TNB RESEARCH

Innovate With The End In Mind

2017 IERE-TNB Putrajaya Workshop

A Dynamic Optimization Sizing Tool for Waste Heat Recovery-Gas Turbine Inlet Cooling

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TNB Research

Background

An R&D project driven by opportunities for energy efficient operations

Overall power generation efficiency	➡	***Key element in power production***
Power Production Agreements (PPA)	➡	***LIMIT power production & Waste of Additional Power***
Need for Optimization	➡	**INCREASE efficiency** ***without producing additional power***

Targets

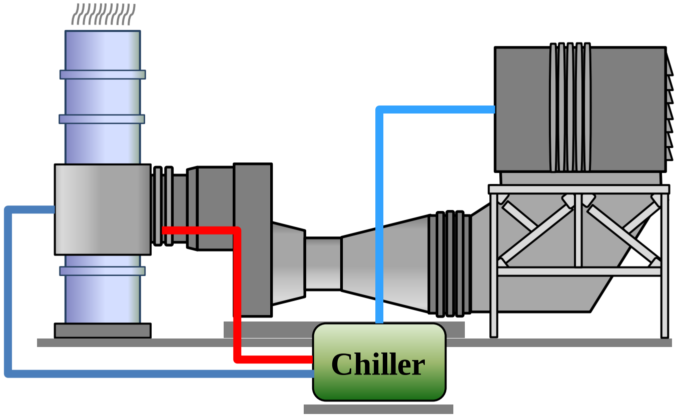
Project objectives to realize adaptable deliverables

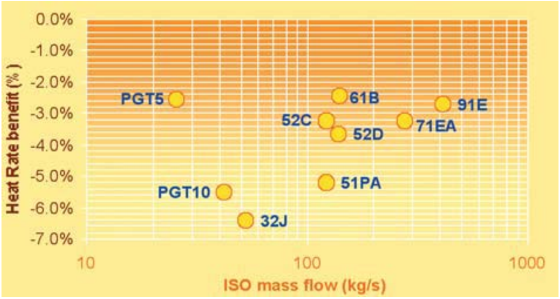
- Validated model to **estimate GT Heat Rate reduction** by air inlet cooling
- **Sizing tool** to optimize the design of a GT – Absorption Chiller (AC) system
- Estimation of **potential savings** from waste heat recovery system without additional power production.

Program impact and value creation

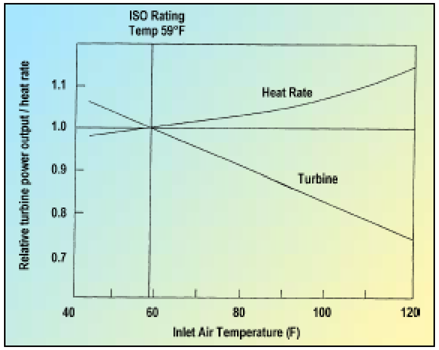
Established benefits from gas turbine air inlet cooling

- Heat rate improvement – fuel savings!!
  - Potential HR improvement of 1.2%
- Independence of fluctuations in ambient conditions
  - Increase operational flexibility
- Turbine life extension





GE experience with inlet air cooling performance improvements



Performance comparisons with standard conditions

Comparison of cooling options

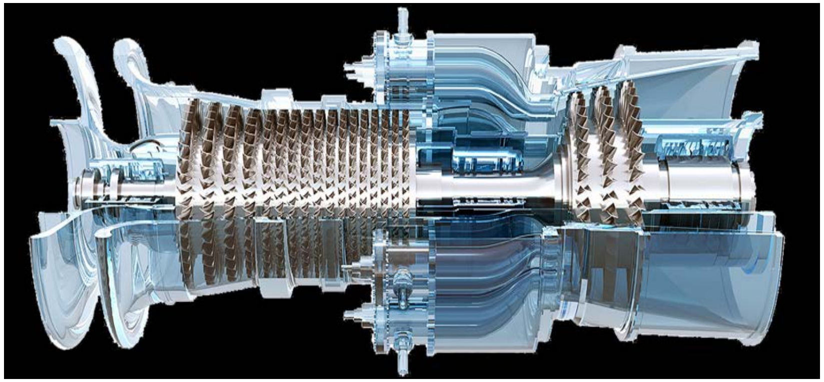
Turbine inlet cooling systems which are commercially available

Water Evaporation

- (A) **Wetted Media**
- (B) **Fogging**

Heat Transfer

- (C) **Vapor Compression**
- (D) **Adsorption / Absorption**



	Stand-alone	Environment factors	Pybck < 5yrs	Complexity
Wetted media evaporative cooling (A)	Green	Red	Green	Green
High pressure fogging (B)	Green	Red	Green	Green
Refrigerative cooling (mechanical) (C)	Red	Green	Yellow	Yellow
Absorption chillers (D)	Green	Green	Green	Yellow
Adsorption chillers (D)	Yellow	Green	Red	Green

