CEEE CENTER *for* ENVIRONMENTAL ENERGY ENGINEERING

Heat Pump Research Center For Environmental Energy Engineering

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UNIVERSITY OF 18 56 MARYLAND

CEEE

CEEE Vision

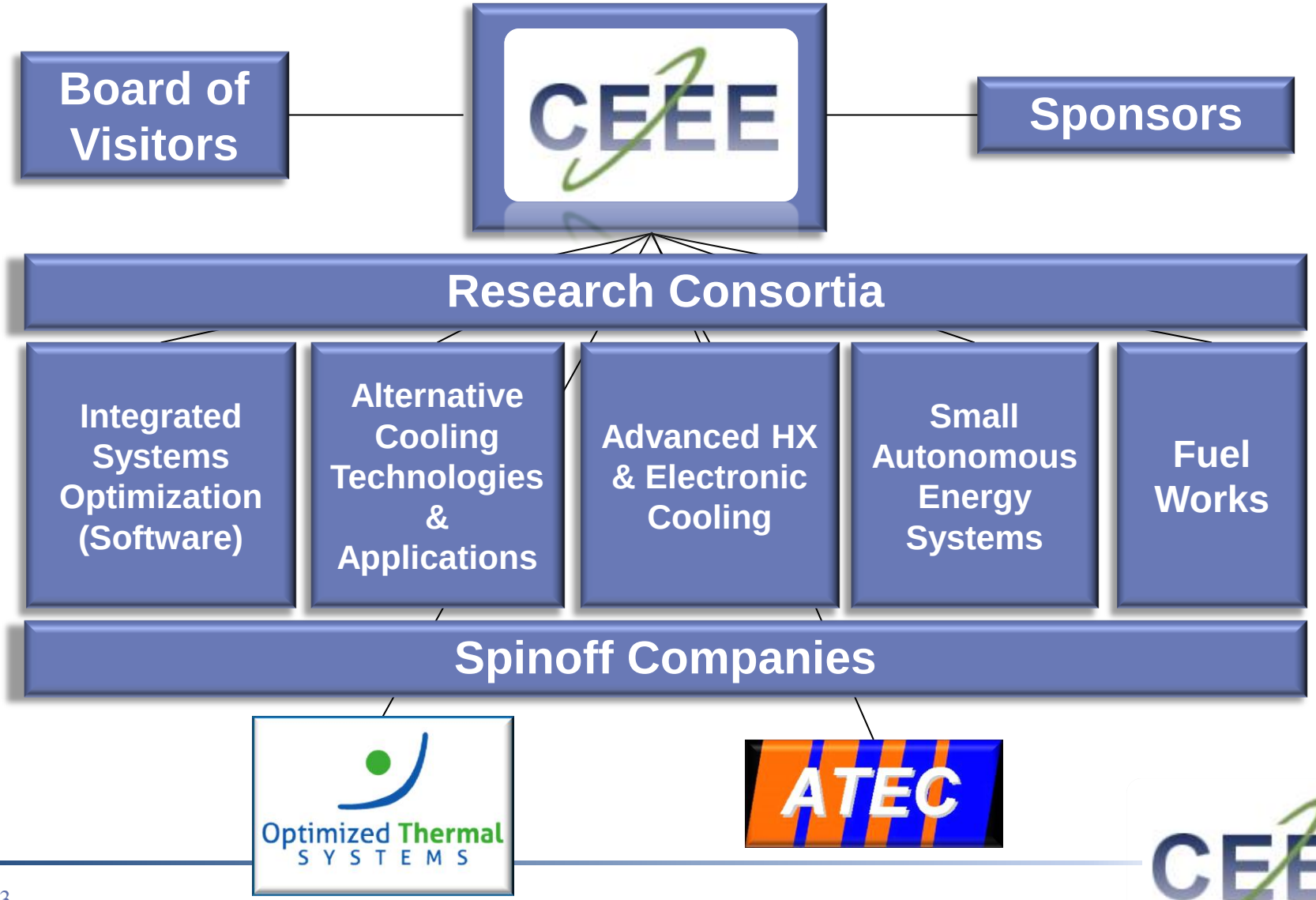
Enabling Energy Sustainability

Energy Efficiency & Renewable Energy

Helping Engineers Innovate

Leveraging computing power to free engineers' creativity and intuition!

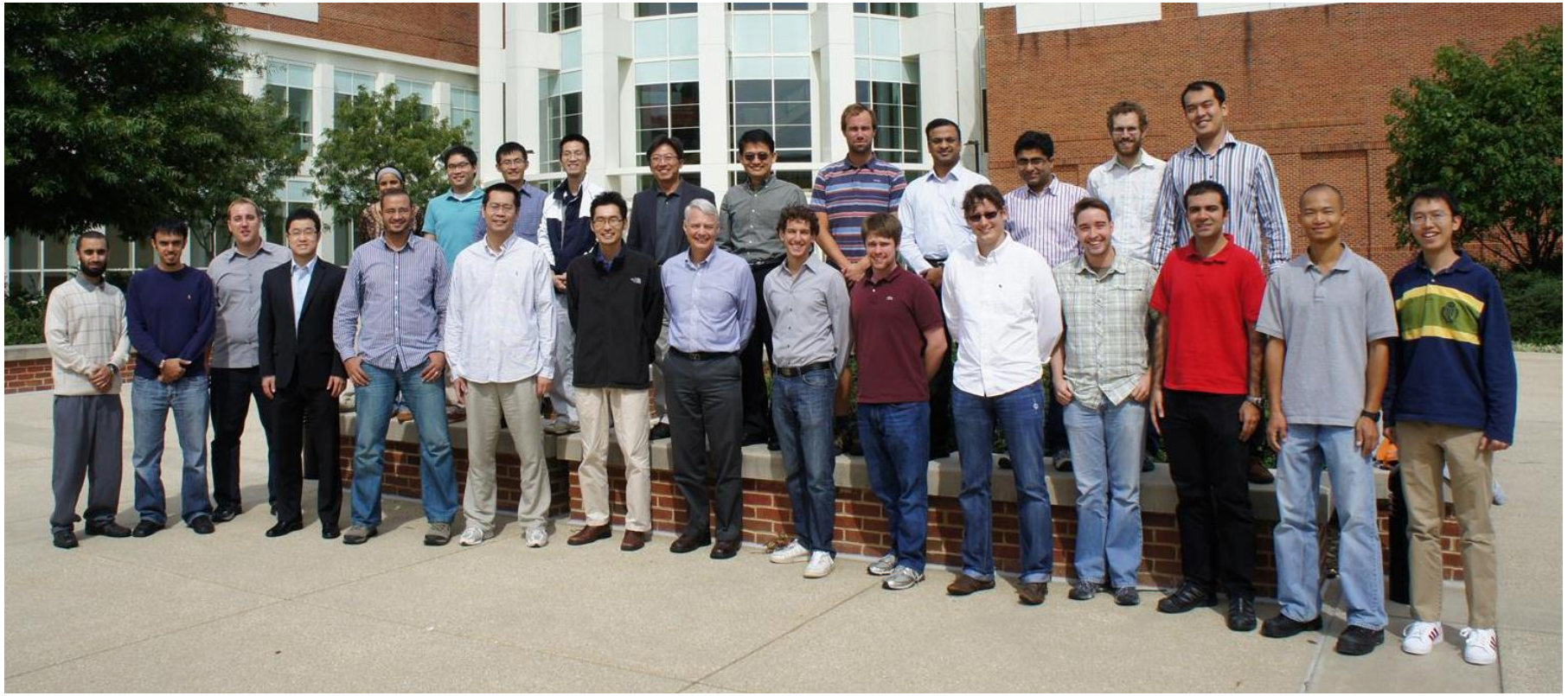
CEEE Organization

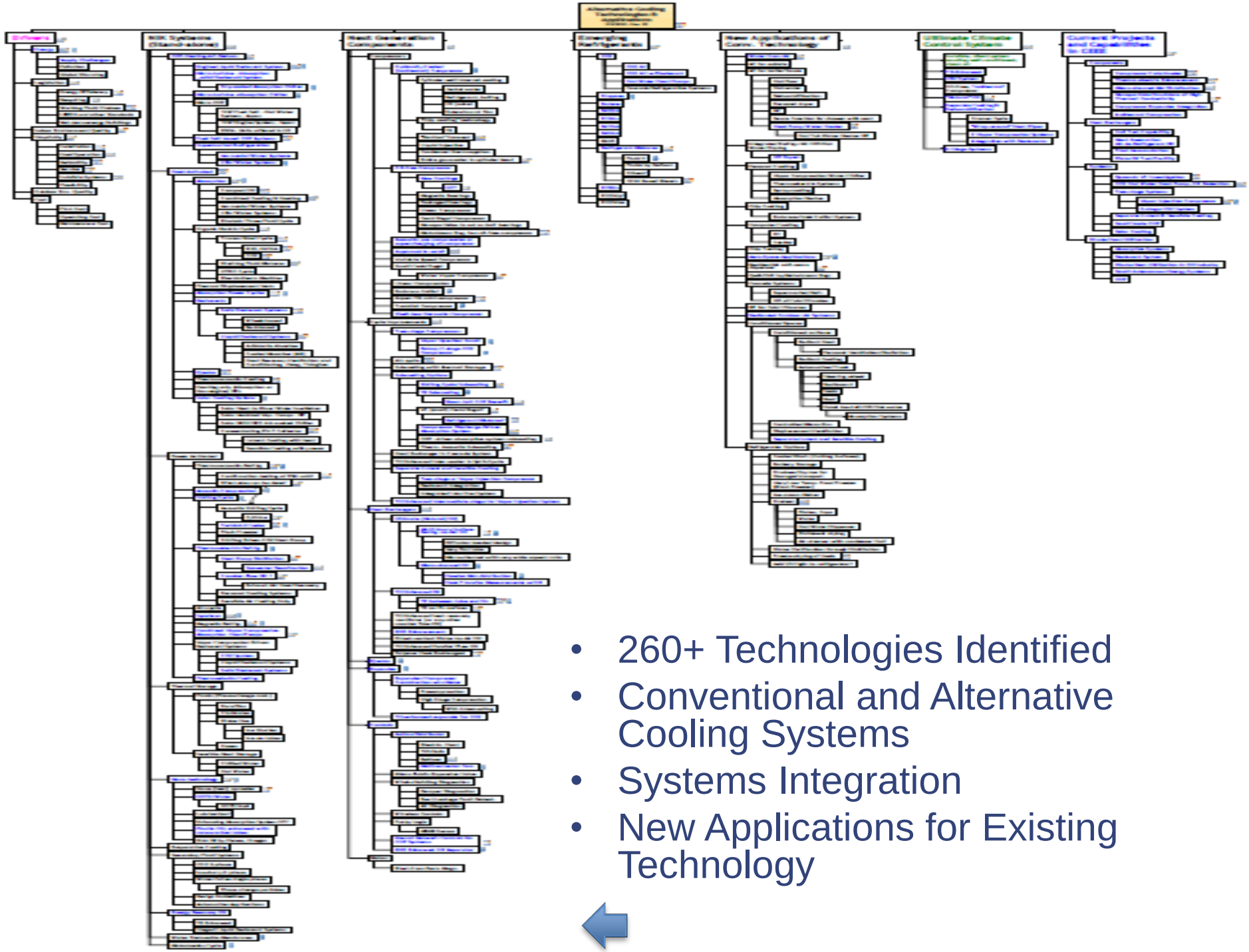


CEEE Sponsors

1	Arcelik	12	Gree	23	Mitsubishi Plastics
2	Ballard	13	Guentner	24	Modine
3	Bosch/FHP	14	HTPG	25	**Petroleum Institute**
4	Daikin + McQuay	15	Honeywell	26	Sanden
5	Danfoss	16	Hydro	27	Sanhua
6	Delphi	17	Ingersoll Rand	28	Sanyo
7	Denso	18	Johnson Controls	29	SAPA
8	**DOE/ORNL**	19	LG Electronics	30	Shanghai Hitachi
9	DunAn	20	Luvata	31	Sub-Zero
10	Emerson +Liebert	21	**Mainstream Eng.**	32	Suez
11	GE Appliances	22	Midea	33	Whirlpool
				34	Wolverine

HP Faculty, Students and Staff



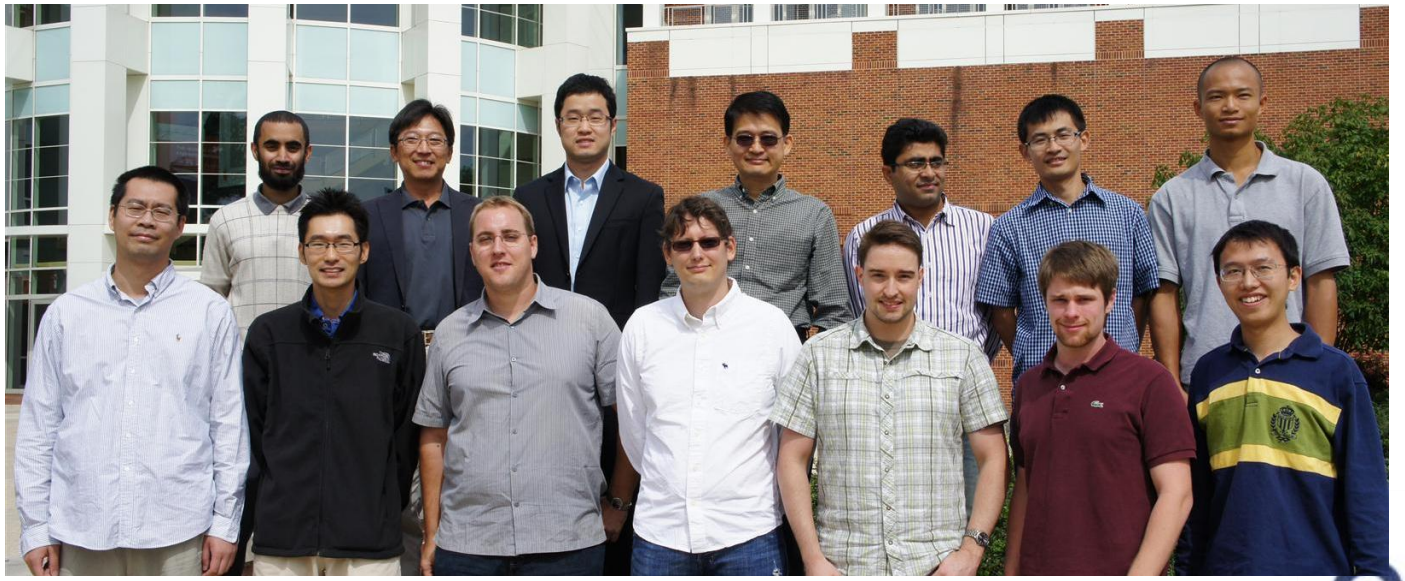


- 260+ Technologies Identified
- Conventional and Alternative Cooling Systems
- Systems Integration
- New Applications for Existing Technology

