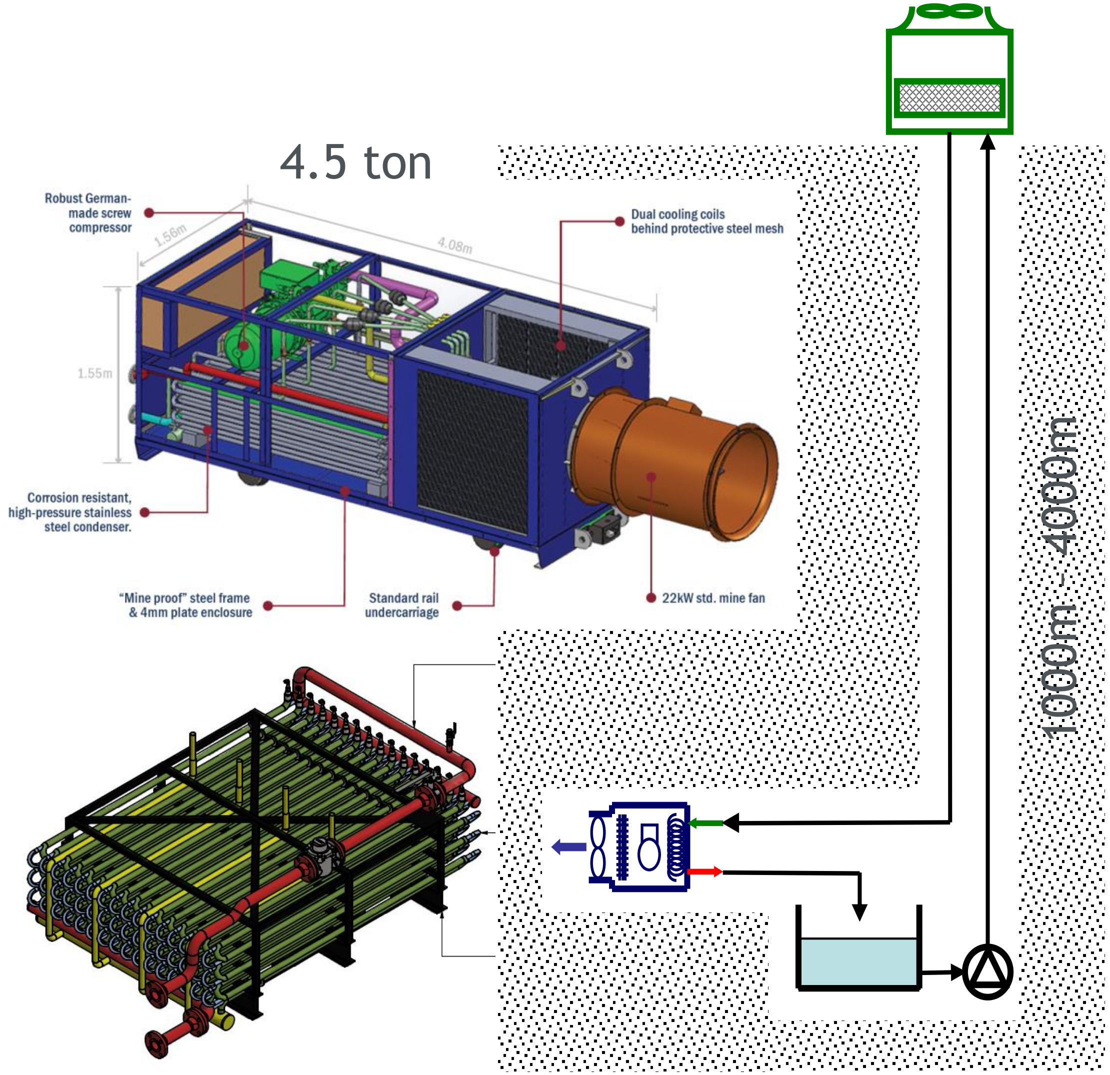
Simple analogue control



Intelligent control 15-25% cost saving

Application:
Heat pump condition monitoring

- Deep mine Air Cooling Unit (ACU):
  - Modular direct expansion heat pump.
  - Large cooling capacity (>250 kW).
  - Cools air at the point of operation.
  - Rejects heat to water pumped to surface.
- Value addition:
  - Detect, locate, and quantify degradation.
  - Fundamental physics-based thermofluid model of heat pump cycle.
  - Train and apply DNN surrogate models.
  - Combine with parameter discovery.



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Thank you
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Thermofluid systems modelling - Summary

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- Thermofluid systems include:
  - Biomass, coal, and gas-turbine power plants.
  - Concentrated solar, nuclear, and pumped storage power plants.
  - Heat pumps and refrigeration cycles.
  - Large water distribution networks.
- Modelling is applied to:
  - Evaluate novel technologies.
  - Perform parametric and what-if analysis.
  - Optimize system designs.
  - Improve efficiency and control of processes.
  - Detect anomalies for condition monitoring.
- Modelling tools and methods:
  - Fundamental physics-based models.
  - Machine learning and optimization methods.