- Red: **Difficult**
- Yellow: **Moderate**
- Green: **Ready**

Absorption chiller technology

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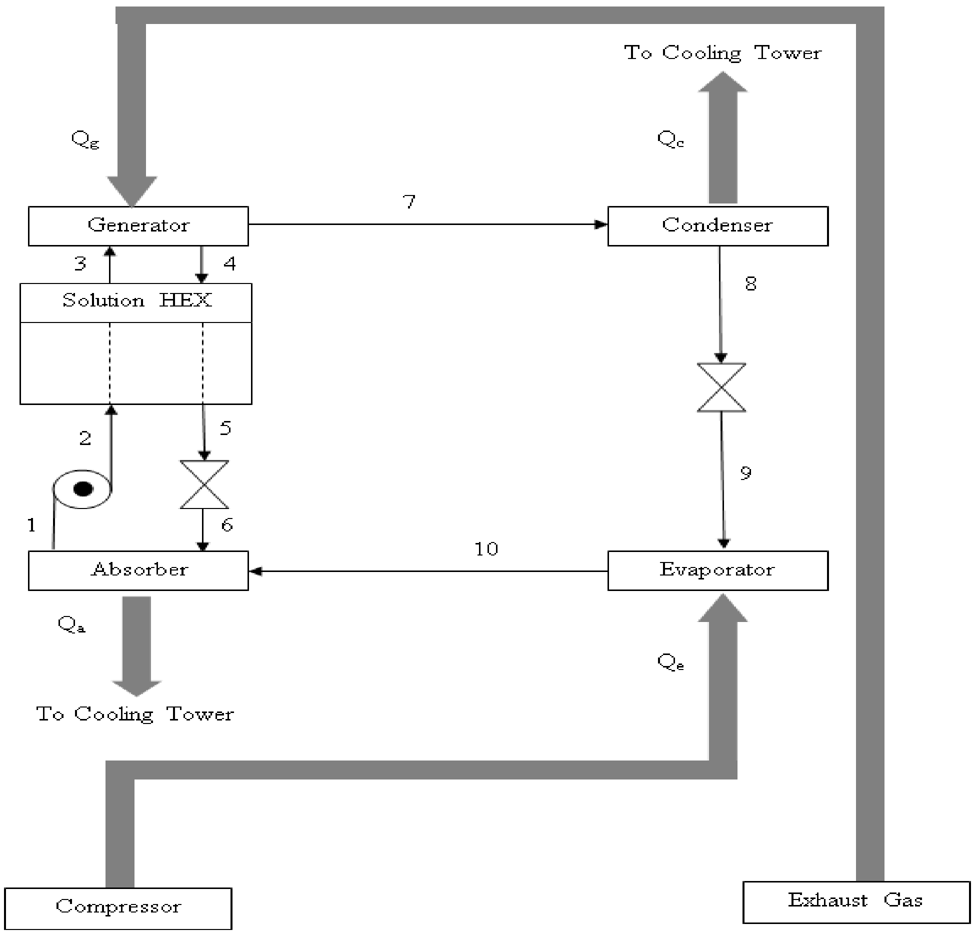
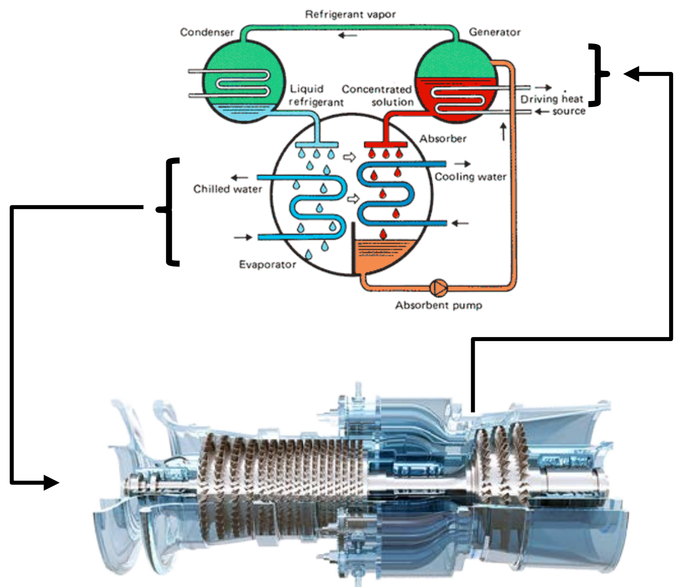
Re-use of waste heat to cool gas turbine compressor air intake



