Optimization of air conditioning performance using Model Based System Engineering (MBSE) approach using GT-SUITE

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Content Outline

- Company Overview
- Simulation Foot-Print
- Need For 1-D Simulation
- Problem Definition
- Modelling Approach
- Design Iterations
- Results
- Conclusion

Company Overview

Emerging as One-Stop FMEG destination with Global Presence.

21 Product verticals

14 Manufacturing units

3 Research centres

35 Branch offices

~14,000 Strong dealer network

60+ Countries Global presence

5,970 People strength

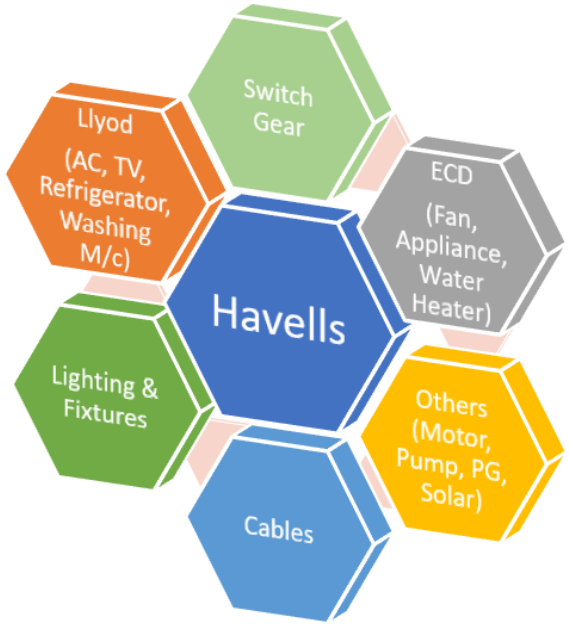
5 Brands

HAVELLS, Crabtree, LLOYD, STANDARD, REO

DJSI 7th Rank Globally Sustainability Yearbook Member 2022 S&P Global

CRISIL Rating Strong CRISIL An S&P Global Company

Great Place To Work. Certified NOV 2021-NOV 2022 INDIA



Highlights, FY 2021-22

₹13,889 Cr Net Revenue

₹1,758 Cr EBITDA

₹1,195 Cr PAT

56% Reduction in specific GHG intensity since FY 2015-16

47% Water recycled

60% Increase in installed solar capacity over FY 2020-21

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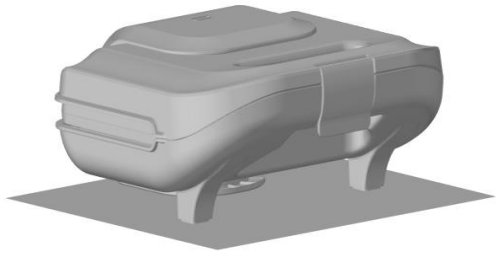
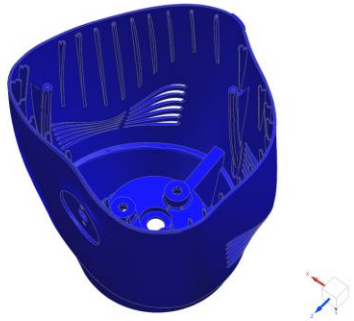
GT Gamma Technologies