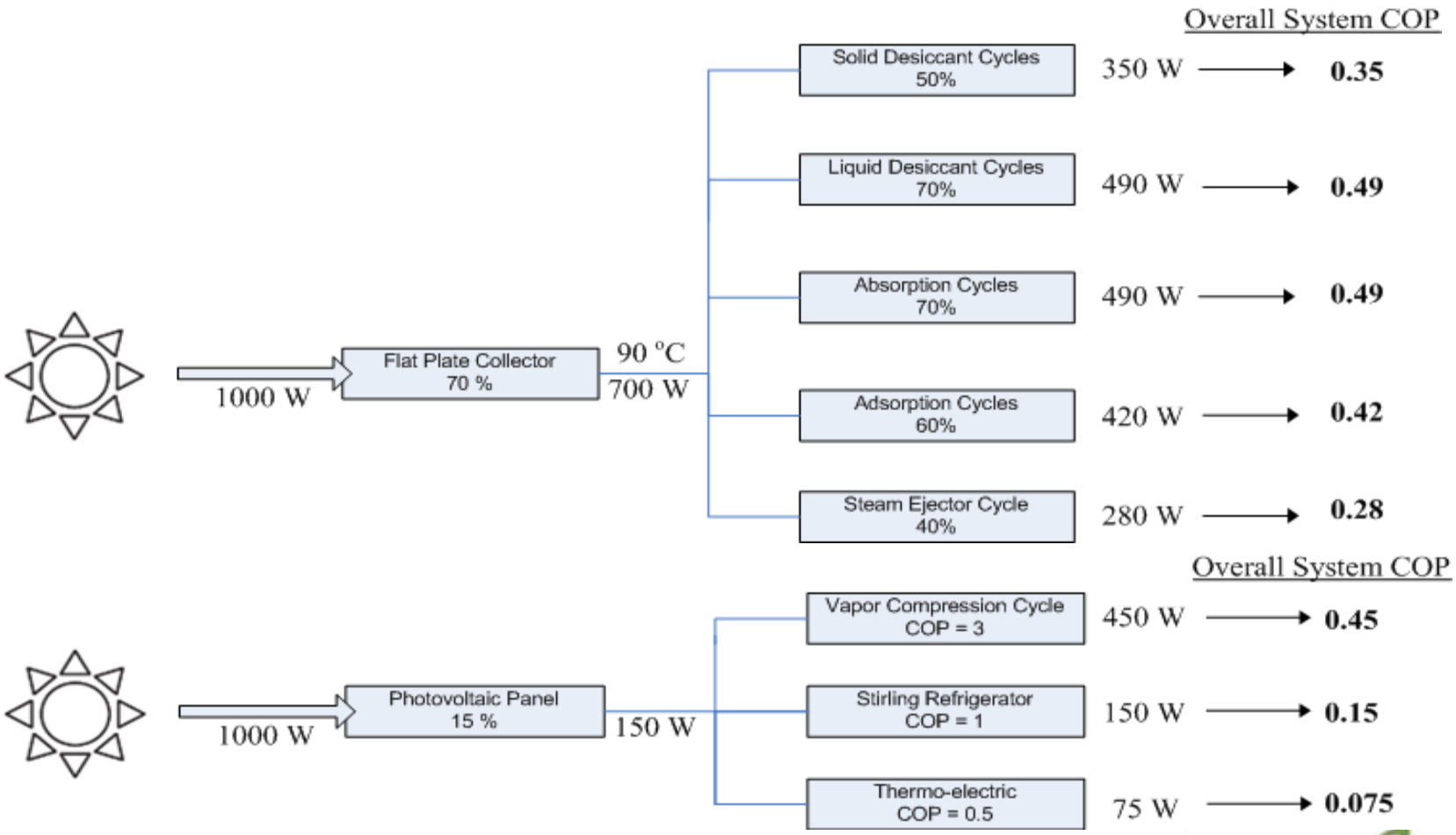
Alternative Cooling Techn. & Appl. Consortium

Projects

- Vapor Inj. HP System
- VRF Field Tests
- Secondary Loop System
- Low H-Flux HT
- Solar Cooling and Solar Decathlon
- Water Retention
- Plate HX Test Facility
- Separate Sensible & Latent Cooling
- TE-VC Integration
- ACTA Map
- Past Projects

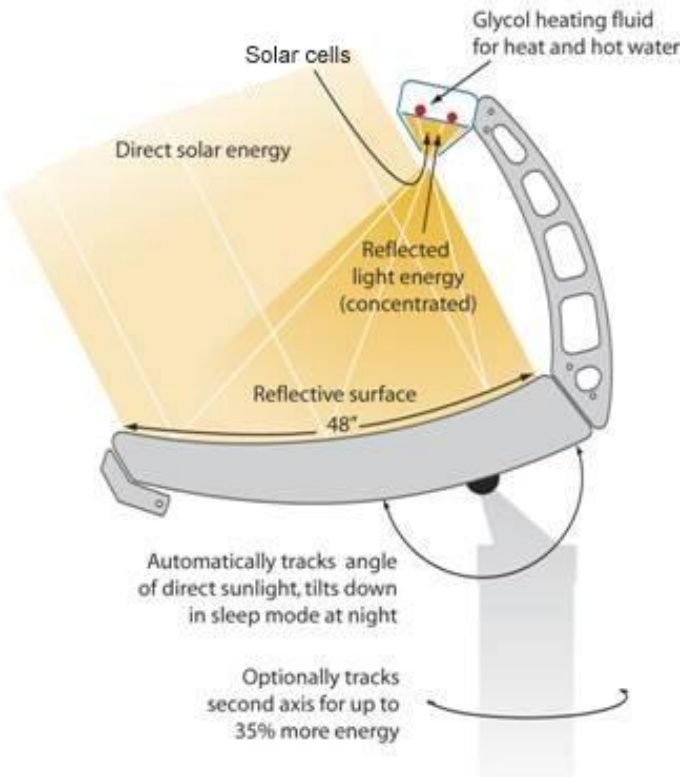


Solar Cooling Efficiency Comparison

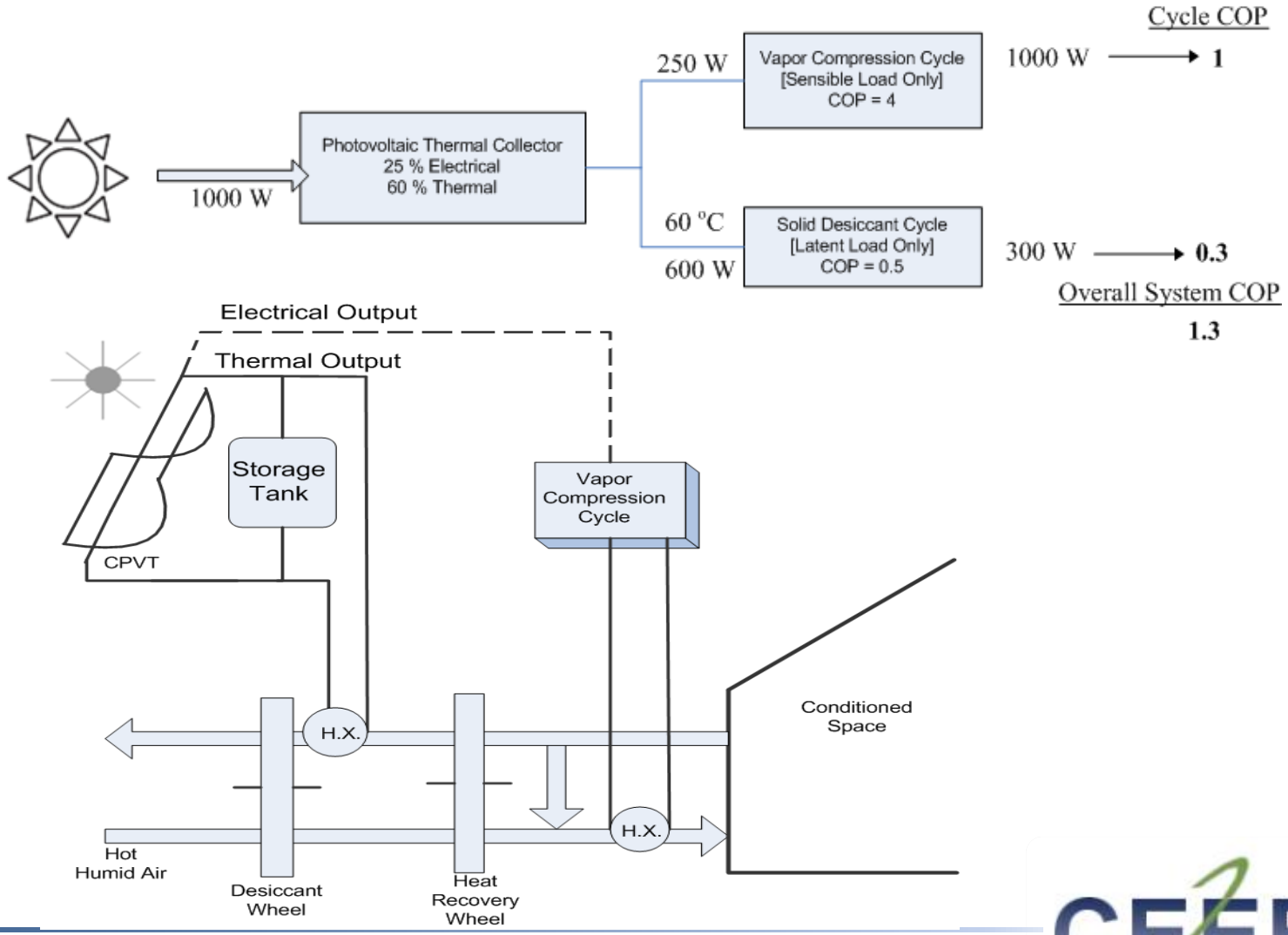


Preferred Collector

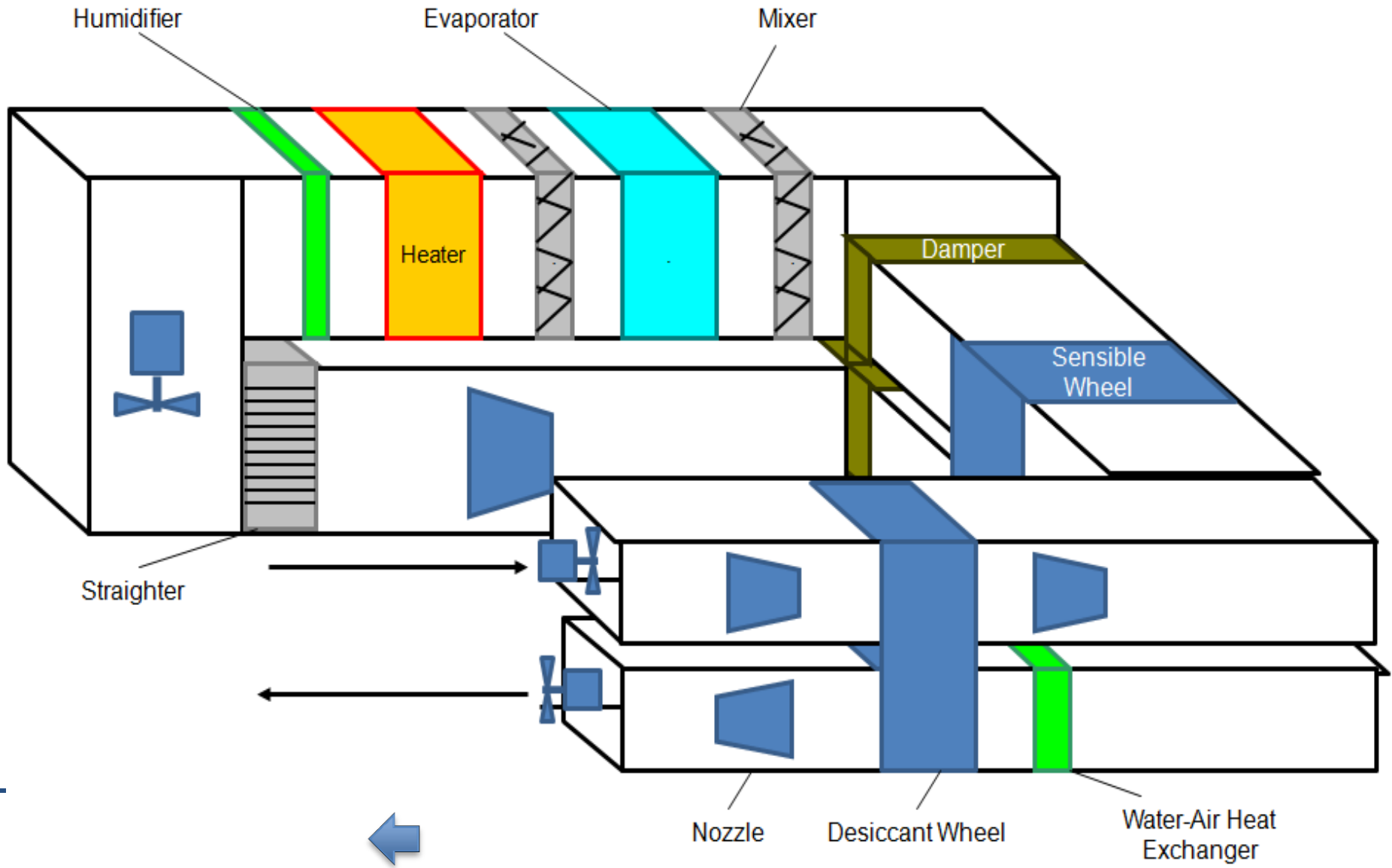
- **Concentrated Photovoltaic/Thermal Collector:**
  - **Two collectors combined into one**
  - **Electricity**
  - **Hot water**
- **Potential for higher combined efficiency**