Absorption Chiller package

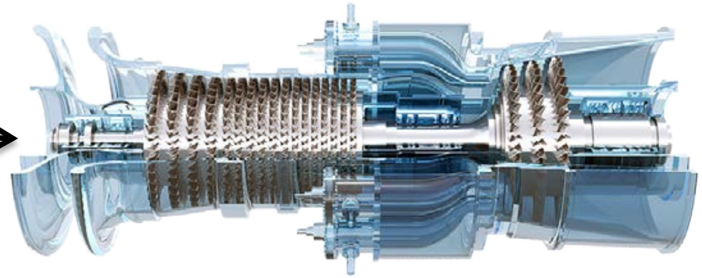


Mechanism

Benefits of air cooling within the power purchase agreement limitations

Normal Operations without air cooling

Air – ambient temperature (typical 35°C)



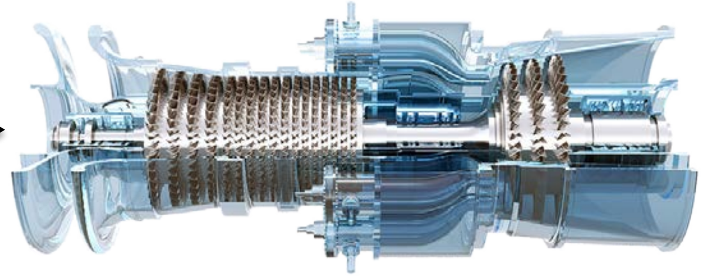
120 MW

Fixed by PPA

Fuel – 7.8 kg/s

With Air Cooling

Cooled air (fixed at 25°C)



