Thoughts on the Future of Building Thermal Management

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Center for Environmental Energy Engineering

University of Maryland

October 1, 2015

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Some CEEE Students and Staff

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1	**ACET/DOD**	14	Honeywell	27	Mitsubishi
2	Arcelik	15	Hussman	28	**Panasonic**
3	**Daikin**	16	Hydro/SAPA	29	Pusan Nat. University
4	Danfoss	17	**Ingersoll Rand**	30	Samsung
5	Delphi	18	ICA	31	Sanden
6	**DOE/ORNL**	19	**Johnson Controls**	32	**Sandia NL**
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9	Emerson +Liebert	22	**Luvata**	35	Stiebel Eltron
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11	Gree	24	Midea	37	Subros
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13	HTPG	26	**MIPS**		

Contents

- Background
- Evolutionary Progress
- (Potentially) Revolutionary Developments
- Food for Thought

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Background

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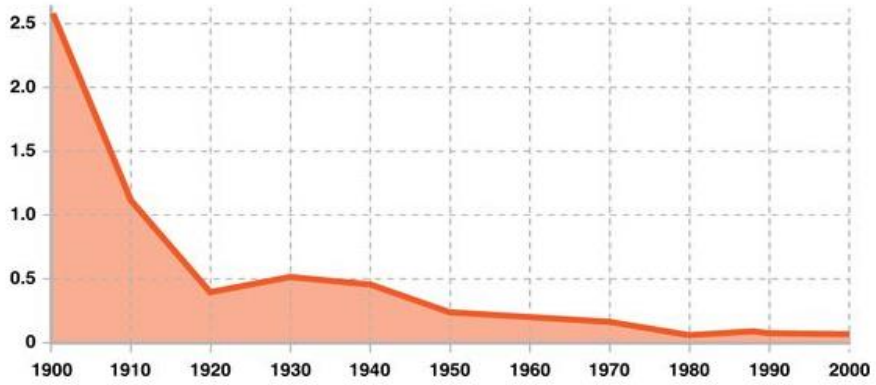
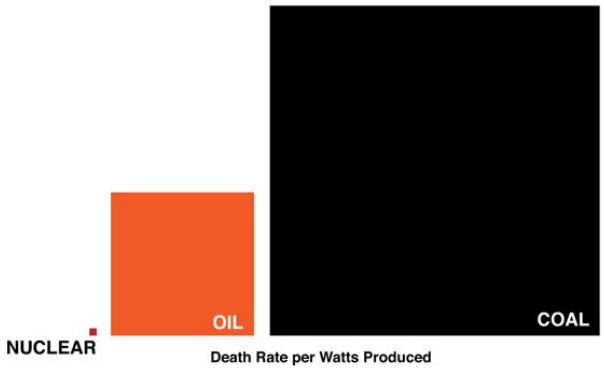
The World is Changing

35 Average Price of US Electricity over Time ($ per kWh at 1990 prices)

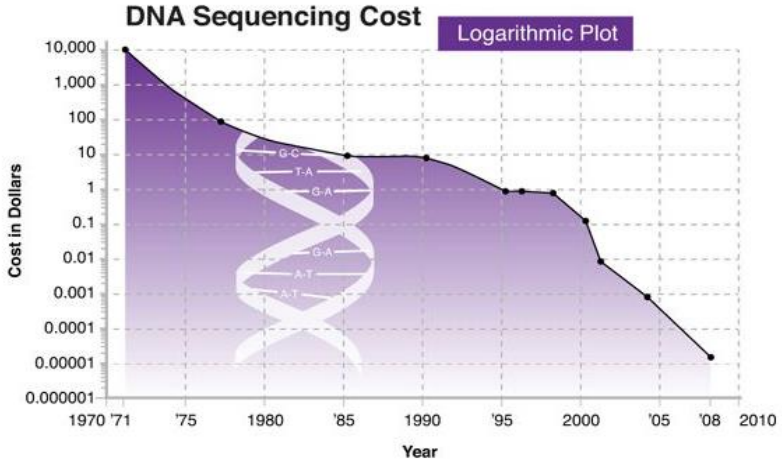


Smartphone displaces $900K worth of equipment

36 Deaths per TWh by Energy Generation Source



29 Exponential Decrease in DNA Sequencing Costs



Diamandis, Peter H.; Kotler, Steven (2012-02-21). Abundance: The Future Is Better Than You Think (Kindle Locations 4226-4228). Free Press. Kindle Edition.

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Appalachian Mountains, WV

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…after Mountaintop Removal

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What Does the Future Hold?