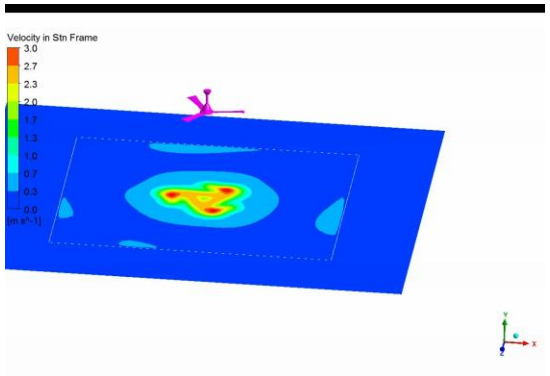
Simulation Footprints

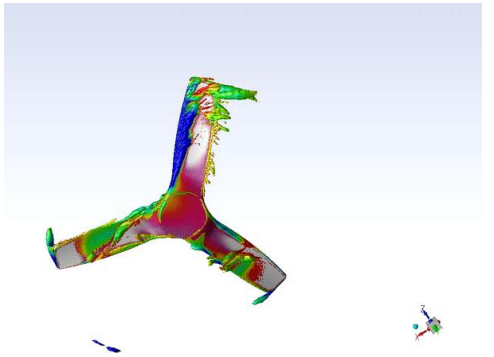


Structural



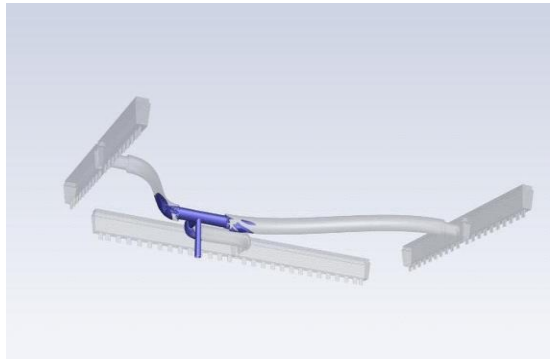
Modal



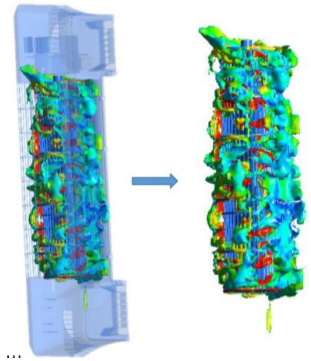


Airflow : Steady & Transient

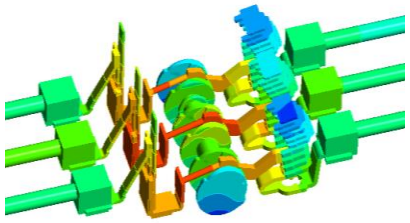
Hydraulic Efficiency



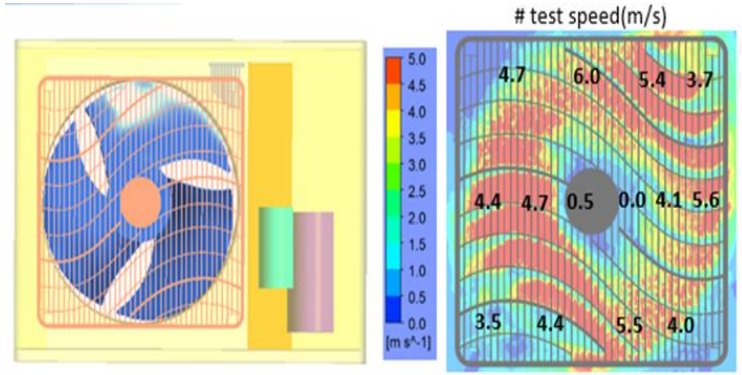
Multiphase



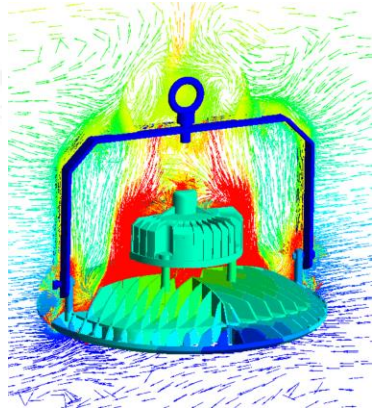
Noise



EM: Joule Loss



Porous Drop



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Need For 1-D Simulation

Development Cycle

- Product Refresh Rate in Consumer Durables (CD) are around 6-8 months.
- Reduced CAE development cycle time < 1-2 months.
- Complicated and Unexplored field.
- Simulation in CD is still not matured and is evolving.
- Limited database and literature review.

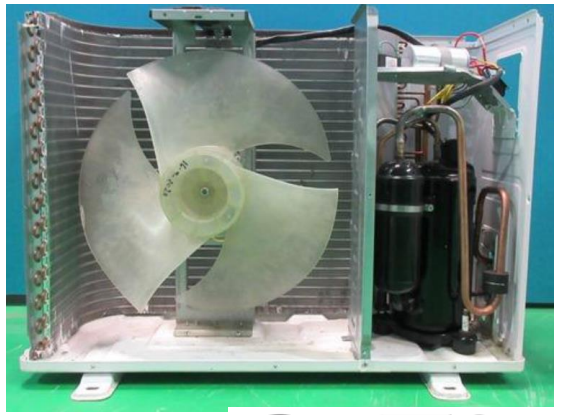
How 1-D simulation Helps

- Making parametric study possible and feasible → Time reduction.
- Providing and generating better input data for 3-D simulations → Quality Improvement.
- Training and tuning of data for AI based physics simulations → AI leveraging.

Problem Definition

To Select the best combination of design among below design alternatives:

- Compressor : (4)
- Condenser: (2)
- Evaporator: (2)



Input to GT Suit

Geometric

Condenser
TXV/Capillary
Refrigerant Line
Evaporator

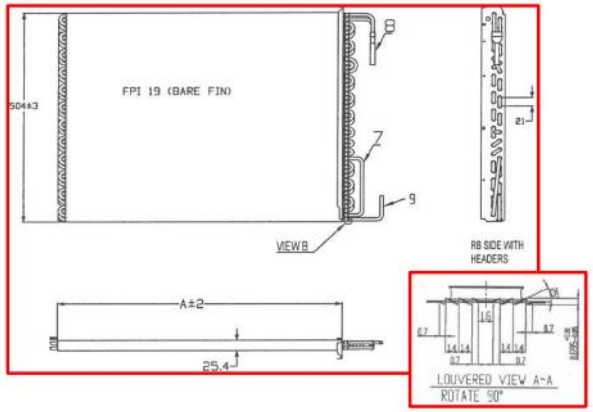
Performance

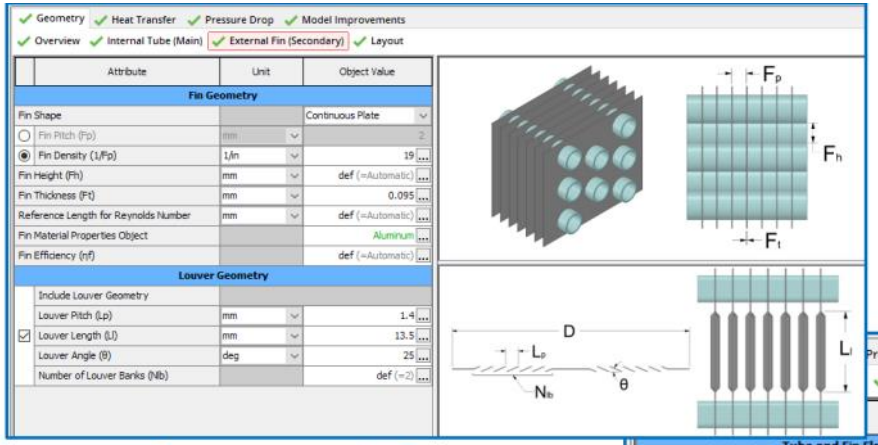
Blower Speed, Mass flow rates, Temperature, Pressure Rise