120 MW

Fixed by PPA

Driving fuel savings

113 MW

New set-point

Fuel – 7.7 kg/s

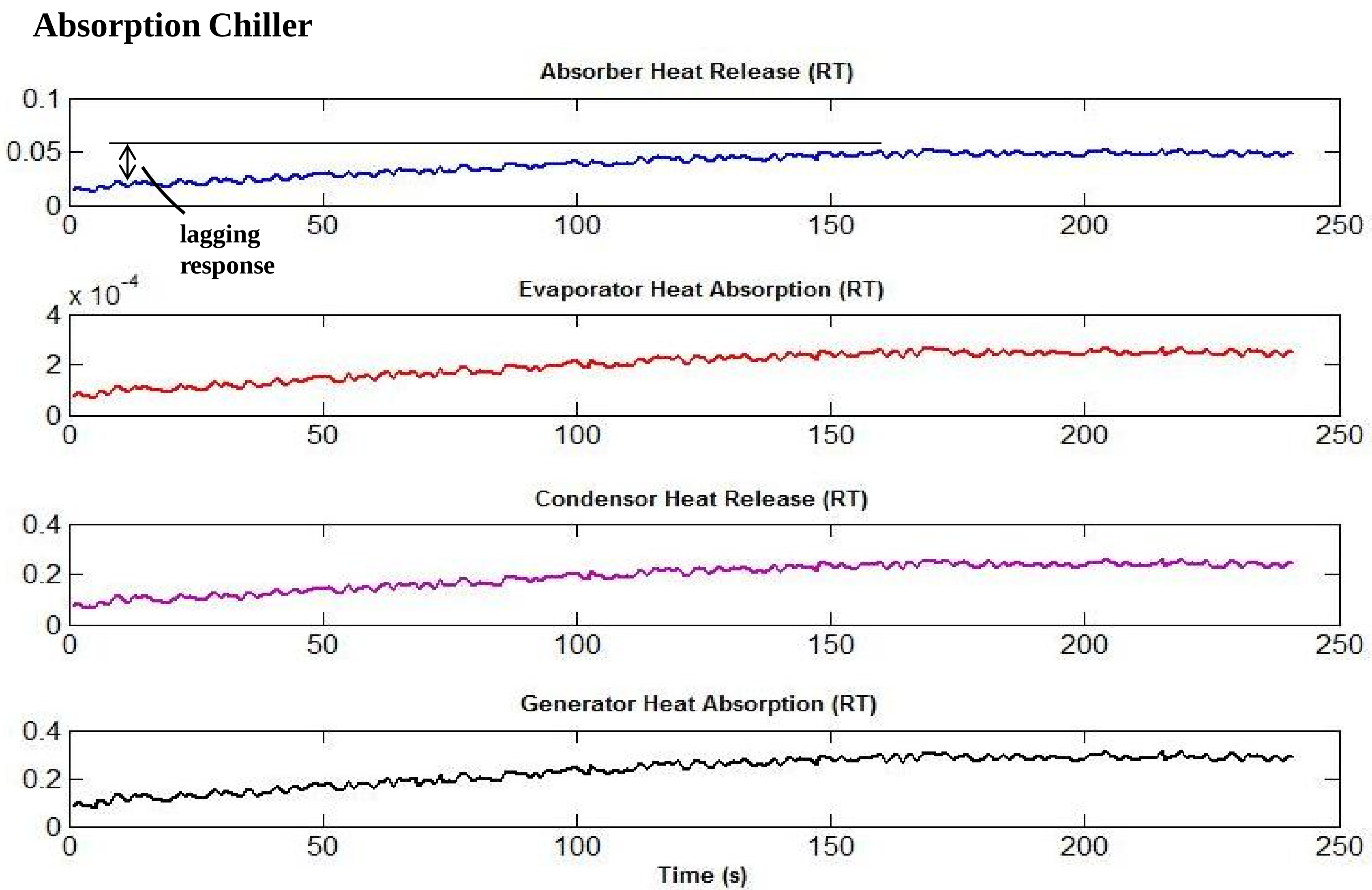
Dynamic simulation and sizing tool

Required to address environment and system dynamics

- Process integration/dynamic simulation of combined GT and Absorption Chiller System
- Incorporates weather data and transient thermodynamic models
- Evolutionary algorithm as an optimization strategy
- Validated on existing GT plants
- Provide component and system sizing estimates