Proposed System



Experimental Work



Two Solar Decathlon Entries

UMD

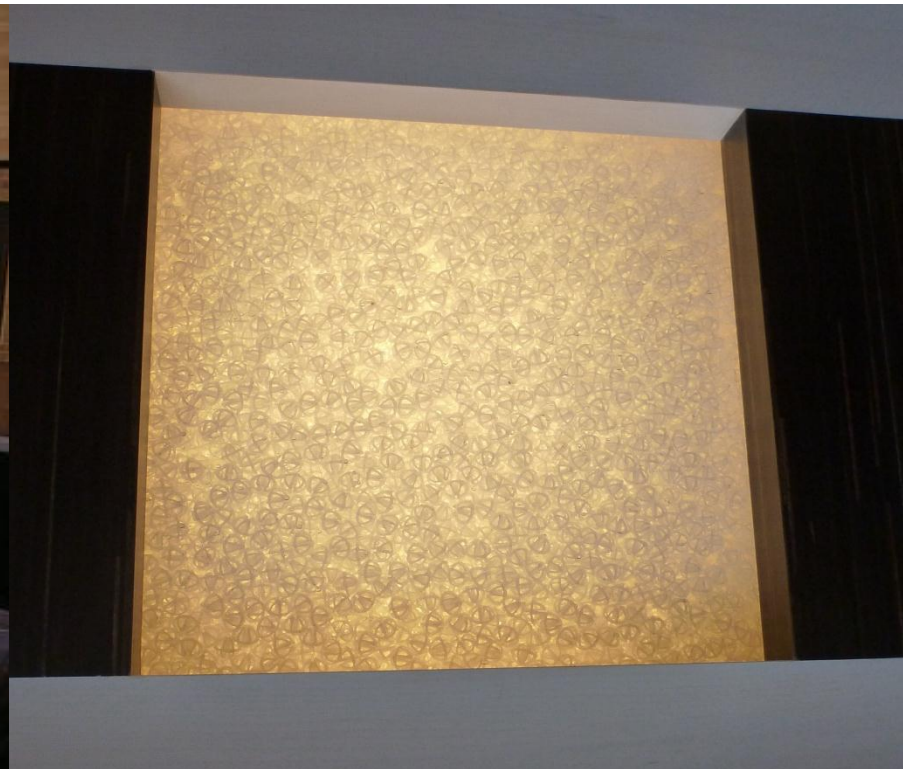
- 2nd Place 2007
- 1st Place, 2011


Leafhouse 2007


Watershed 2011

Dehumidification

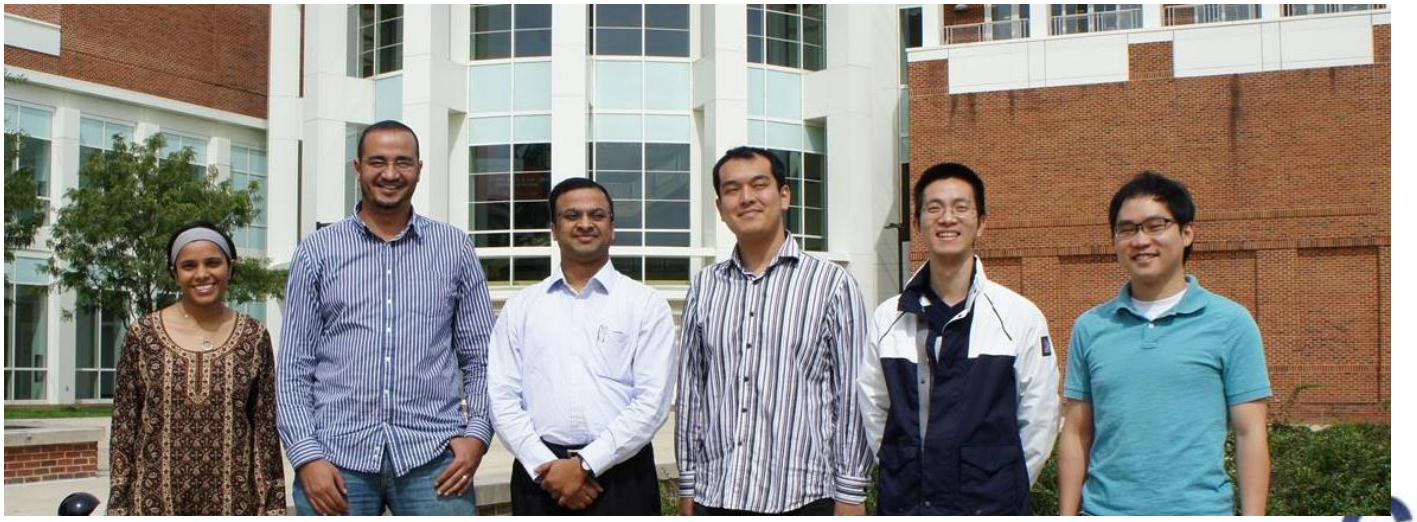
- Liquid Desiccant (Water)Fall
  - Architectural feature
  - CaCl2 Solution
  - Solar hot water regeneration
  - Solution storage tank
  - Split system AC
  - Now basis for start-up company



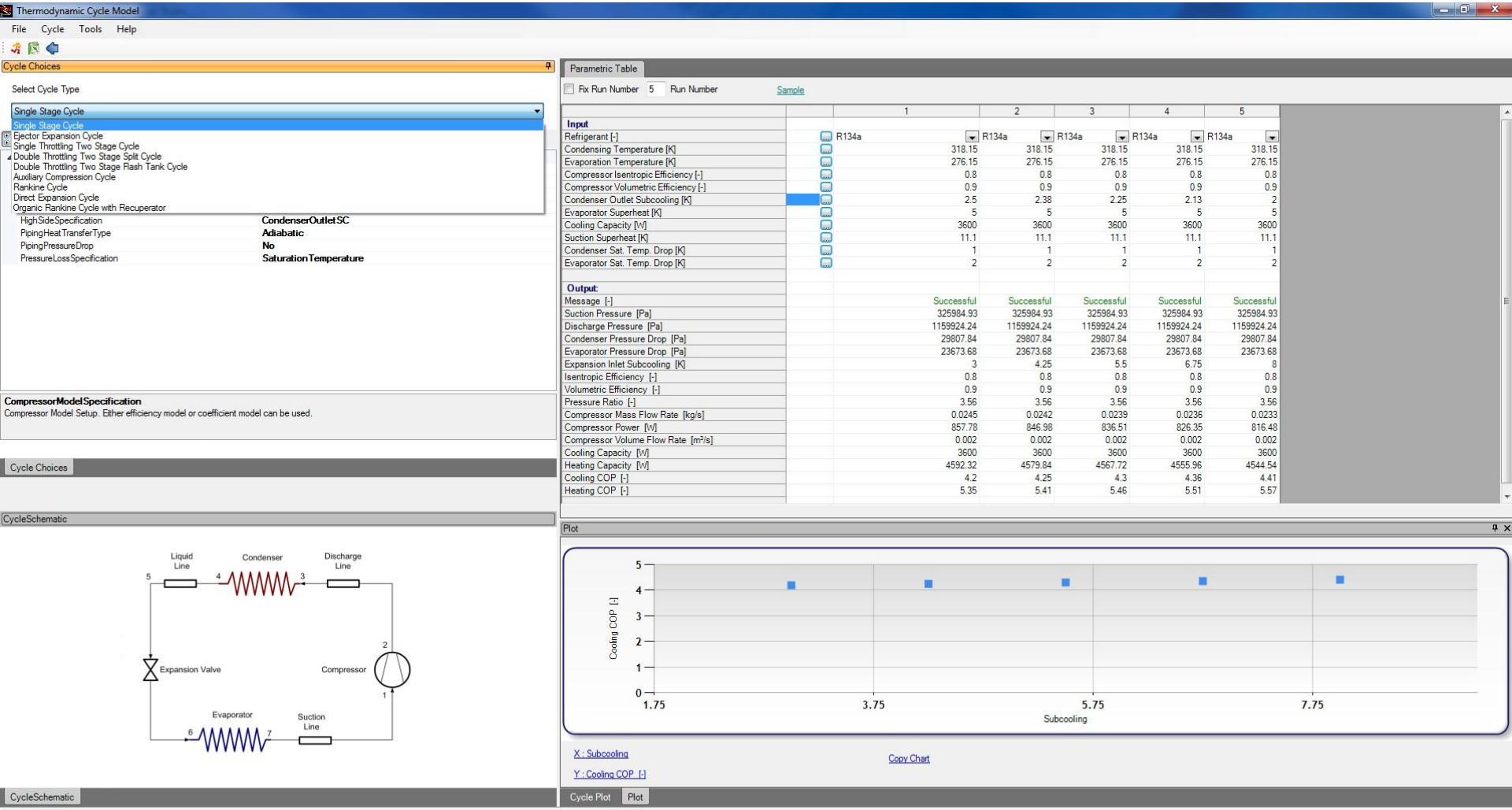
Integrated System Optimization Consortium

Software Projects

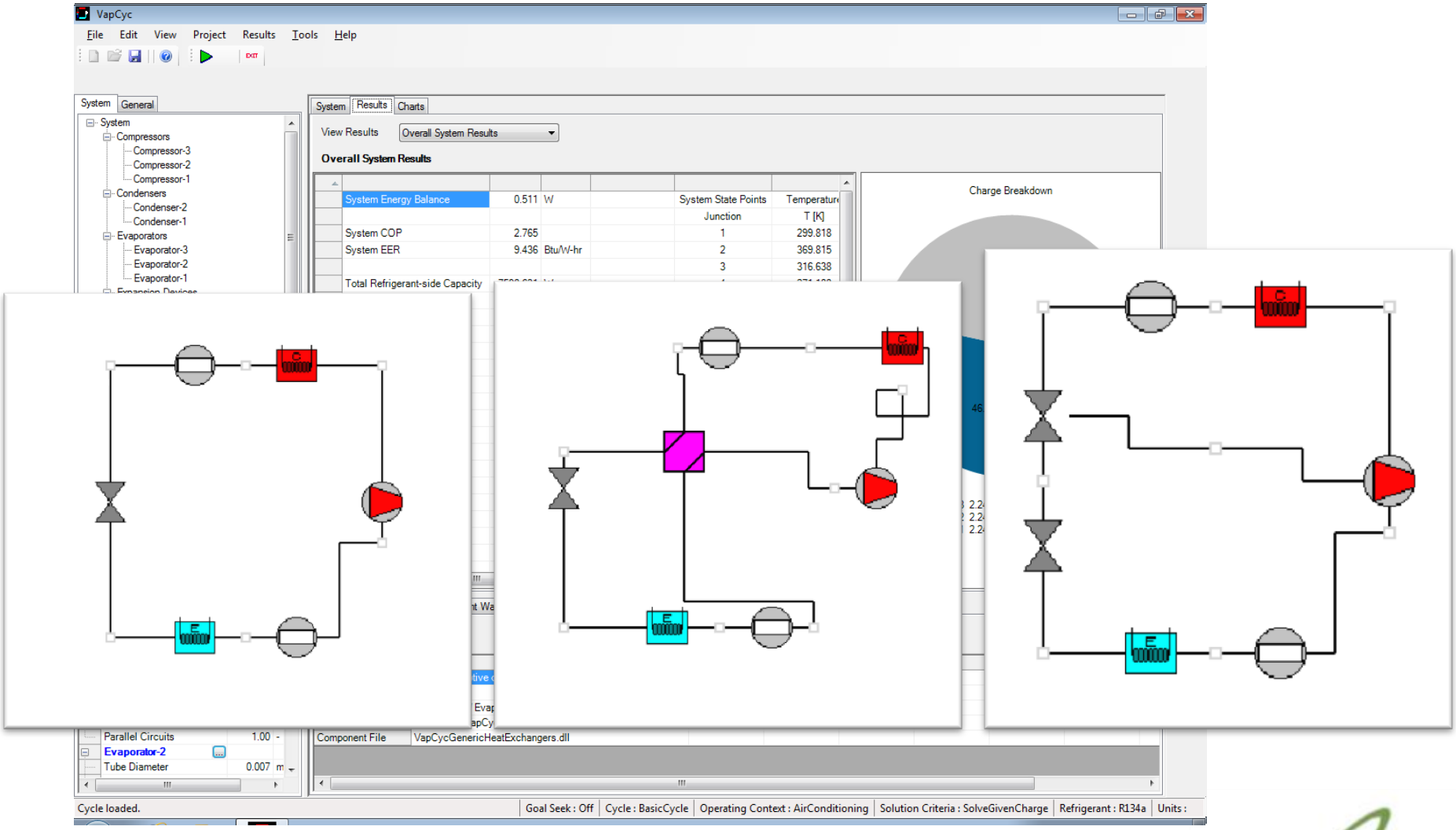
- CoilDesigner and Other Heat Exchangers
- PHESim
- VapCyc, TCM
- TransRef, Dymola/Modelica-SimScape
- TSIOP (Maximizing Innovation)
- DAVi
- NGHX, Optimization & Verification
- Positive Displacement Compressors/Expanders
- Usage Statistics
- Long-term ISOC Goals