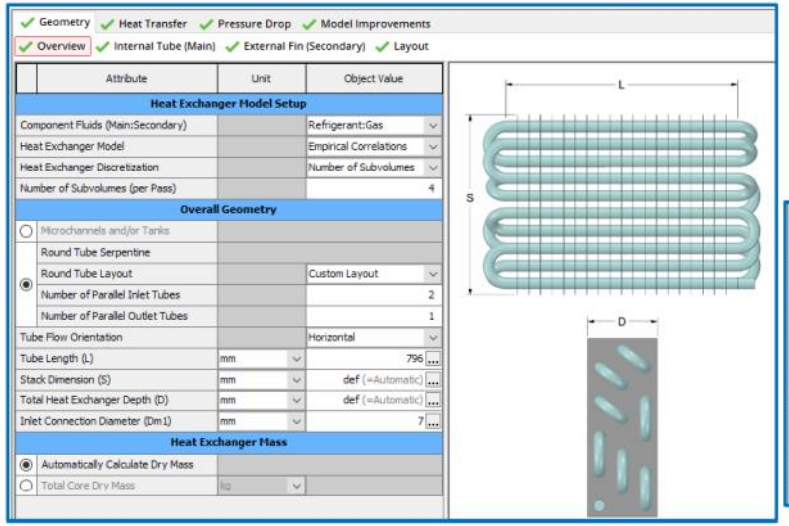
Total DOE Combination: 4*2*2 =16 feasible designs!!!