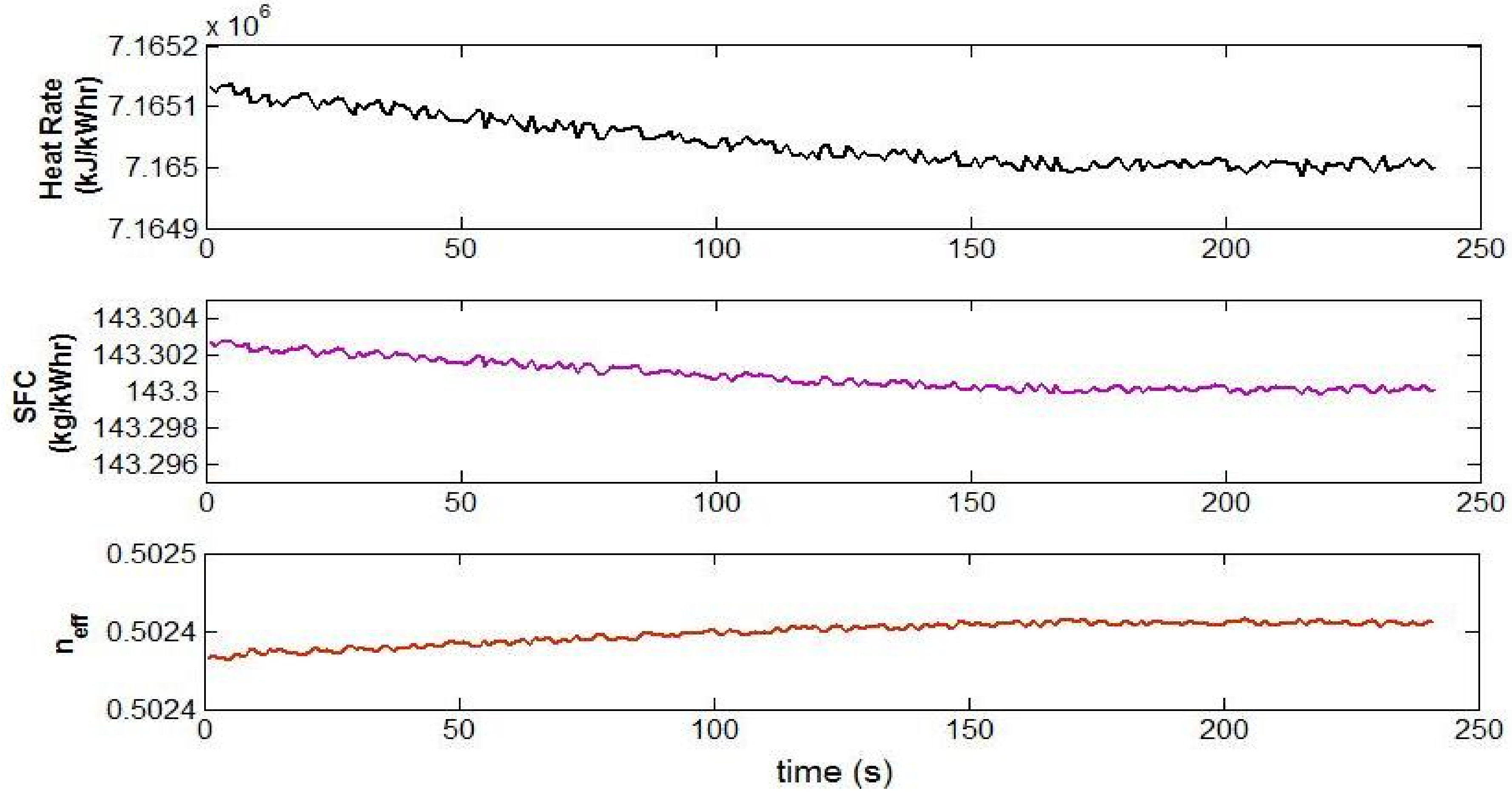
Dynamic simulation – component level

Simulated transient behavior of absorption chiller components in operation



Dynamic simulation – systems level

Simulated transient behavior of air cooling system

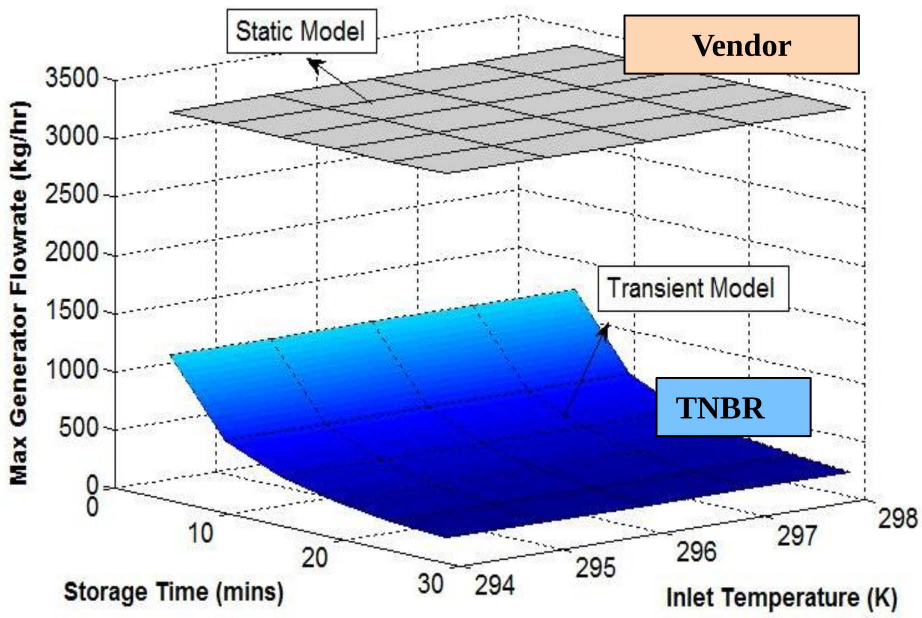


Chiller sizing from dynamic model

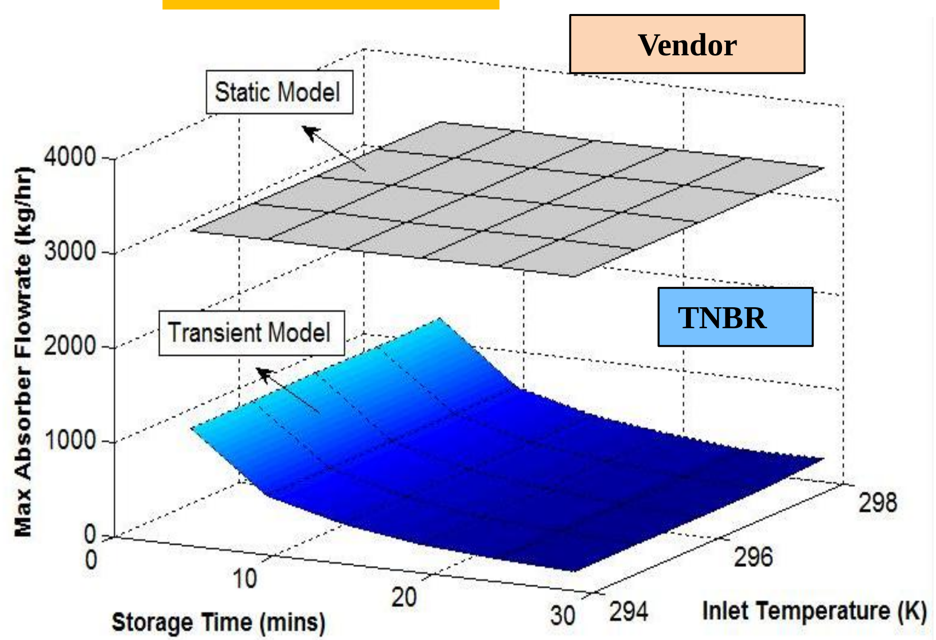
Comparing absorption chiller capacities with vendor (static model)

Company	Vendor	TNBR
Capacity (kW)	4488	1450

Generator Sizing



Absorber Sizing



Absorber and Generator components are indicators of overall absorption chiller package size

Chiller CAPEX

Savings from sizing with dynamic model

Item	Total CAPEX cost (USD)
Chiller ABS Model: YX550-174H2 capacity = 496RT/1450kW	*1,011,594*
Chiller ABS Model: 4X550-44942 capacity = 1276RT/4488kW	*1,280,664*