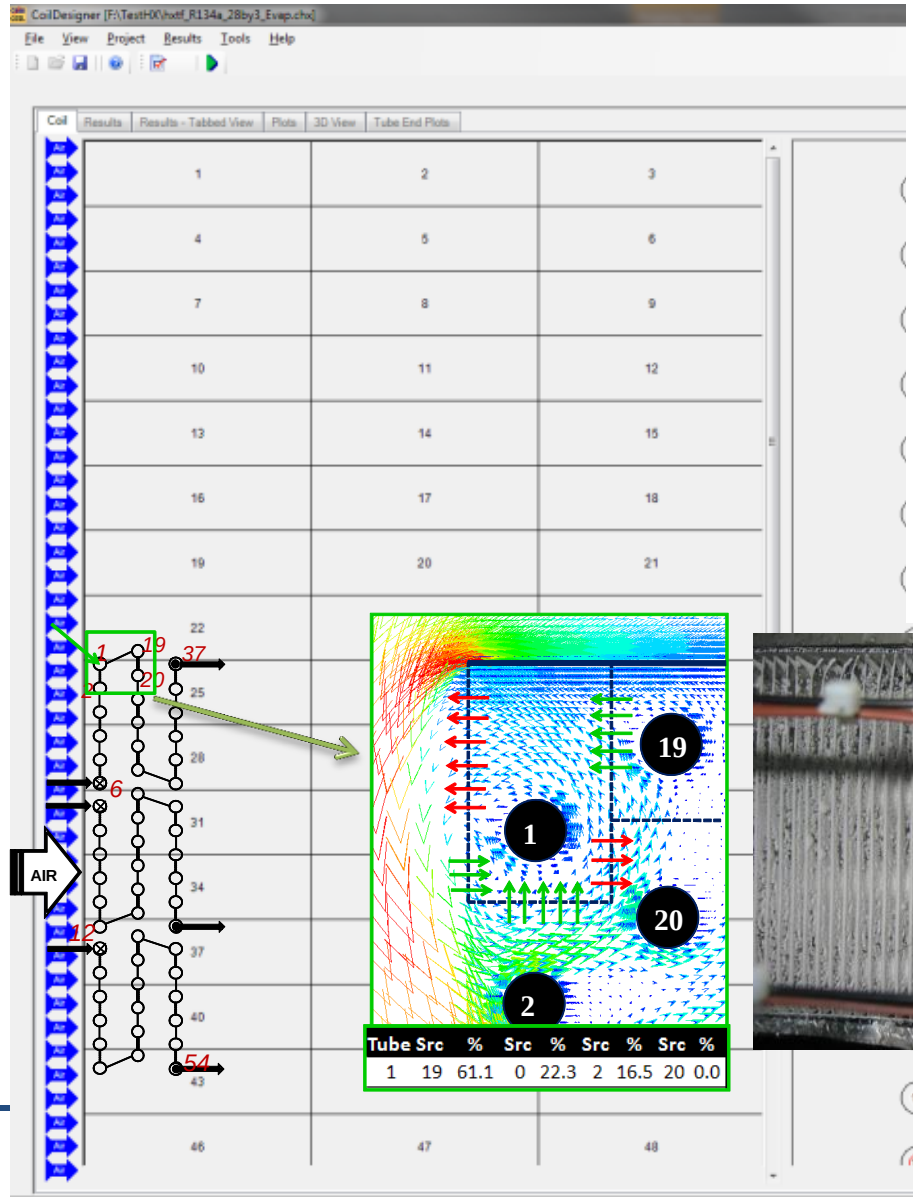
Thermodynamic Cycles Model

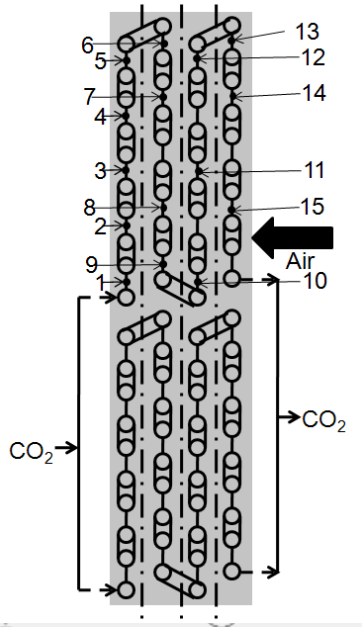


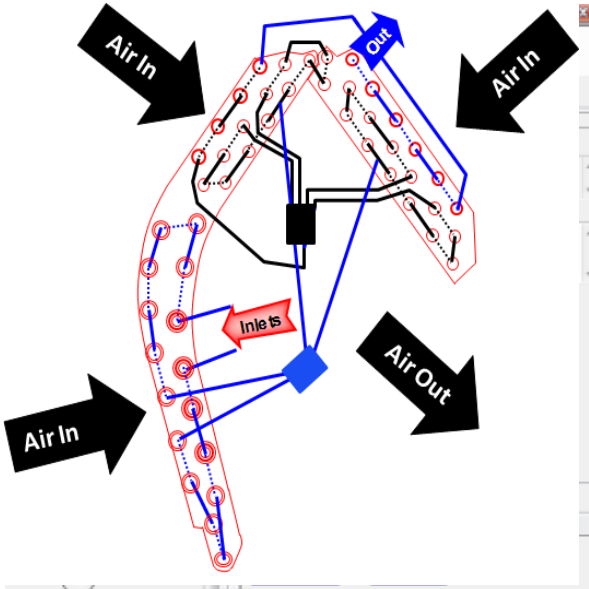
VapCyc

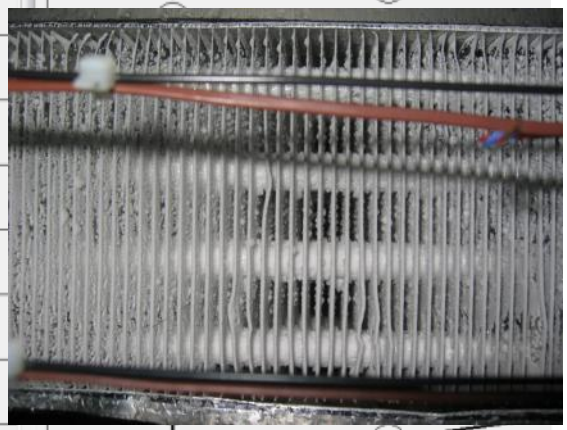

VapCyc
File Edit View Project Results Tools Help
System General
System
Compressors
Compressor-3
Compressor-2
Compressor-1
Condensers
Condenser-2
Condenser-1
Evaporators
Evaporator-3
Evaporator-2
Evaporator-1
System Results Charts
View Results
Overall System Results
Overall System Results
System Energy Balance 0.511 W
System COP 2.765
System EER 9.436 Btu/W-hr
Total Refrigerant-side Capacity
System State Points
Junction
T [K]
1 299.818
2 369.815
3 316.638
Charge Breakdown
Parallel Circuits 1.00
Evaporator-2
Tube Diameter 0.007 m
Component File VapCycGenericHeatExchangers.dll
Cycle loaded.
Goal Seek : Off
Cycle : BasicCycle
Operating Context : AirConditioning
Solution Criteria : SolveGivenCharge
Refrigerant : R134a
Units :

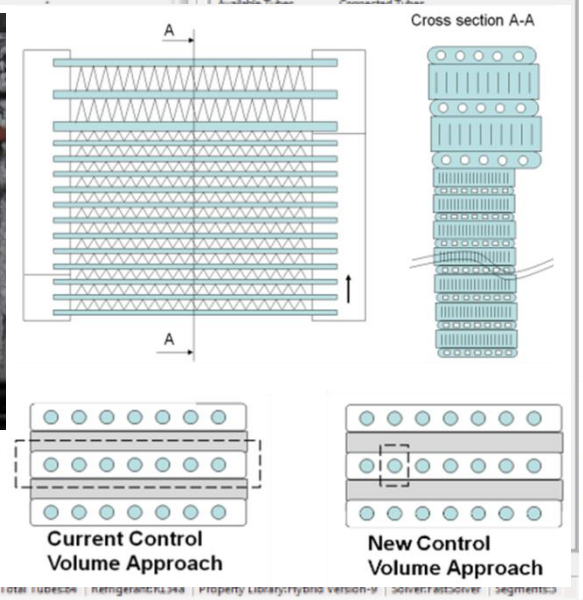
CoilDesigner



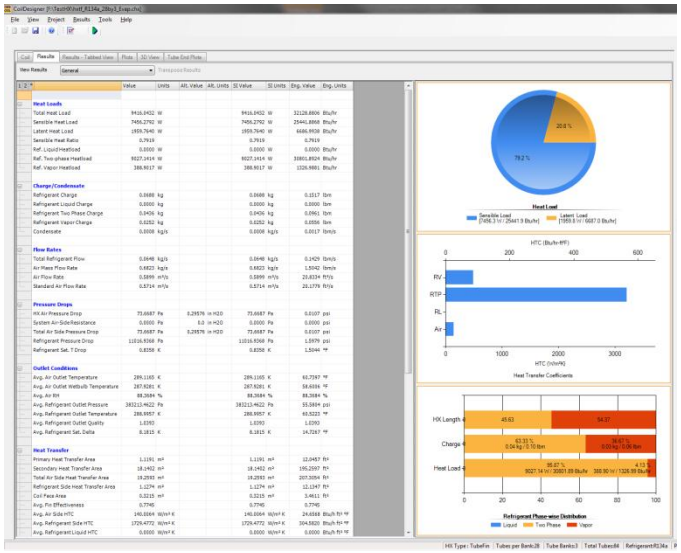


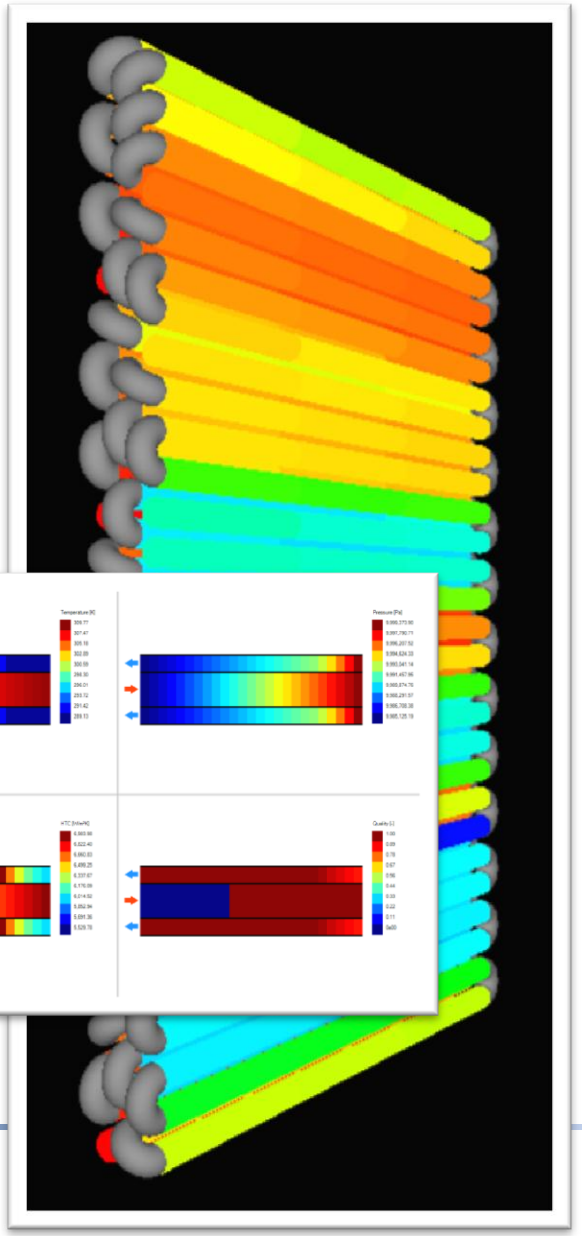


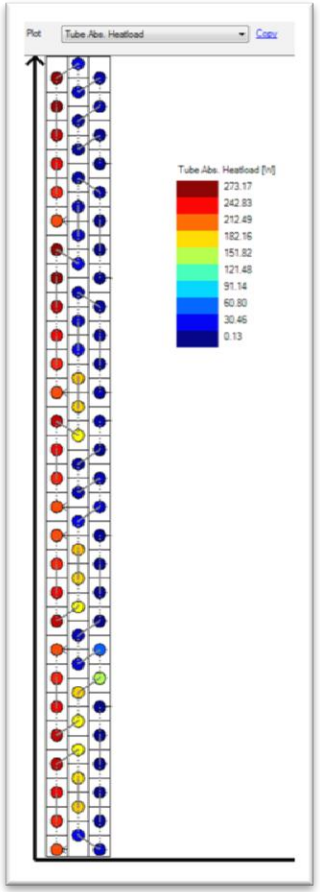


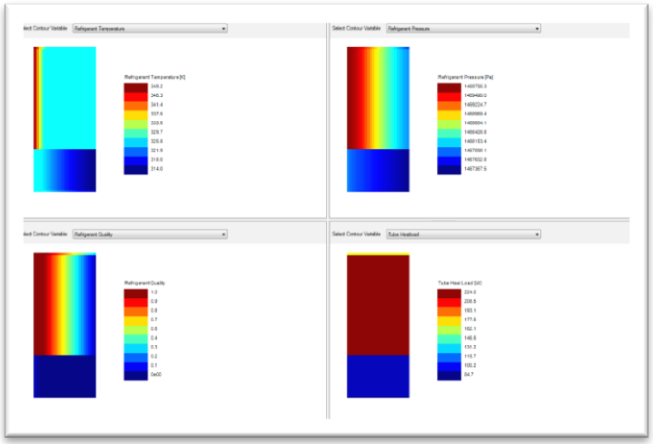


CoilDesigner









ΦSim UI

Geometry Input

Flow Arrangement

Fluid Input

Results

PHE SIMULATION

Geometry

Plate Type: Plain Plate | Length: 0.9 m | Width: 0.6 m | Plate Number: 12

Plate Pitch: 0.005 m | Port Distance: 1.0 m | Plate Thickness: 0.0005 m | Segment Number: 10

Chevron Angle: 60 | Enlongation Factor: 1.2 | Corrugation Pitch: 0.01 m

Fouling Factor (Cold): 0 | Fouling Factor (Hot): 0 | Plate Conductivity: 28 W/m K

Pass Arrangement

Pass Arrangement: User Defined

Flow Arrangment (hot side)

Entry Position: 3

Number of Passes: 3

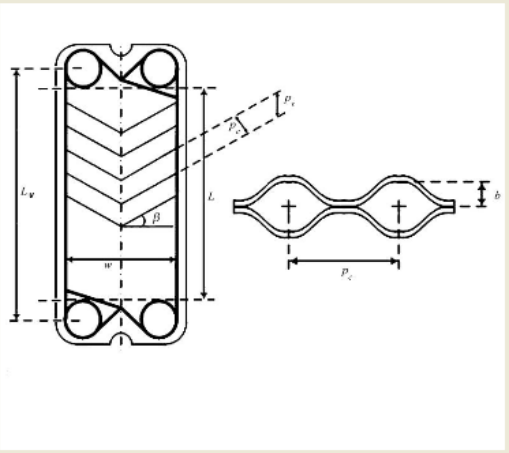
	Channel Number (Hot)
	1
	2
▶	2
*	

Flow Arrangement (Cold side)

Entry Position: 1

Number of Passes: 5

	Channel Number (Cold)
	1
	1
	2
	1
▶*	



Fluids (Hot side)

Fluid Type: Water | Mass flow Rate: 0.2 kg/s

Temperature: 293 K | Pressure: 100000 Pa

Fluids(Cold side)

Fluid Type: Water | Mass flow Rate: 0.2 kg/s

Temperature: 353 K | Pressure: 100000 Pa

Correlations

HTC and DP Correlation: Kumar

Correlation

Results

Total Heat transfer (Hot side): 27528.073 W

Outlet Temperature (Hot fluid): 320.128 K

Pressure Drop (Hot side): 91.415 Pa

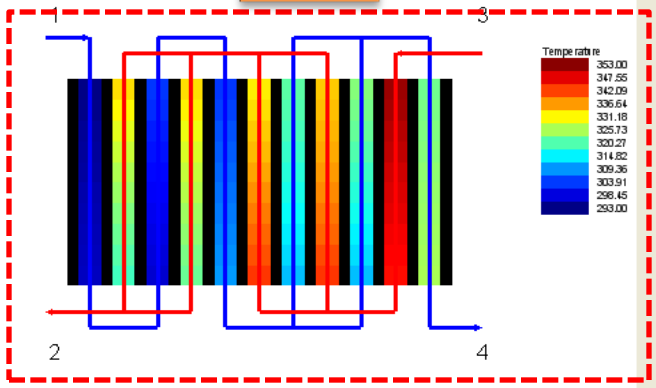
Total Heat Transfer (Cold side): 28022.959 W