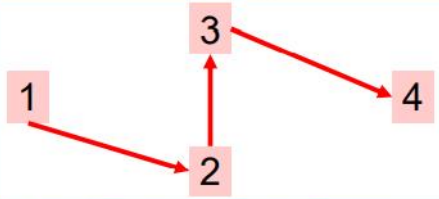
Modelling Approach

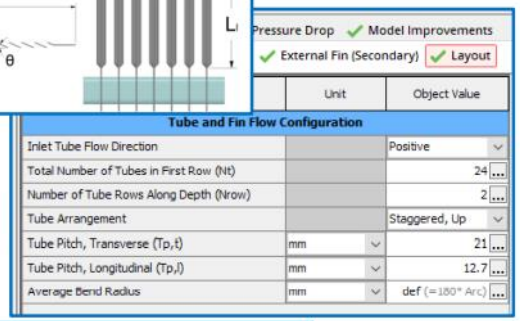
Condenser

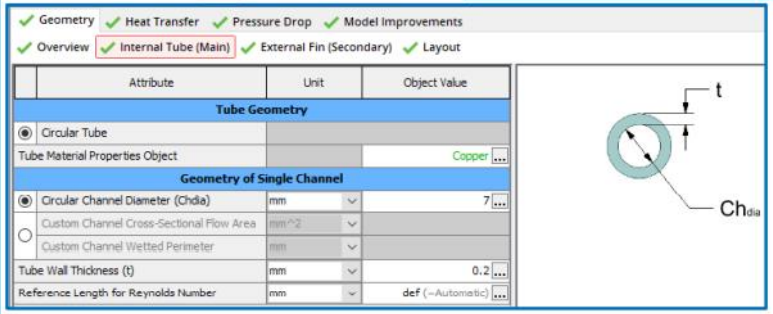


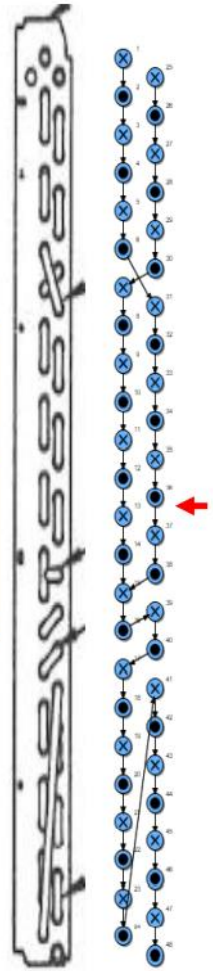






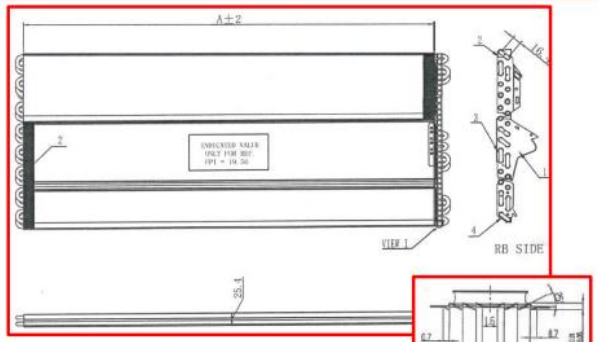


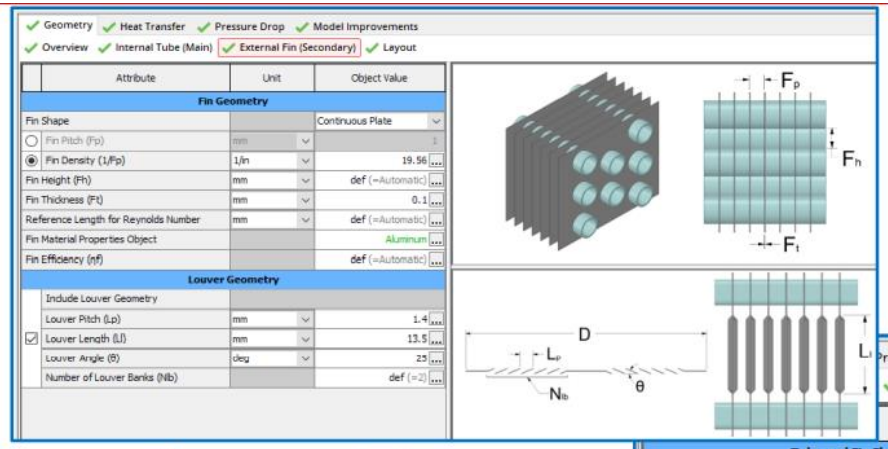


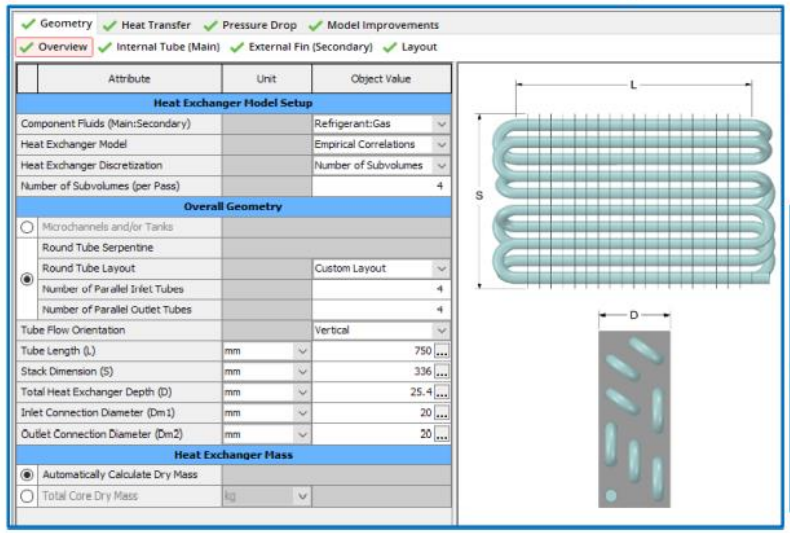


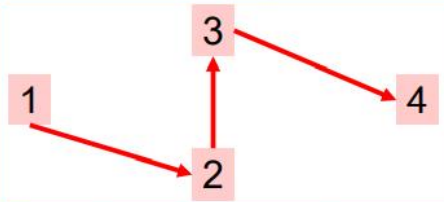
Modelling Approach

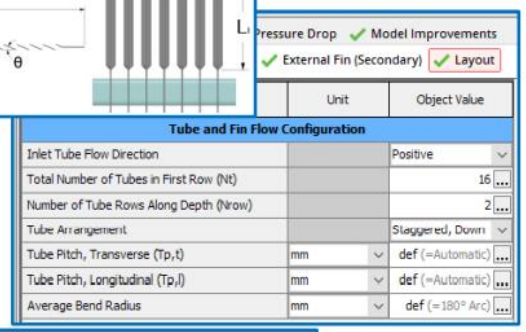
Evaporator

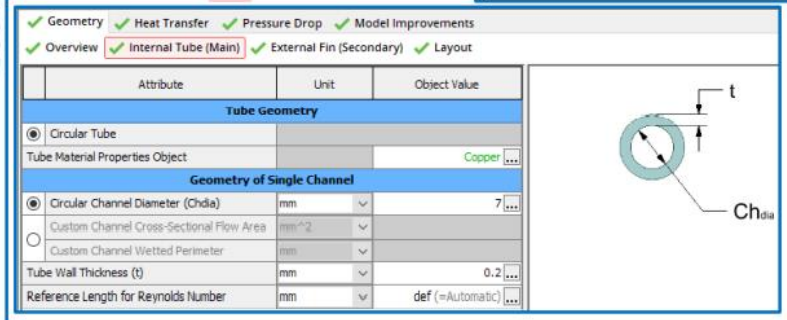


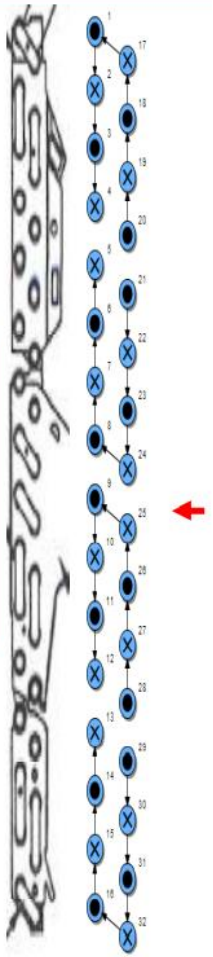






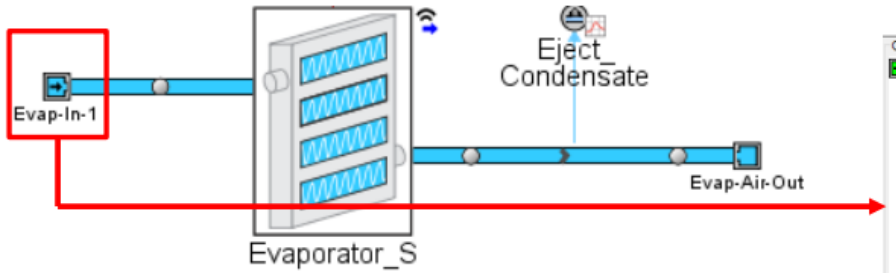






Modelling Approach

Compressor, Evaporator, Blower



Object Family: Evap-In → Evap-In-1

Main | Humidity | Plots

Attribute	Unit	Object Value
Volumetric Flow Rate	See Case S...	[Evap-Blower_VFR]
Density for Conversion to Mass Flow Rate		Reference Pressure
Reference Pressure	bar	def (=1)
Mass Flow Rate (or air scfm)	kg/s	
Velocity	m/s	
Mass Flux	(kg/s)/m^2	
Temperature	See Case S...	[Evap-Air-Inlet-Temp]
Composition		air2
Initialize Flow Rate for Adjacent Connection?		☐