CAPEX SAVINGS ≈21%

Chiller OPEX

Case study from a cogeneration plant in Malaysia

Items	Annual Cost (USD)
Utilities (water/power)	38, 579
Chemical LiBr, anticosrrosion etc.	76, 417
Service & Maintenance (10 year average)	22, 022
TOTAL (per annum)	**137, 019**

CAPEX +OPEX = 1,011,594 +137,019
= $3,054,254 per annum
=$11, 418 per month

Fiscal savings

Calculating payback period for a peaking plant in Malaysia

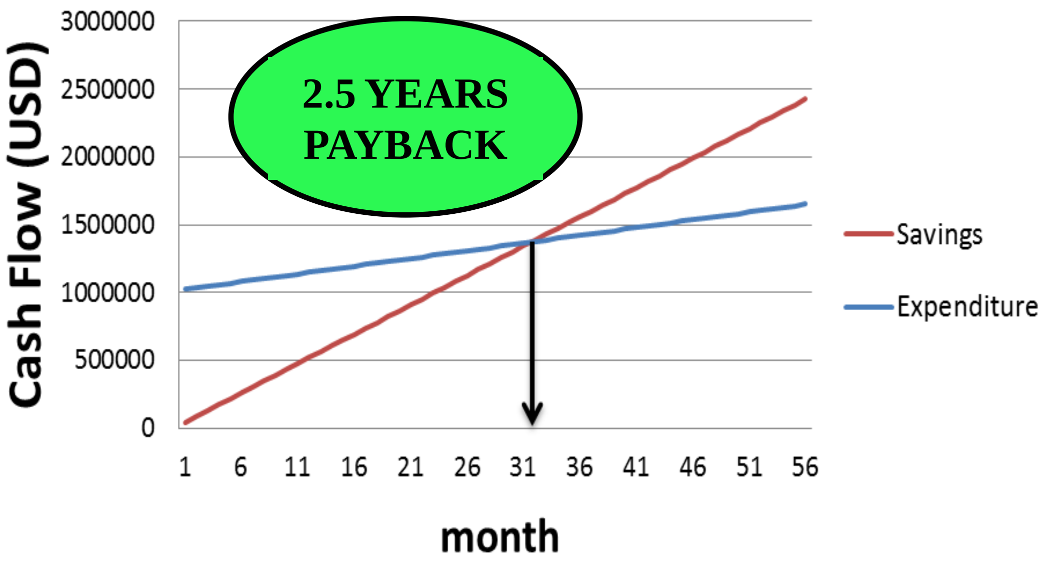
Description	*WITH INLET COOLING*	*WITHOUT INLET COOLING*
COP	1.31098	-
Thermal Efficiency	0.322	0.355212
Heat Rate (kJ/kWh)	10562	11204
Power Output (MW)	116	116.655
Natural Gas Fuel inlet (kg/s)	7.7	7.8

Approximate Fuel Price: 0.17 USD/kg

Average of 3 hours of runtime per day

(BASED DAILY DATA FOR 4 MONTHS)

AVERAGE SAVINGS FROM REDUCED FUEL CONSUMPTION	
USD/month	**USD/annum**
43, 294	**519, 528**



Conclusions

- *A reliable tool was developed for optimizing the sizing of ACs based on GT specifications.*
- *The tool is suitable for feasibility studies – economics and technical considerations when selecting ACs for GT inlet air cooling.*
- *Optimization performed using the tool was shown to produce significant savings in terms of fuel consumption by the GT and cost of the AC.*
- *The tool is robust – where it can be used to size chillers for GTs with any specification (while considering uncertainties in weather conditions).*

THANK YOU

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Publications

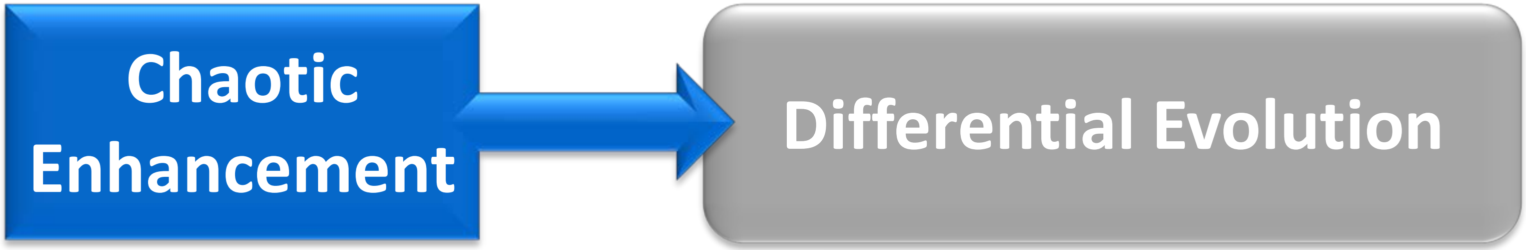
Book Chapter:

Ganesan, T., Aris, M.S. and Elamvazuthi, I., (2017), Multiobjective Strategy for an Industrial Gas Turbine: Absorption Chiller System, Handbook of Research on Emergent Applications of Optimization Algorithms, IGI Global, 531-556.