Outlet Temperature (Cold side): 326.516 K

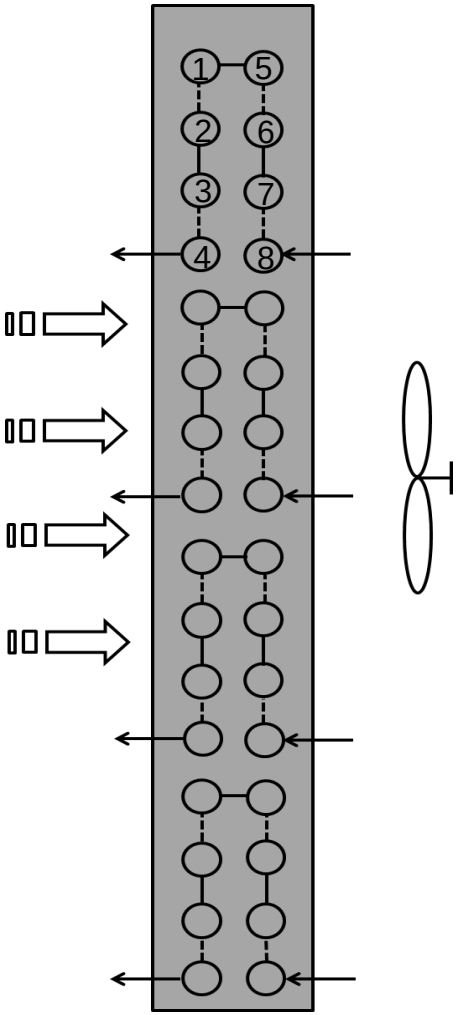
Pressure Drop (Cold side): 467.676 Pa

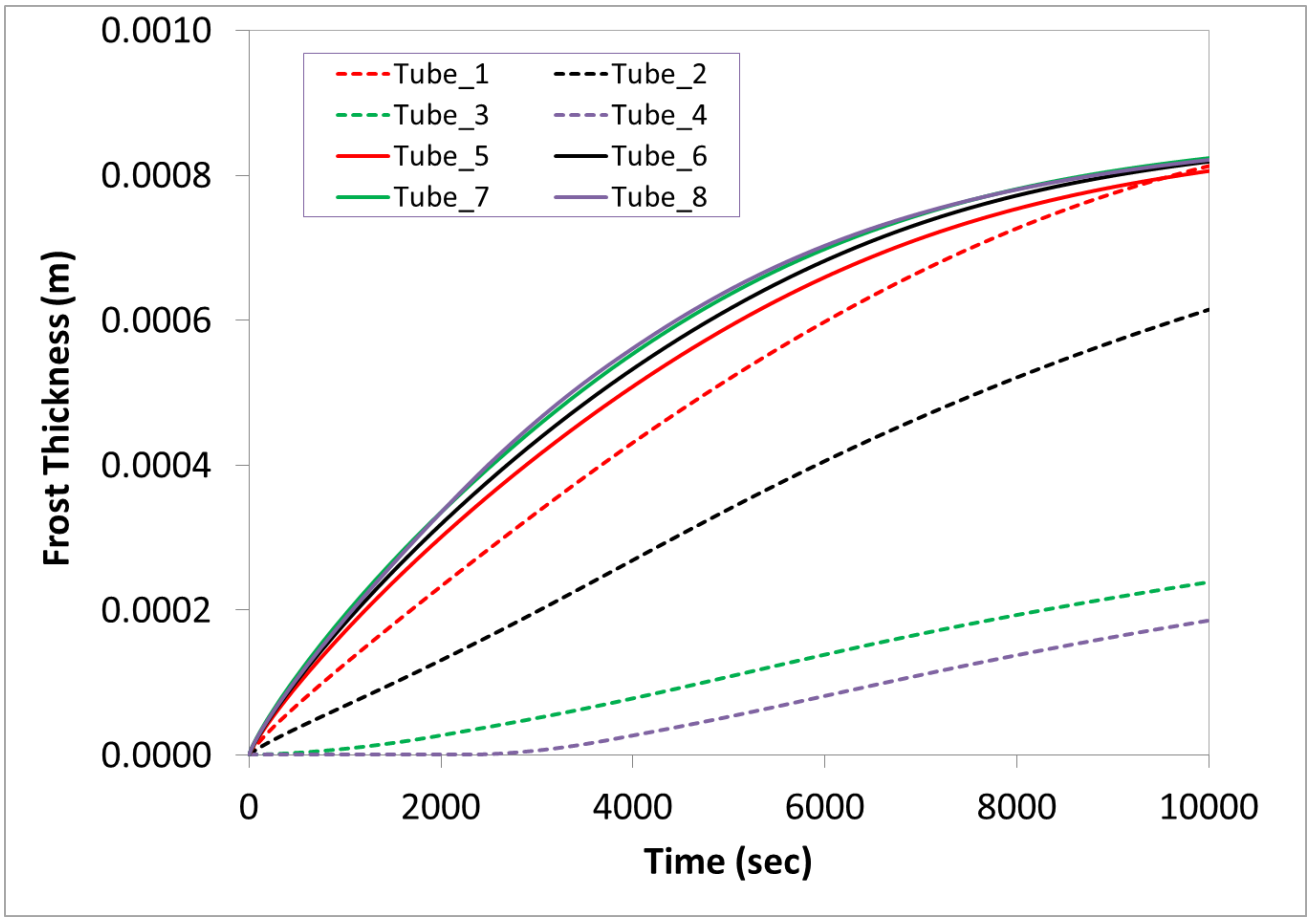
Save Inputdata | Load Inputdata | Calculate | Quit

Results

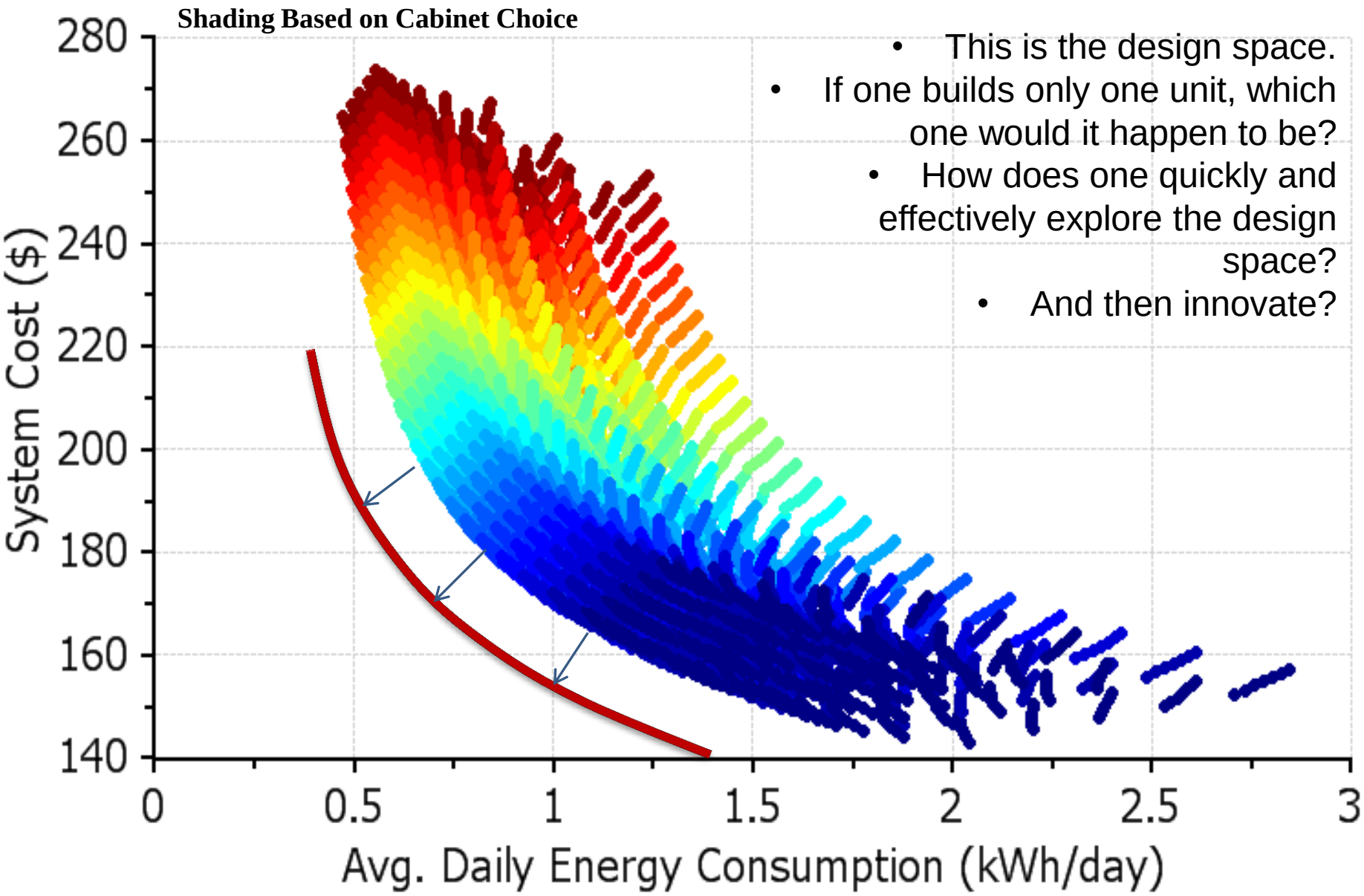


Dymola/Modelica Coil Frosting Simulation





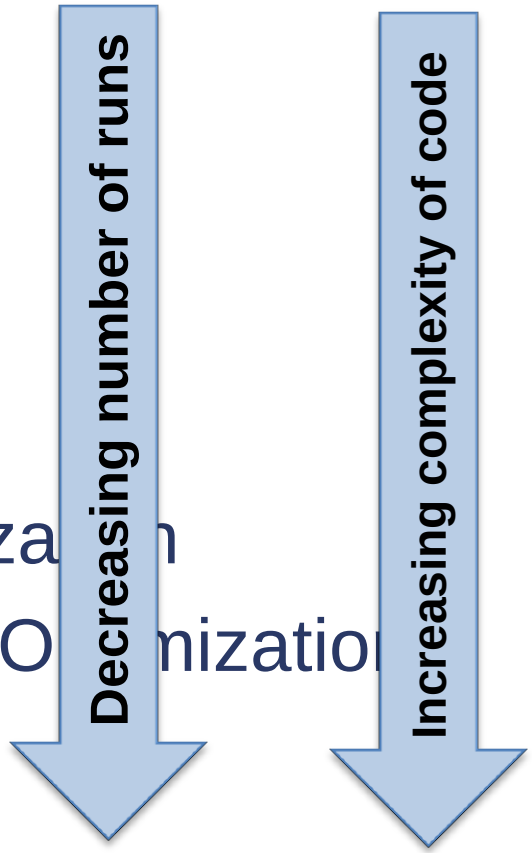
Helping Engineers Innovate



- This is the design space.
- If one builds only one unit, which one would it happen to be?
- How does one quickly and effectively explore the design space?
- And then innovate?

Methods to Find Best Designs

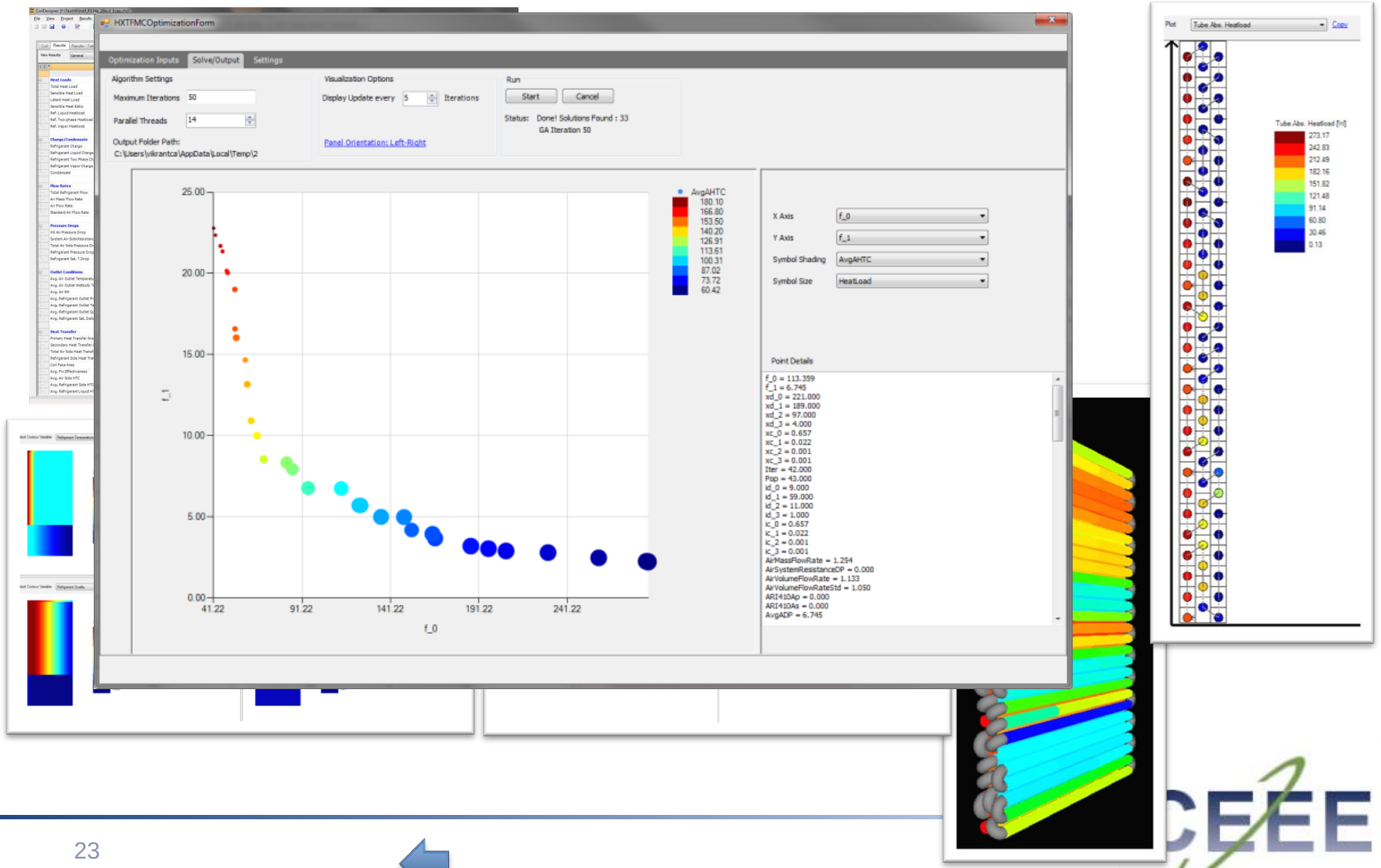
- Exhaustive Search
- DOE
- Optimization
  - Gradient based (calculus)
  - Heuristic (genetic algorithms)
- Approximation Assisted Optimization
- Online Approximation Assisted Optimization