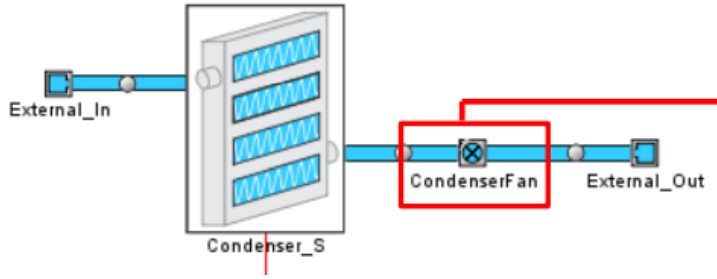
Main | Humidity | Plots

Attribute	Unit	Object Value
Relative Humidity	See Case S...	[Evap-Air-Inlet-RH]
Relative Humidity Definition		fresh air only
Humidity Species		h2o-vap
Apply Humidity to Initial Conditions		
Reference Pressure	atm	1
Reference Temperature	See Case S...	[Evap-Air-Inlet-Temp]

Object Family: Compressor → Compressor

Main | Options | Plots

Attribute	Unit	Object Value
Volumetric Efficiency	See Case S...	[Comp-Vol_Eff]
Displacement	See Case S...	[Comp-Disp]
Isentropic Efficiency	fraction	=[Comp-Isen_Eff(fracti...
Relaxation Factor		def



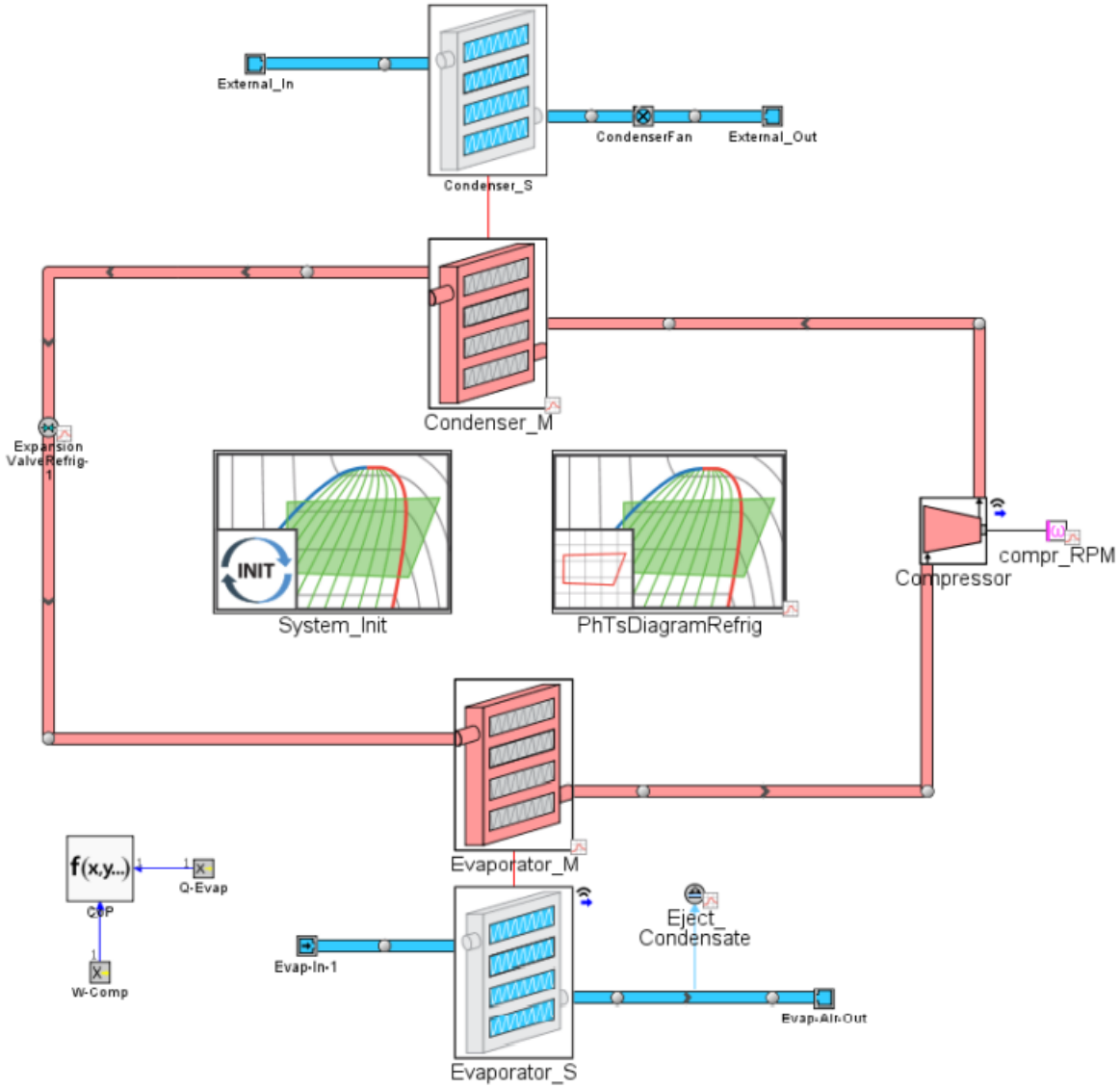
Object Family: CondenserFan → CondenserFan

Main | Plots

Attribute	Unit	Object Value
Volumetric Flow Rate	See Case S...	[Cond-Fan-VFR]
Isentropic Efficiency		[Cond-Fan-Eff]
Relaxation Factor		def (=0.5)

Modelling Approach

GT-Model



Design Iterations

DOE Settings in GT-Suit

Main | Compressor | Condenser | Evaporator | CooledRegion | Init | Design of Experiments | All

Parameter	Unit	...	Value 1	Value 2	Value 3	Value 4
Compressor (DOE)			Comp-Base	Comp-2	Comp-3	Comp-4
Condenser (DOE)			Cond-Bas...	Cond-2		
Evaporator (DOE)			Evap-Bas...	Evap-2		