Conference Paper:

Ganesan, T., Aris, M.S., Elamvazuthi, I. and Tageldeen, M.K., (2017). Type–2 Fuzzy Programming for Optimizing the Heat Rate of an Industrial Gas Turbine via Absorption Chiller Technology. Conference Proceedings of World Academy of Science, Engineering and Technology, pp.232-238.

Evolutionary Strategy



Algorithm: Chaos-Driven Differential Evolution (CDDE)

Step 1: Set parameters: N and P.

Step 2: Deterministically initialize population vectors, x^{G}_{i}.

Step 3: Iterate chaotic logistic map.

Step 4: *IF* $n > N_{max}$, proceed to next step

else go to Step 3.

Step 5: Randomly select one principal parents, x^{p}_{i}

Step 6: Randomly select three auxiliary parents, x^{a}_{i}

Step 7: Perform differential mutation & generate mutated vector, V_i

Step 8: Recombine V_i with x^{p}_{i} to generate child trial vector, x^{child}_{i}

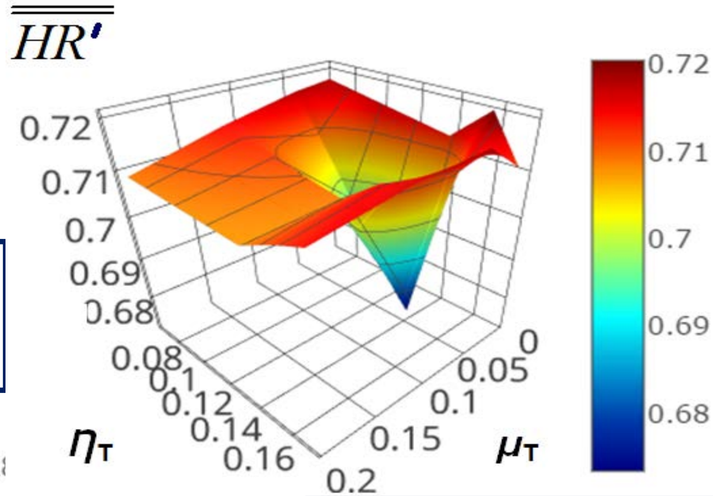
Step 9: Evaluate fitness of the new x^{child}_{i}.