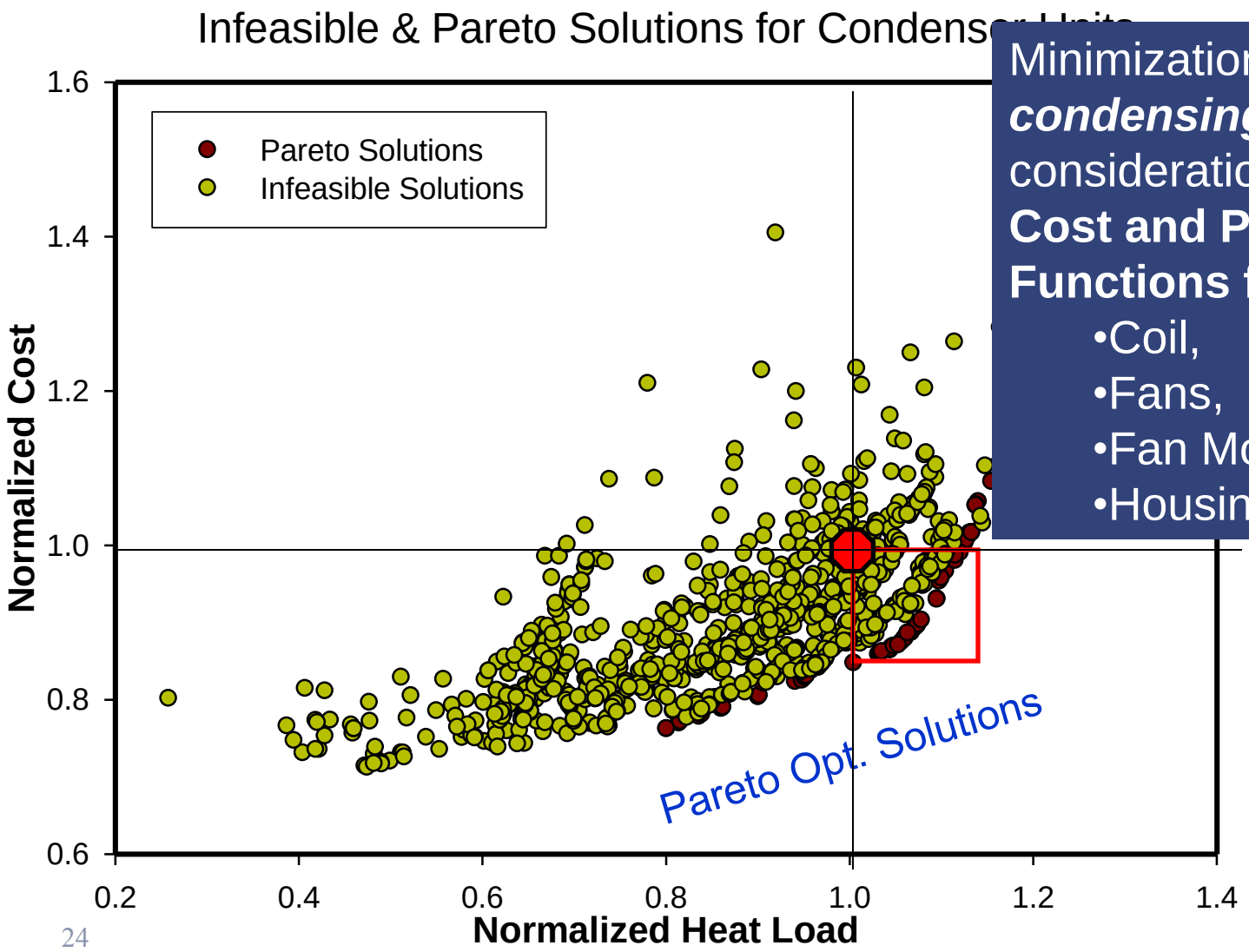
ISOC Staff has Experience and Software for All of These Cases.

CEEE

CoilDesigner



Cost Minimization Example: Condensing Unit



Minimization of first cost of ***condensing unit*** under consideration of:

Cost and Performance Functions for

- Coil,
- Fans,
- Fan Motors and
- Housing

13 SEER Evaporator Cost Minimization

ADVANCED HEAT TRANSFER LLC

Optimization Results

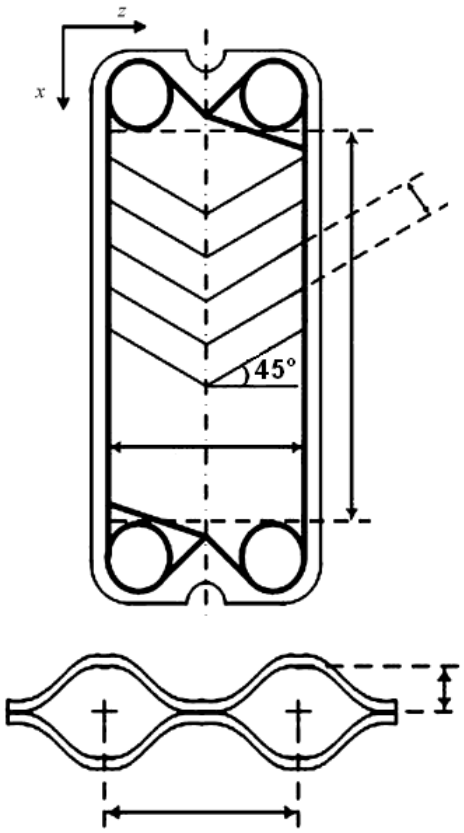
Heat exchanger slabs, distributor and manifold

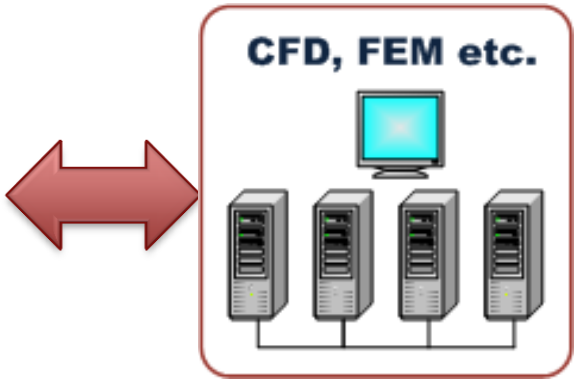
Tube Dia	Tube Pitch	# rows	#circuits	Height Reduction	Weight Reduction	Cost Savings
3/8" baseline	1.00" x 0.625"	3	6	0	0	0
Dia A	Pitch A	3		12%	25%	15%
Dia A	Pitch B	4		20%	20%	10%
Dia B	Pitch C	4		20%	13%	7%
Dia B	Pitch D	3		9%	12%	8%

20

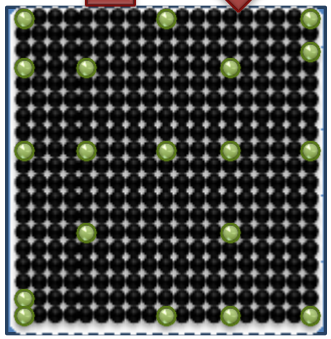
Optimization with CFD

Need to minimize computation effort in CFD prediction for optimizing HX

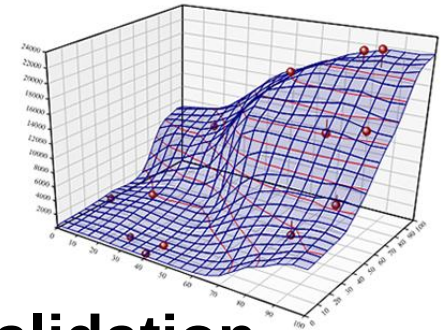




1. DOE

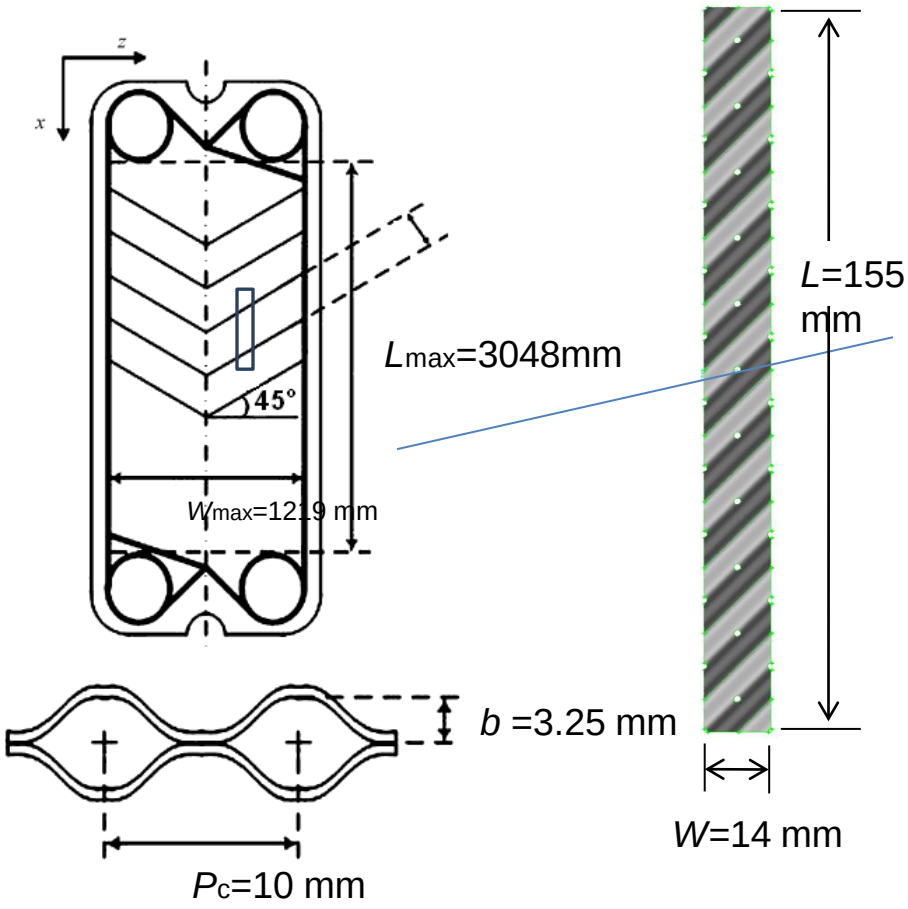


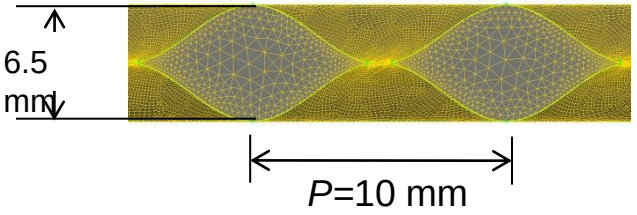
2. Meta-modeling



3. Validation

Plate HX CFD Simulation





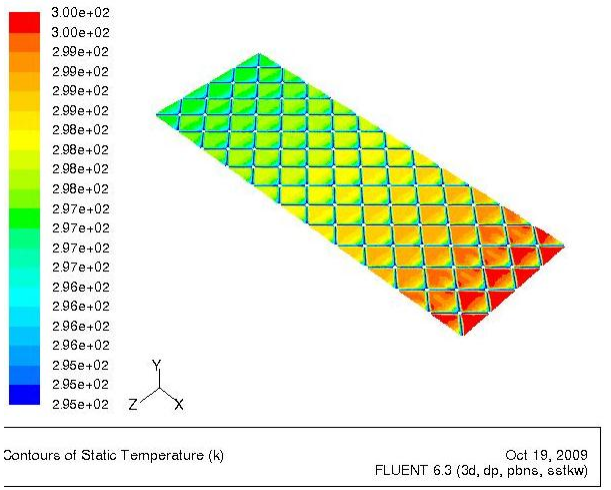


Plate HX Optimization

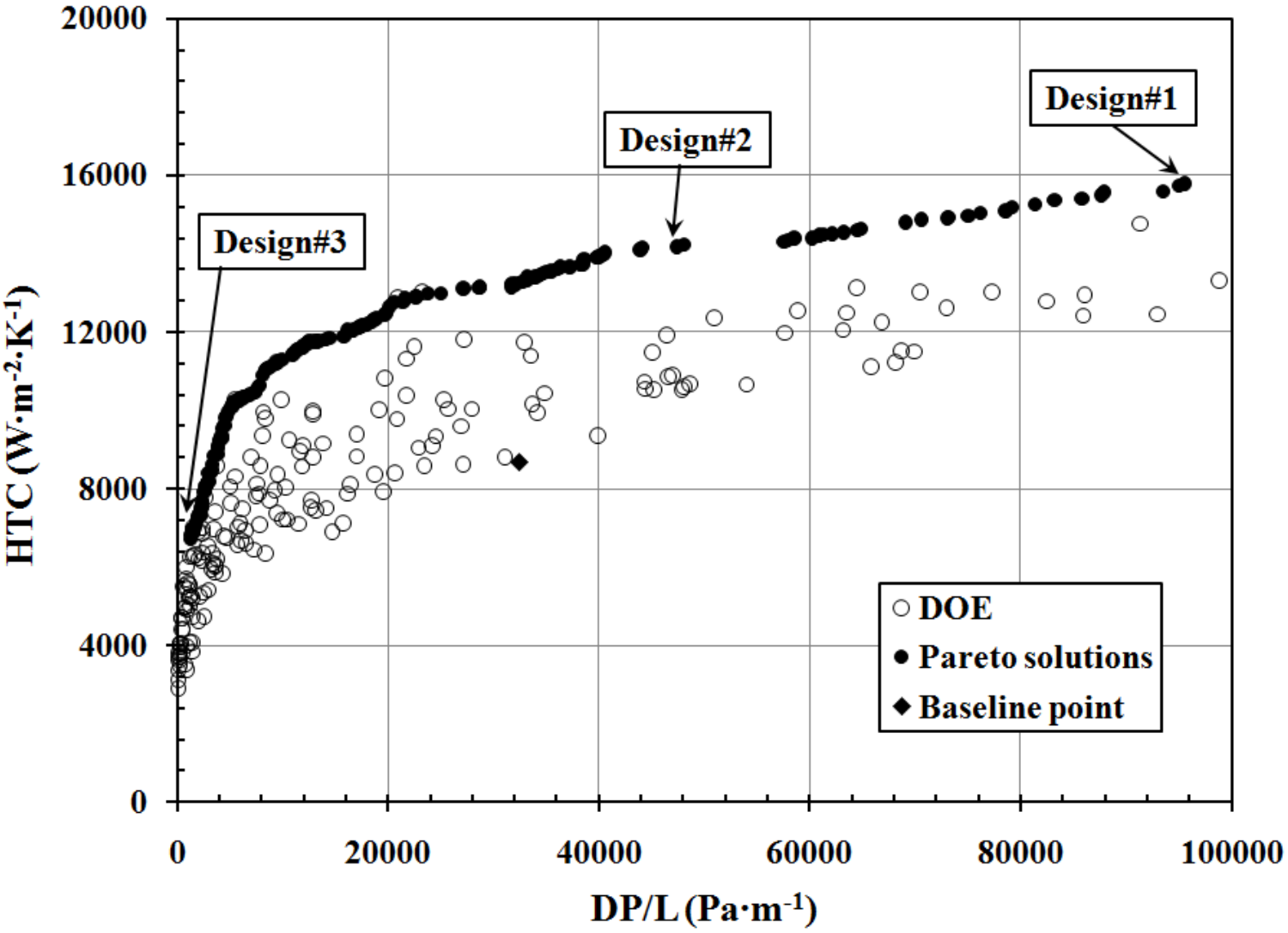


Fig. 6. Pareto solutions for maximum HTC and minimum DP/L

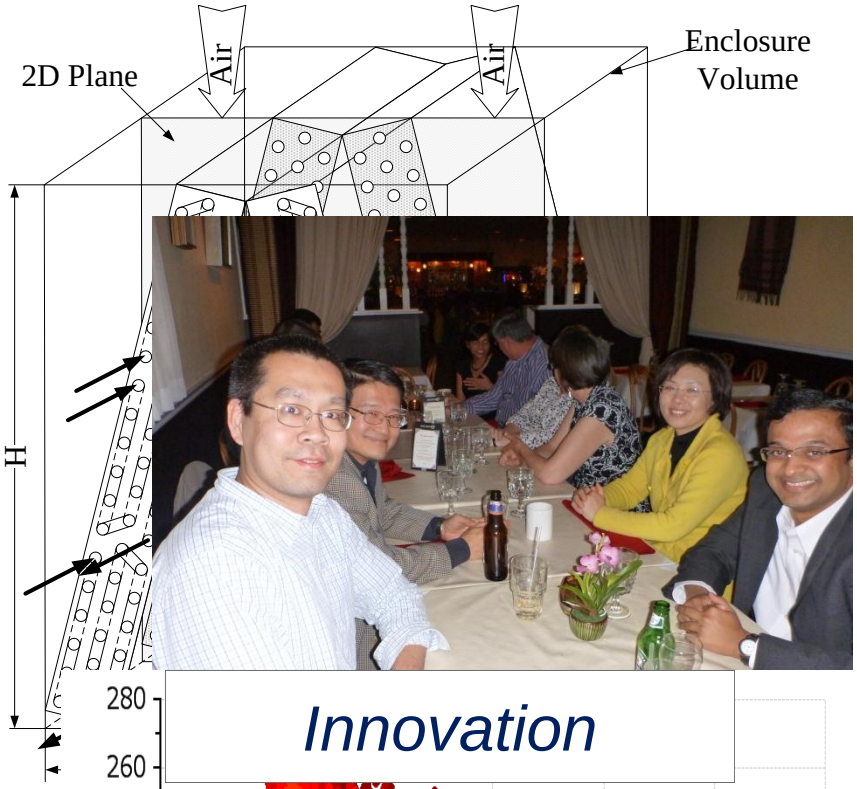
Example for Providing Time for Innovation