Compressor Base – 17 cc, 3000 RPM, η_{isen} = 79.5%, η_{vol} = 85%
Compressor 2 – 17 cc, 4000 RPM, η_{isen} = 79.5%, η_{vol} = 85%
Compressor 3 – 20 cc, 3000 RPM, η_{isen} = 79.5%, η_{vol} = 85%
Compressor 4 – 17 cc, 3000 RPM, η_{isen} = 90%, η_{vol} = 90%

Condenser Base – Original Dimensions with length = 790 mm
Condenser 2 – Scaled to length = 996 mm

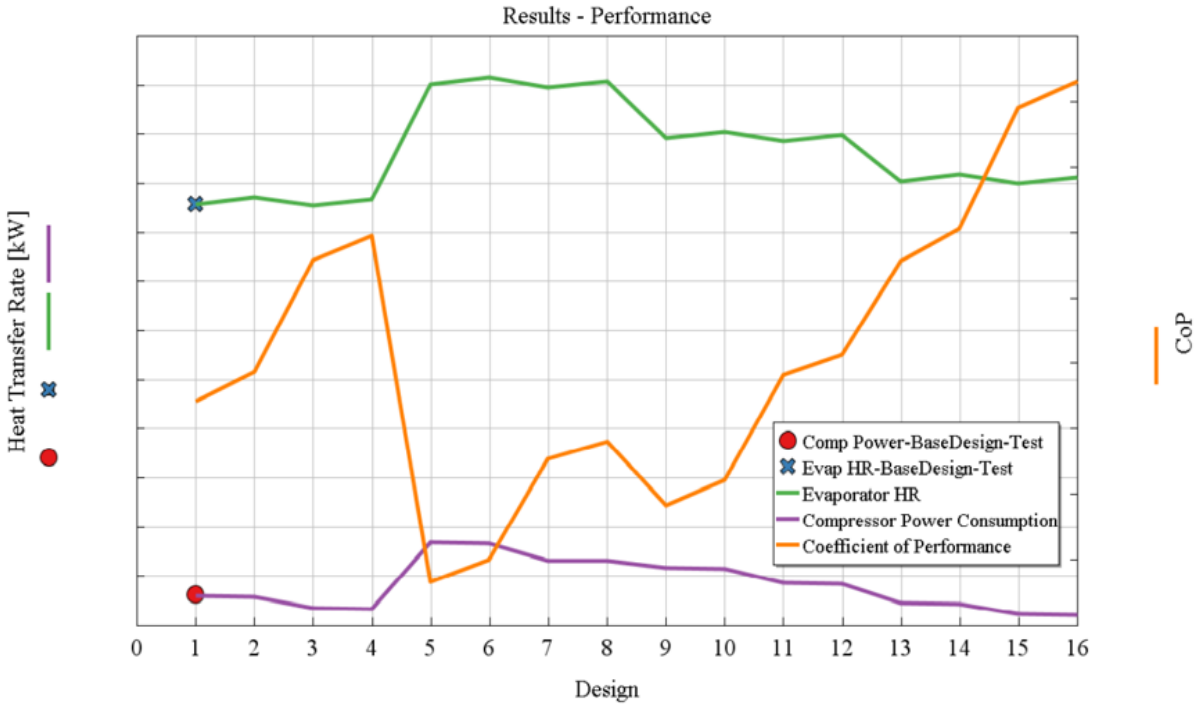
Evaporator Base – Original Dimensions with length = 750 mm
Evaporator 2 – Scaled to length = 950 mm

Parameter	Active	Compressor	Condenser	Evaporator
Units				
Label				
1	☑	Comp-Base	Cond-BaseDesign	Evap-BaseDesign
2	☑	Comp-Base	Cond-BaseDesign	Evap-2
3	☑	Comp-Base	Cond-2	Evap-BaseDesign
4	☑	Comp-Base	Cond-2	Evap-2
5	☑	Comp-2	Cond-BaseDesign	Evap-BaseDesign
6	☑	Comp-2	Cond-BaseDesign	Evap-2
7	☑	Comp-2	Cond-2	Evap-BaseDesign
8	☑	Comp-2	Cond-2	Evap-2
9	☑	Comp-3	Cond-BaseDesign	Evap-BaseDesign
10	☑	Comp-3	Cond-BaseDesign	Evap-2
11	☑	Comp-3	Cond-2	Evap-BaseDesign
12	☑	Comp-3	Cond-2	Evap-2
13	☑	Comp-4	Cond-BaseDesign	Evap-BaseDesign
14	☑	Comp-4	Cond-BaseDesign	Evap-2
15	☑	Comp-4	Cond-2	Evap-BaseDesign
16	☑	Comp-4	Cond-2	Evap-2