Step 10: *IF* the halting conditions are fulfilled halt and print solutions

else proceed to step 2

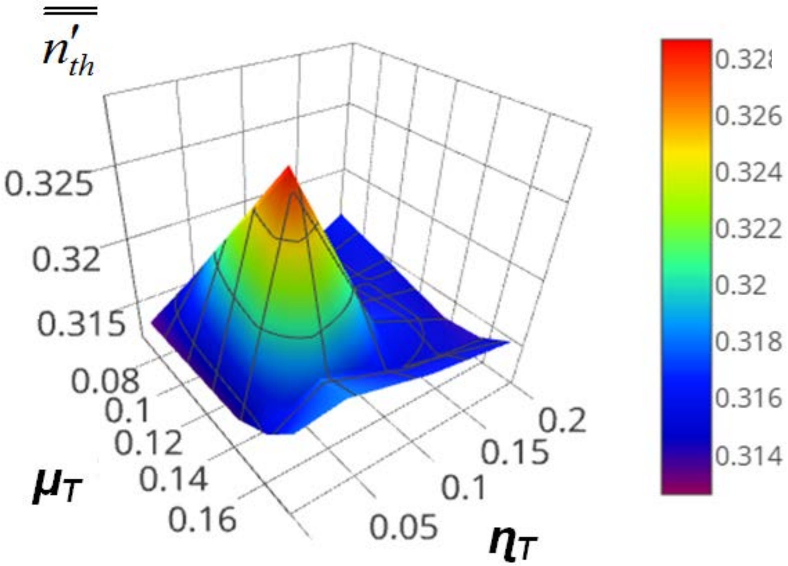
Results

Normalized HR versus membership grades



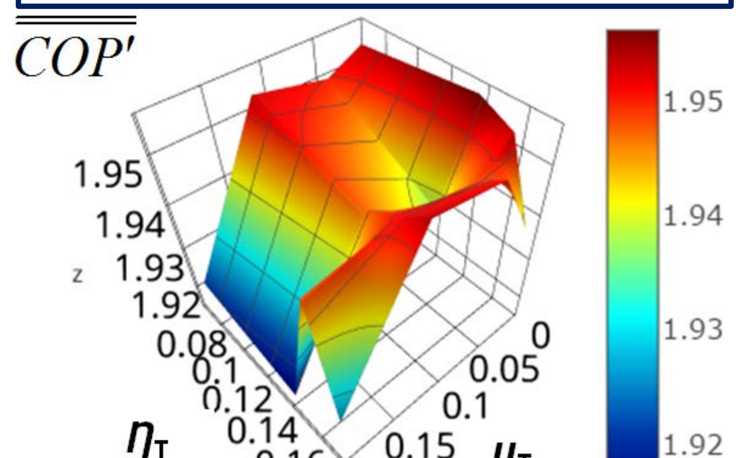
Δ=6.984%

Overall Thermal Efficiency versus membership grades



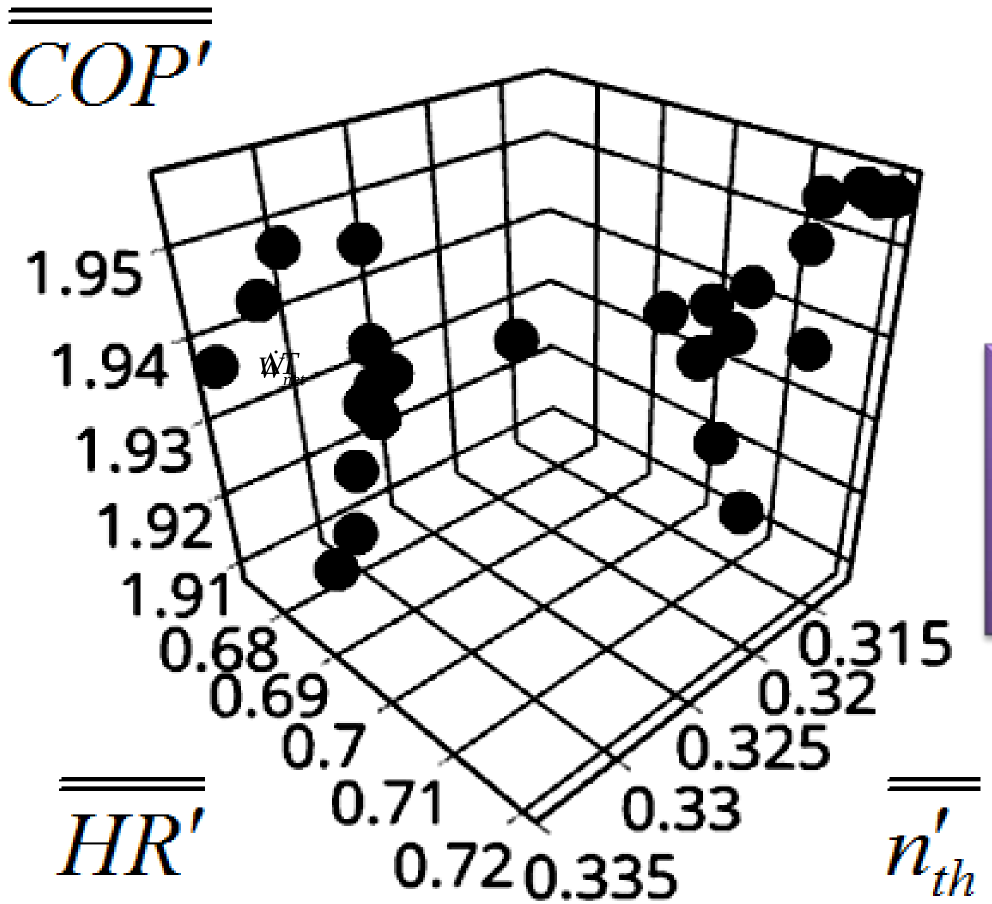
Δ=5.416%

COP of AC versus membership grades



Δ=2.09%

Pareto Frontier



SFC reduction of 6.528%

Solution Rankings

Description		Best	Median	Worst
Objective Functions	n_{th}	0.3343	0.324	0.316
	HR	0.673	0.6945	0.7121
	COP	1.9366	1.9395	1.9172
Decision Variable	t_a	35.8297	35.8152	32.4089
ΔT	t_e	7.9014	7.5902	7.6893
	t_g	489.014	485.902	486.893
	t_c	37.0986	37.4098	37.3107
	E_L	0.5901	0.559	0.5689
	M_a	106.843	103.717	101.302
	M_g	106.843	103.717	101.302
		13.6545	7.4167	2.5977
Parameters	Q_E	379.245	395.578	930.307
		133.727	129.59	126.394
Metric	HVI	341.4796	307.9167	113.01