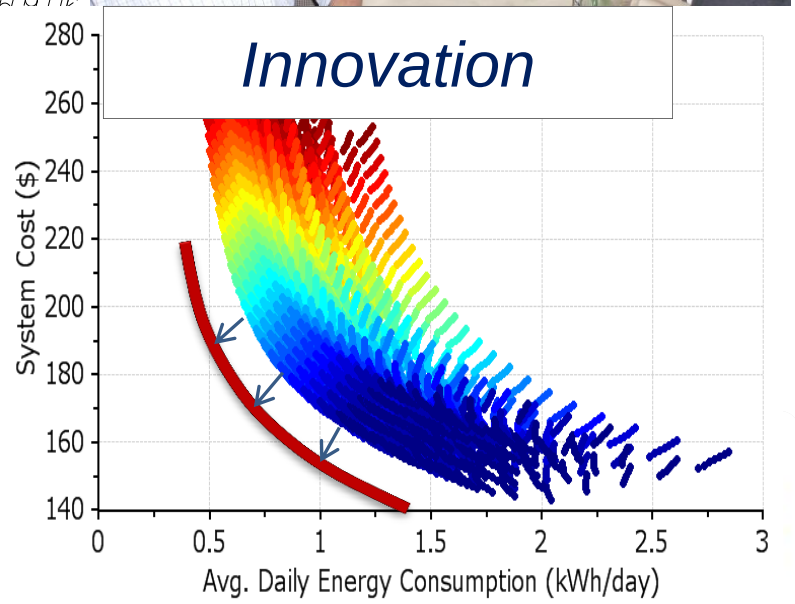
- Engineer has 1 month to come up with a better A-Coil
- Set up code

After 1 month…

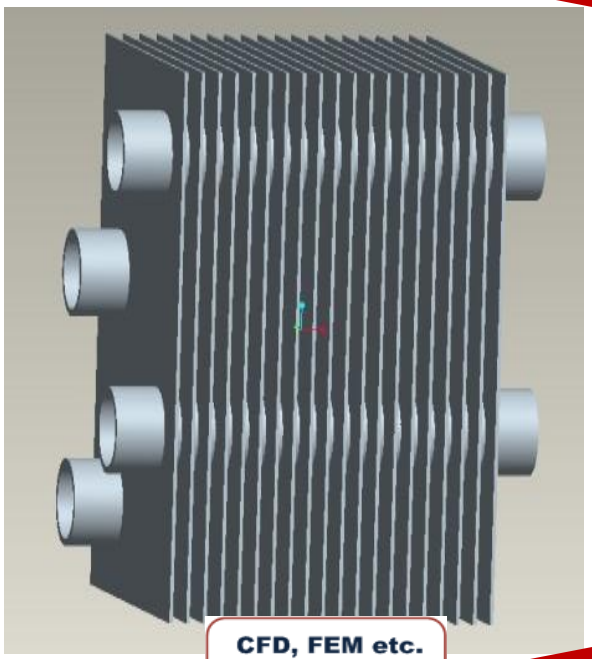
Either 29% reduction in material
or
30% reduction in volume
2 days of engineering!

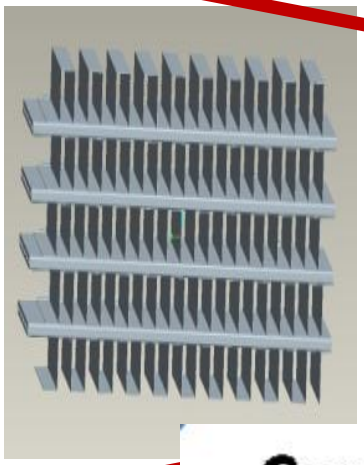
And what do you do for the rest of the time?