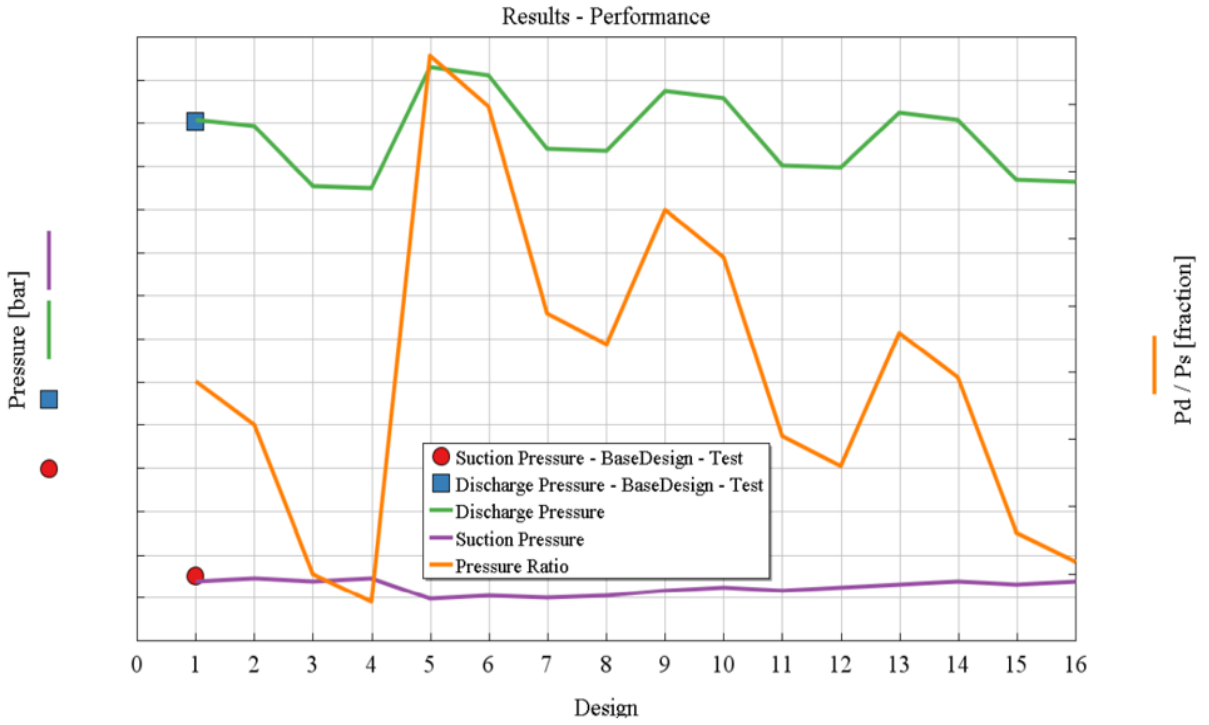
Total DOE Combination:
4*2*2 =16 feasible designs!!!

Results

Heat transfer Rate & COP



Pressure (Suction/Discharge)



Results-Ranking

	Cooling Capacity of Evaporator	Compressor Power	Coefficient of Performance	Refrigerant Mass Flow Rate	Subcool at Condenser Outlet
Unit	kW	kW		kg/h	Delta K
Comp-Base;Cond-BaseDesign;Evap-BaseDesign					
Comp-Base;Cond-BaseDesign;Evap-2					
Comp-Base;Cond-2;Evap-BaseDesign					
Comp-Base;Cond-2;Evap-2 2					
Comp-2;Cond-BaseDesign;Evap-BaseDesign					
Comp-2;Cond-BaseDesign;Evap-2					
Comp-2;Cond-2;Evap-BaseDesign					
Comp-2;Cond-2;Evap-2					
Comp-3;Cond-BaseDesign;Evap-BaseDesign					
Comp-3;Cond-BaseDesign;Evap-2					
Comp-3;Cond-2;Evap-BaseDesign					
Comp-3;Cond-2;Evap-2					
Comp-4;Cond-BaseDesign;Evap-BaseDesign					
Comp-4;Cond-BaseDesign;Evap-2					
Comp-4;Cond-2;Evap-BaseDesign					
Comp-4;Cond-2;Evap-2 1					

Parameter	Calibrated Case
Capillary	ID--1.524mm
	OD --3.2mm
	length 800mm
Gas	930g
Capacity	5.11
Test	5.11
% Diff	0.1
Power	1.34
Test	1.41
% Diff	4.9
Airflow (CMH)	858
GT-SUITE Case Labels	Evap-VFR=858; Charge=930

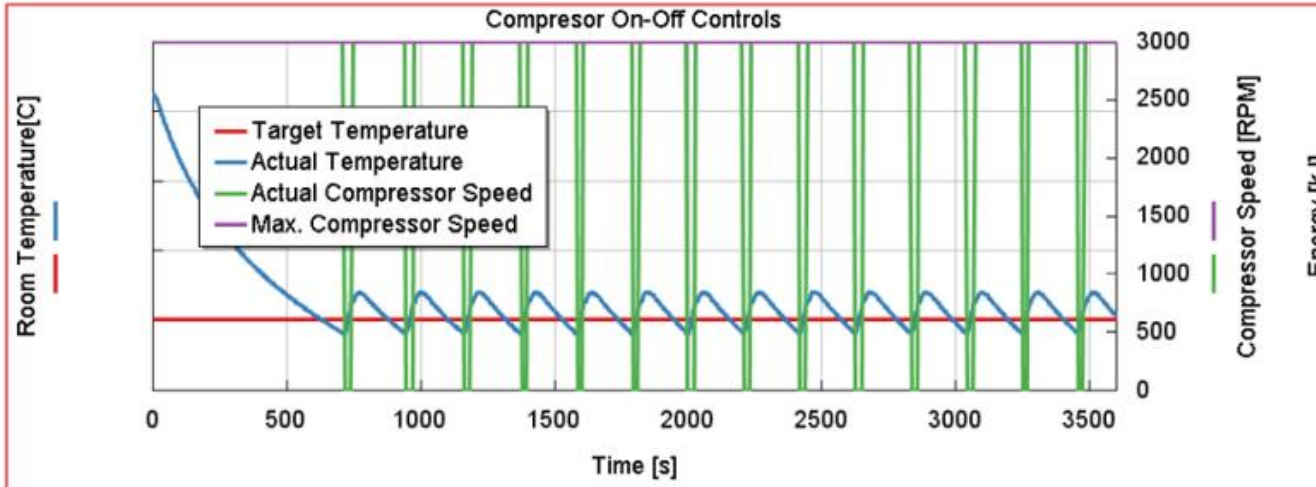
2nd best design by using the same compressor but scaling the heat exchanger