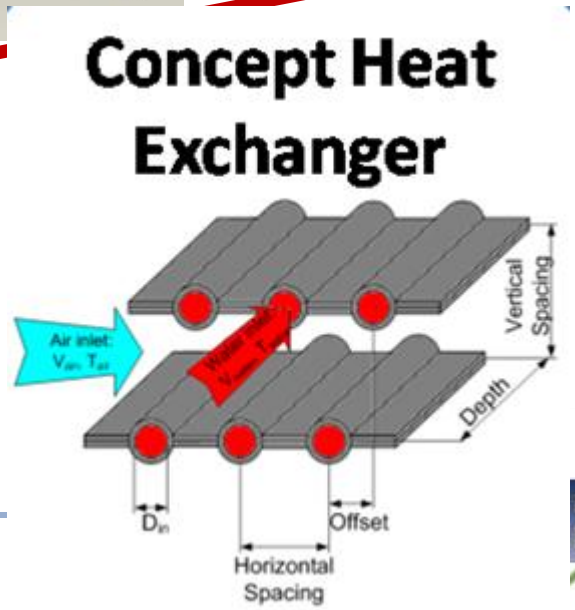


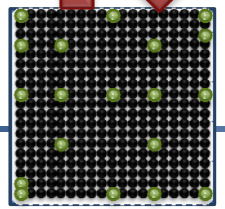


Towards a Next Generation of HXs

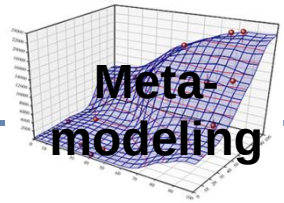








DOE

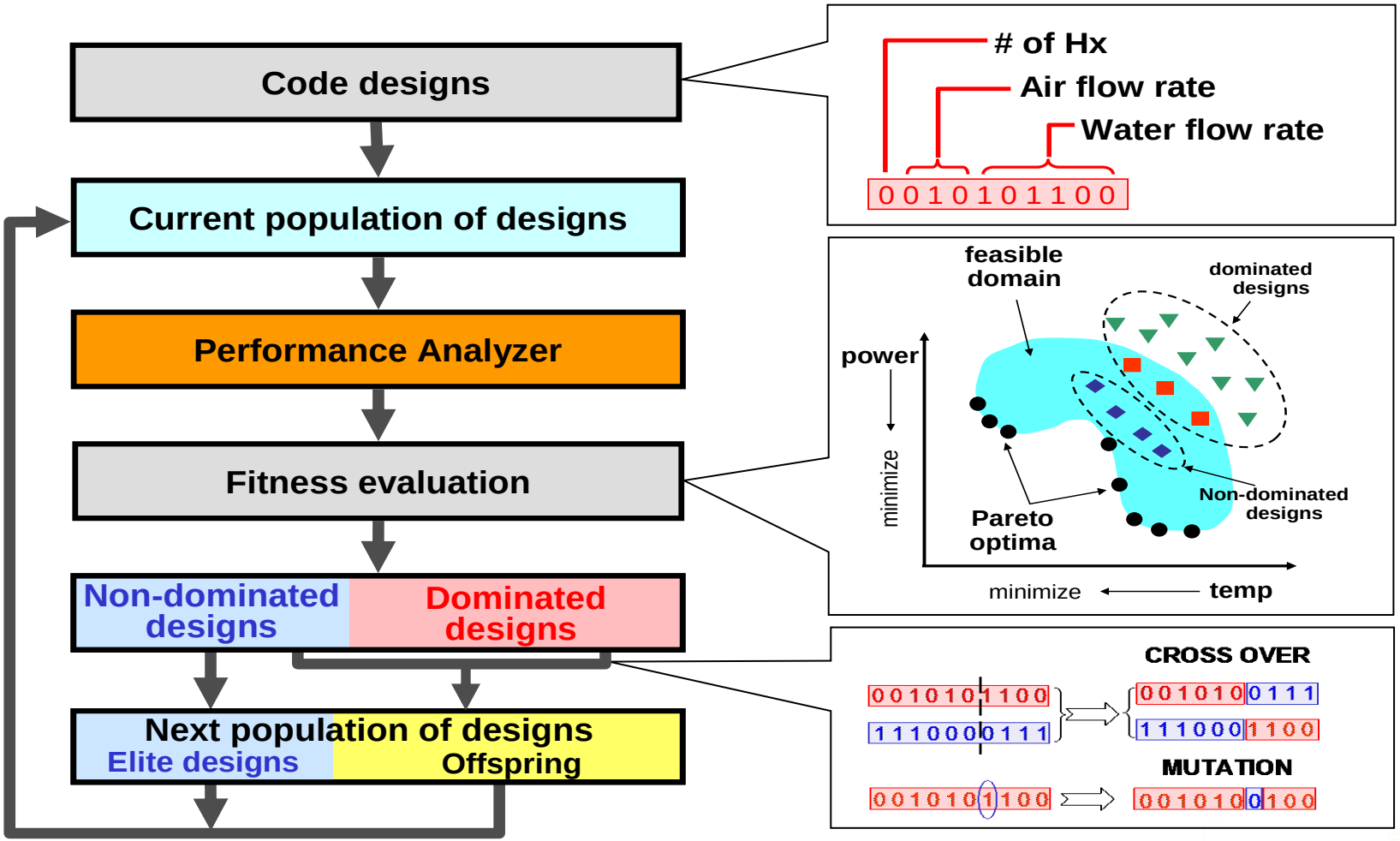


Thank You

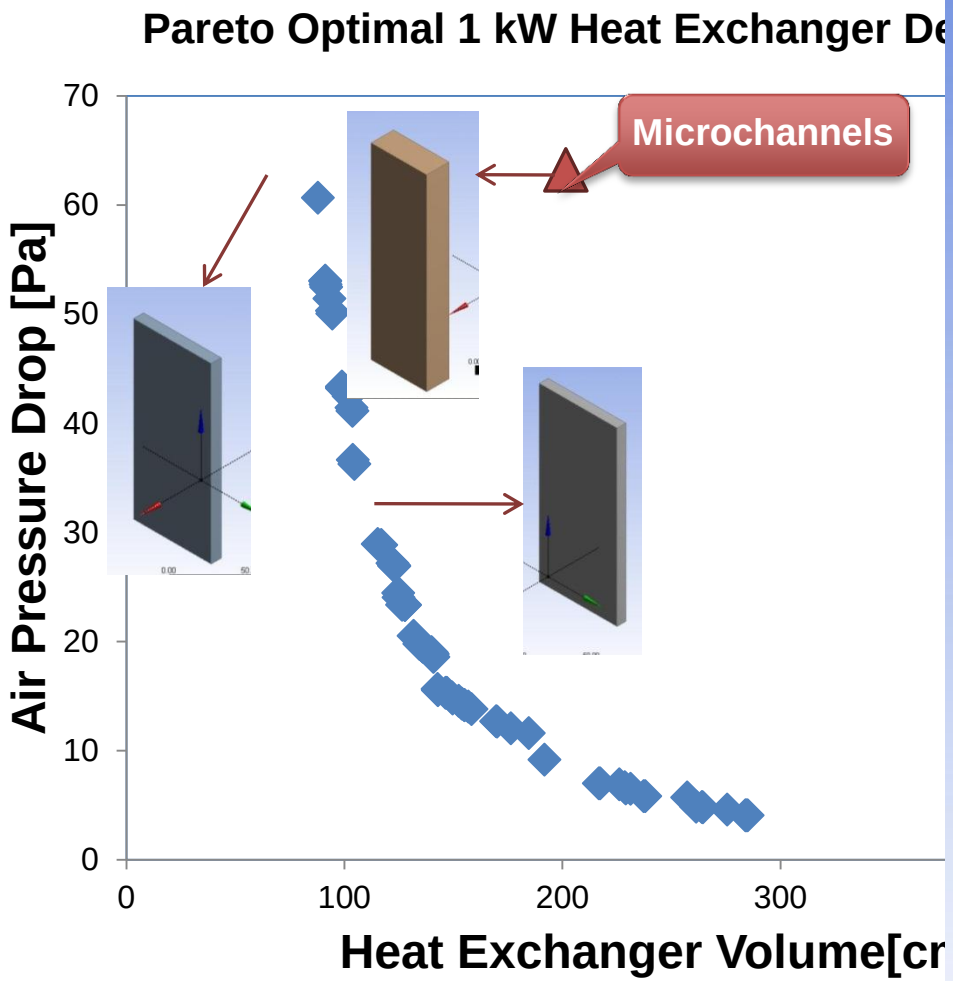
CEEE Board of Visitors

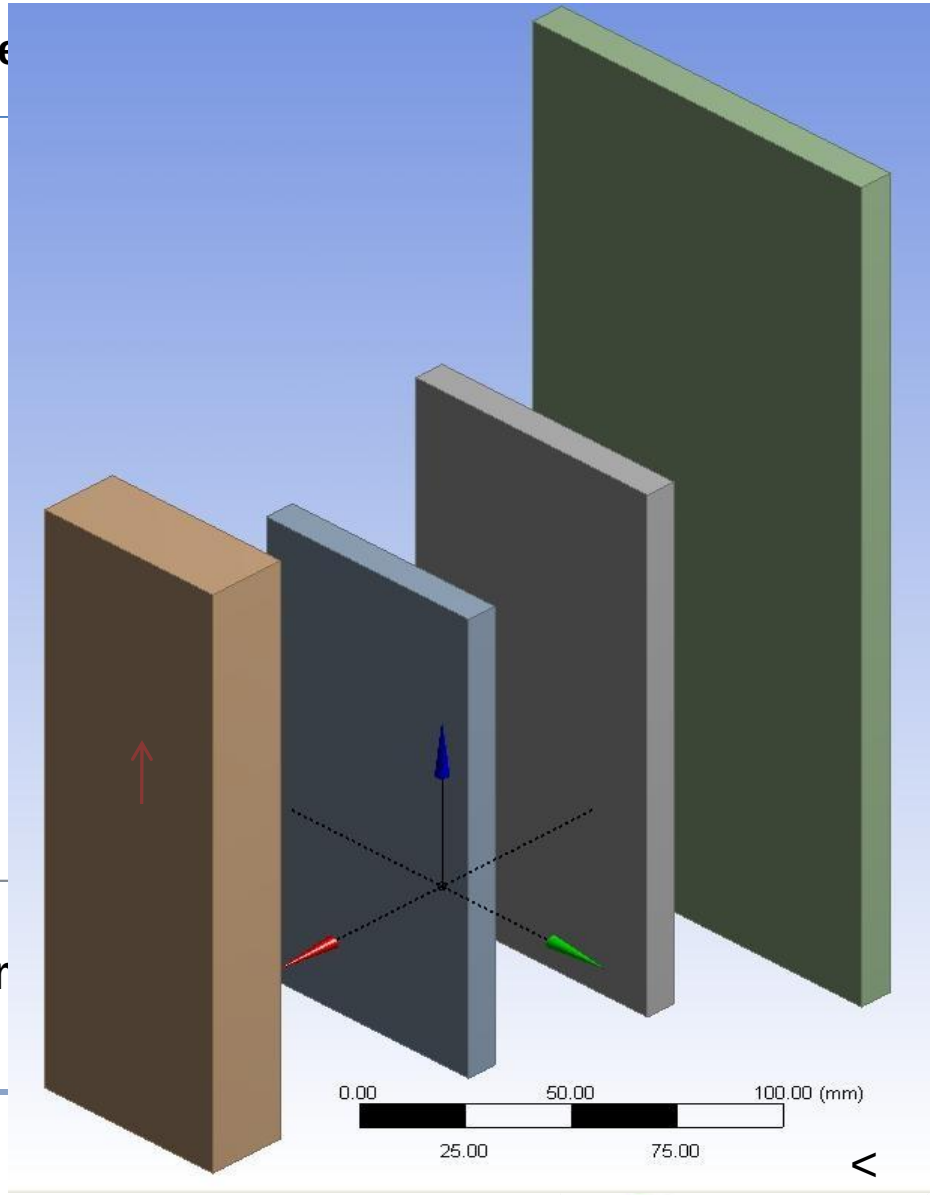
- Toru Inazuka, Daikin
- LinJie Huang, Danfoss-Sanhua
- Simon Wang, Emerson Climate Control
- Bill Fox, Ingersoll-Rand
- Jonathan Wattelet, Modine
- Jurgen Pannock, Whirlpool

Multi-objective Optimization

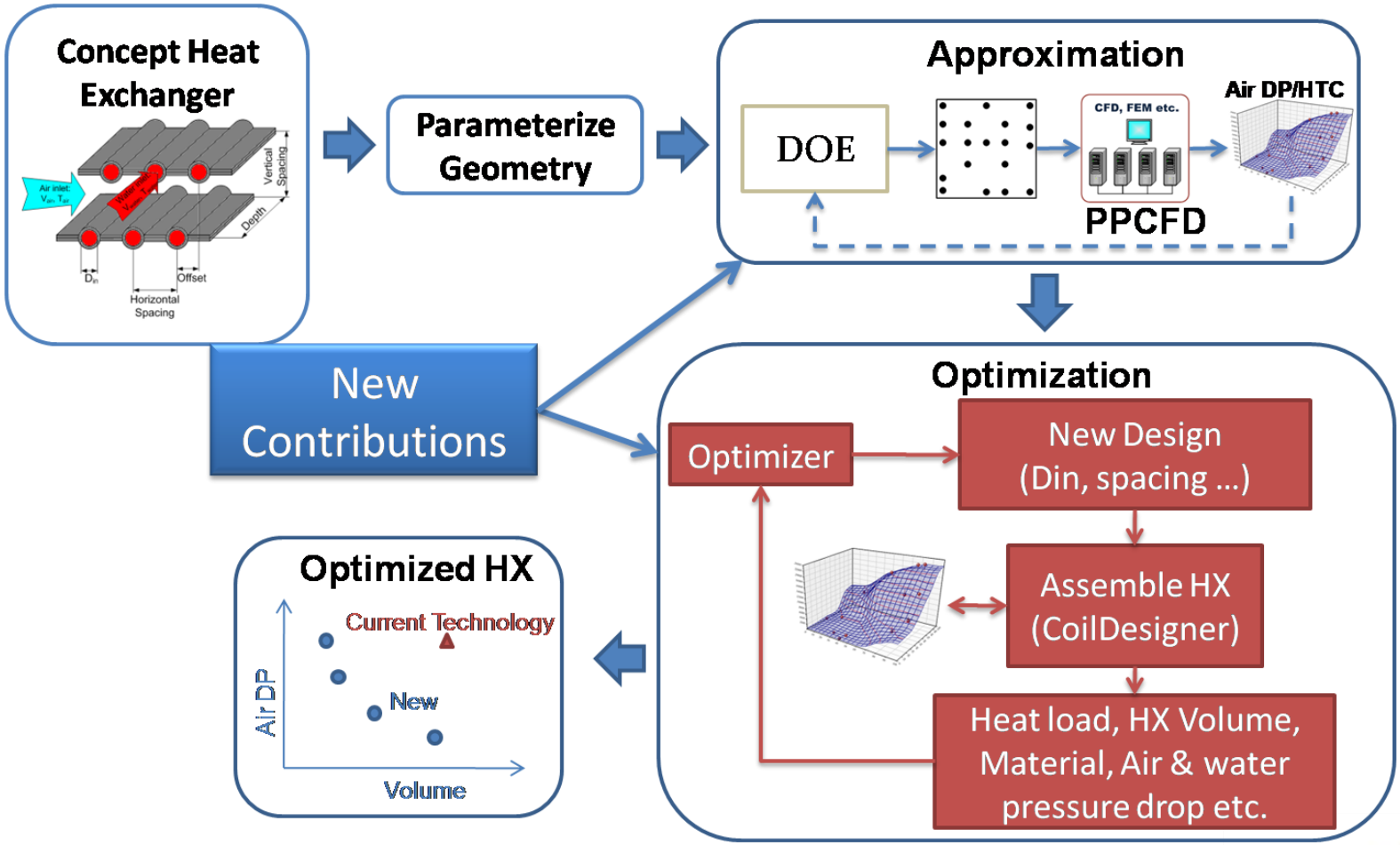


Preliminary Results

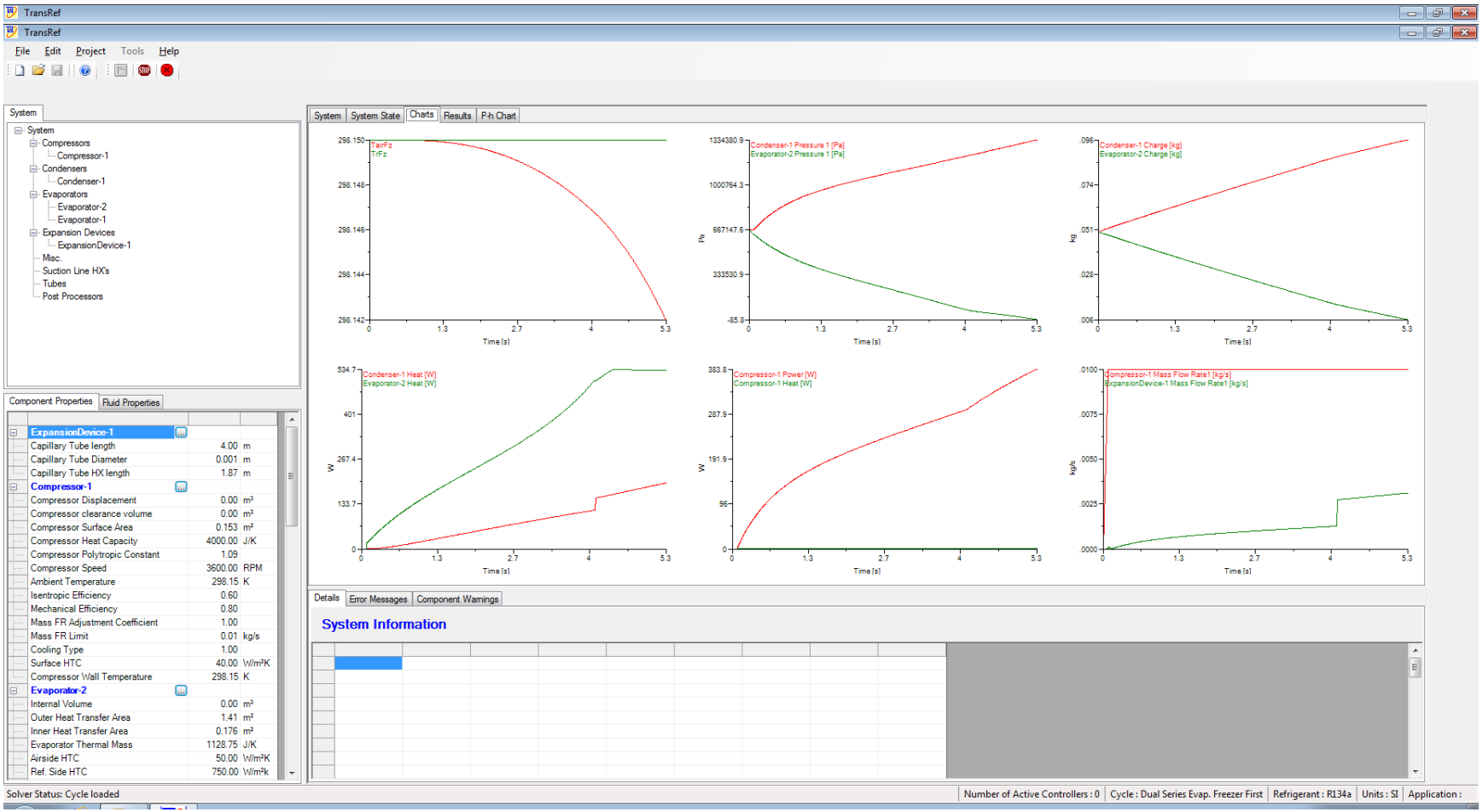




APPROACH


Concept Heat Exchanger
Air inlet
Vertical Spacing
Depth
Horizontal Spacing
Offset
Parameterize Geometry
Approximation
DOE
CFD, FEM etc.
PPCFD
Air DP/HTC
New Contributions
Optimization
Optimizer
New Design (Din, spacing …)
Assemble HX (CoilDesigner)
Heat load, HX Volume, Material, Air & water pressure drop etc.
Optimized HX
Current Technology
New
Air DP
Volume

TransRef


TransRef
File Edit Project Tools Help
System
System
Compressors
Compressor-1
Condensers
Condenser-1
Evaporators
Evaporator-2
Evaporator-1
Expansion Devices
ExpansionDevice-1
Misc.
Suction Line HX's
Tubes
Post Processors
System System State Charts Results P-h Chart
TairFz
TrFz
Condenser-1 Pressure 1 [Pa]
Evaporator-2 Pressure 1 [Pa]
Condenser-1 Charge [kg]
Evaporator-2 Charge [kg]
Condenser-1 Heat [W]
Evaporator-2 Heat [W]
Compressor-1 Power [W]
Compressor-1 Heat [W]
ExpansionDevice-1 Mass Flow Rate1 [kg/s]
Time [s]
Component Properties
Fluid Properties
ExpansionDevice-1
Capillary Tube length 4.00 m
Capillary Tube Diameter 0.001 m
Capillary Tube HX length 1.87 m
Compressor-1
Compressor Displacement 0.00 m³
Compressor clearance volume 0.00 m³
Compressor Surface Area 0.153 m²
Compressor Heat Capacity 4000.00 J/K
Compressor Polytropic Constant 1.09
Compressor Speed 3600.00 RPM
Ambient Temperature 298.15 K
Isentropic Efficiency 0.60
Mechanical Efficiency 0.80
Mass FR Adjustment Coefficient 1.00
Mass FR Limit 0.01 kg/s
Cooling Type 1.00
Surface HTC 40.00 W/m²K
Compressor Wall Temperature 298.15 K
Evaporator-2
Internal Volume 0.00 m³
Outer Heat Transfer Area 1.41 m²
Inner Heat Transfer Area 0.176 m²
Evaporator Thermal Mass 1128.75 J/K
Airside HTC 50.00 W/m²K
Ref. Side HTC 750.00 W/m²k
Details Error Messages Component Warnings
System Information
Solver Status: Cycle loaded
Number of Active Controllers : 0
Cycle : Dual Series Evap. Freezer First
Refrigerant : R134a
Units : SI
Application :

Alternative Cooling Technologies & Applications

Dr. Yunho Hwang, Director

Long Range Goals

- Support Refrigerant Selection Decisions
- Improve Performance
- Not-in-Kind Cooling Systems Integration
- Not-in-Kind Applications of Existing Technology

Integrated System Optimization Consortium

Dr. Vikrant Aute, Director

Long Range Goals

- Helping Engineers Innovate
- Simulation *and Optimization* of Thermal Systems
- Verified, Dynamic Simulation Tools (Accounting for Charge & Lubricant Management, Cost, Reliability….)

13 SEER Evaporator Cost Minimization

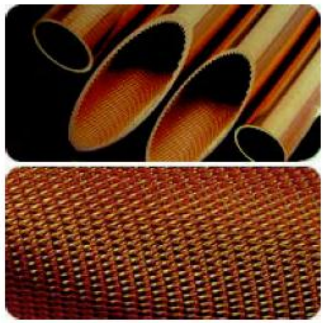
ADVANCED HEAT TRANSFER LLC

Application

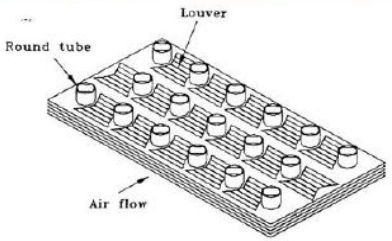
3 Ton, 13 SEER Evaporator

Compact heat exchanger characteristics

- High surface area/volume ratio
- Louvered fin
- Inner grooved tube



Typical Residential Air Conditioning Evaporator



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