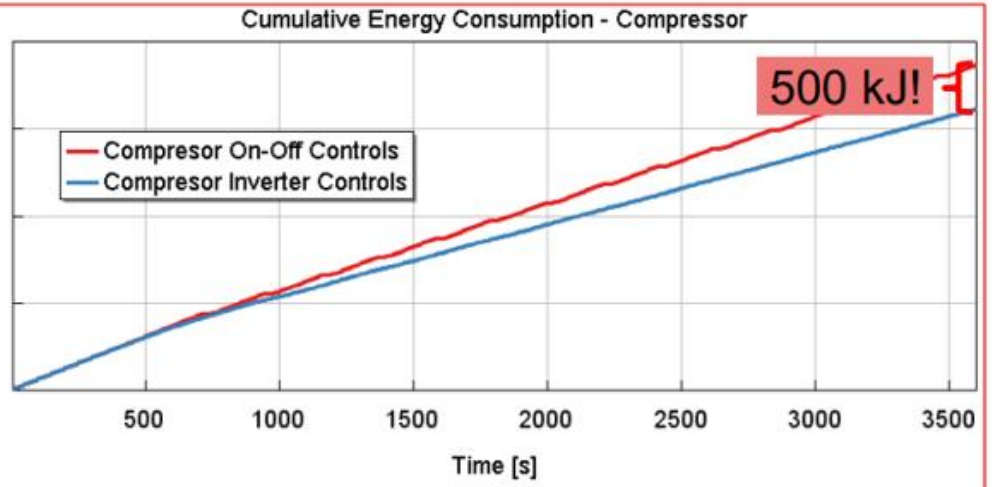
Best Design but getting an efficient compressor is costly

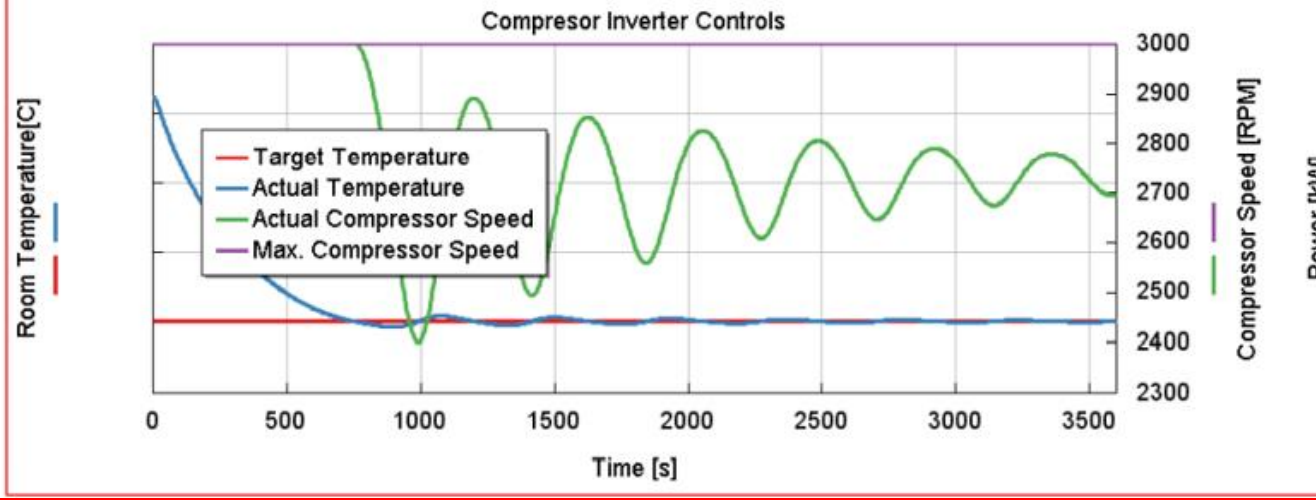
Designs were ranked based on GT results and final selected model was tested having correlation above >95 % w.r.t testing.

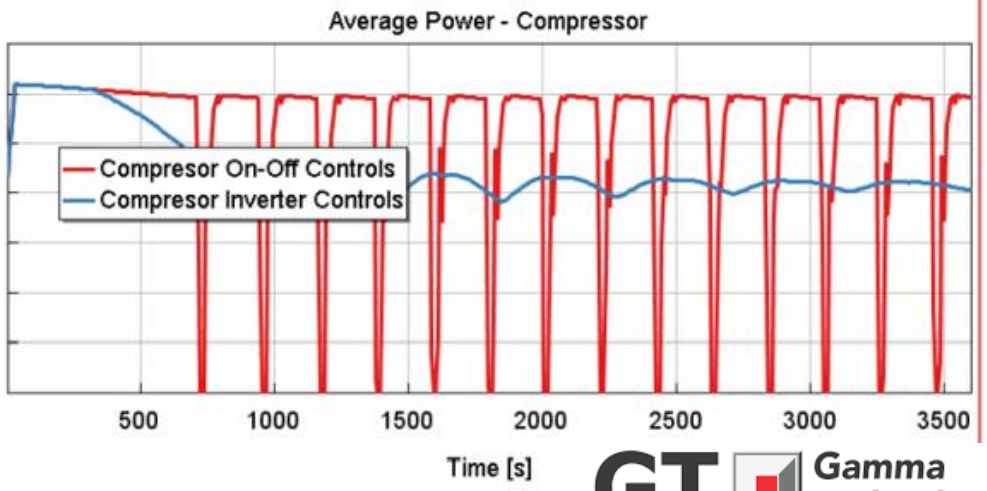
Results: Additional

1. Around 500 kJ (0.14 kWhr or Units of electricity) savings in 1 hour of operations by using variable speed compressors
2. This can be combined with the DoE of different components in the earlier study









Benefit

- Time Saving
  - Week→ Day . (Water Heater Applications: Standing Loss Determination)
- Cost Saving
  - Lesser Number of prototypes
- Performance Improvement
  - Parametric optimizations

Conclusion

- 1D simulation provides key insights in very less time w.r.t. 3D Simulations.
- Model tuning and initial settings and deploying correct physics is important.
- Test bench results can also be feed to design and develop more robust DOE.

HAVELLS

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Thank You !!!

Any Questions ???

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