CEEE Research Roadmap: Macro View

Heating below 100C:

- CHP
- Heat Pumps

Cooling/Refrigeration/Cold Climates

- Heat Pumps

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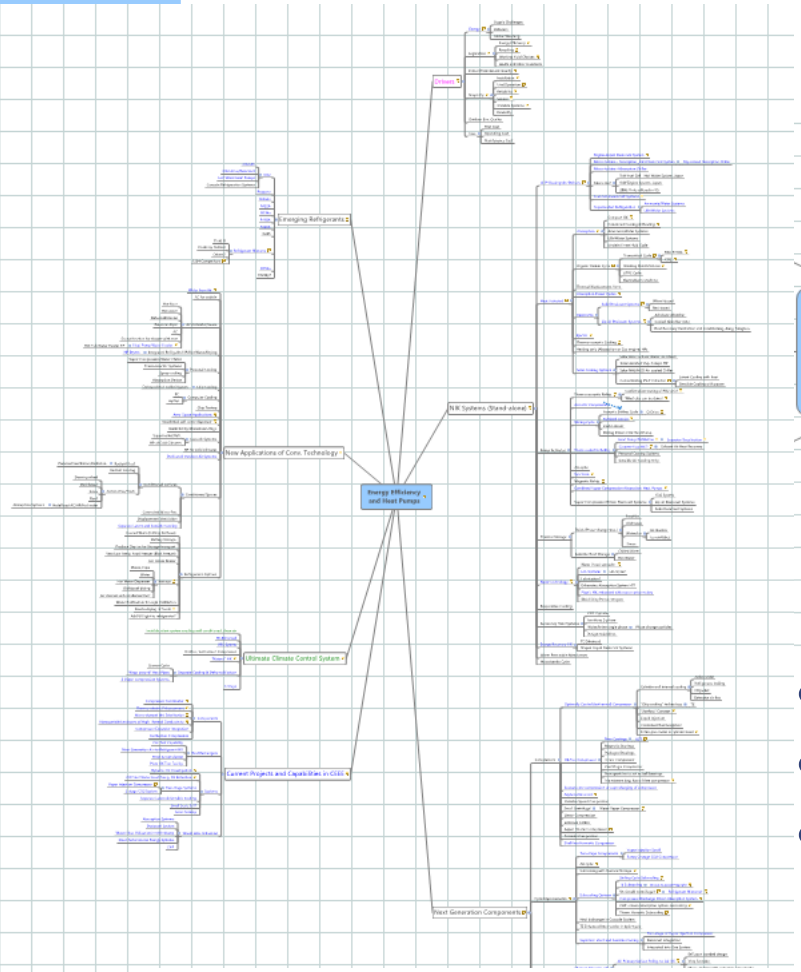
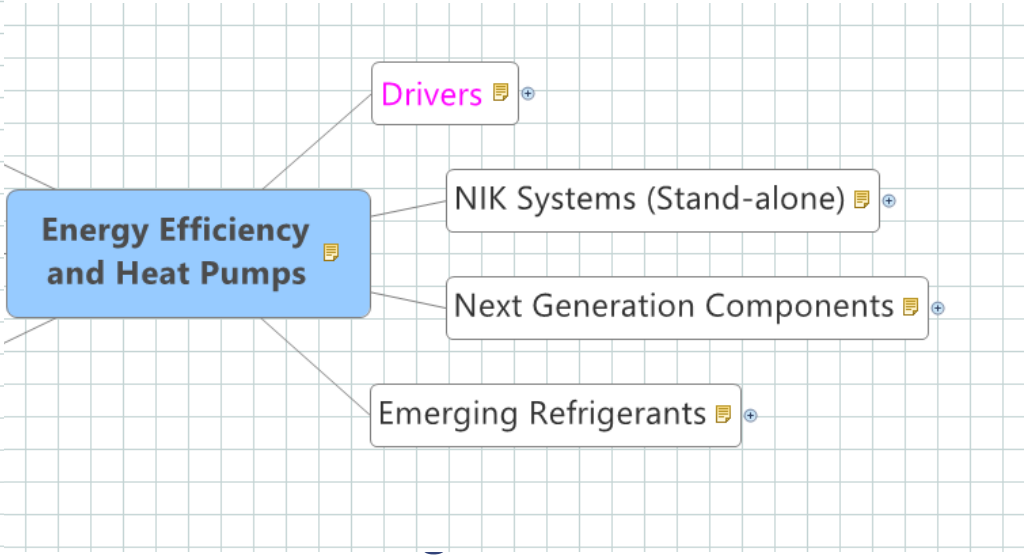
Heat Pump Knowledgebase





- Alternative Cooling Systems
- Systems Integration
- Find New Applications for Existing Technology
  - Water from air
  - system
  - Synchron Cycle

CEEE Technology Roadmap Workshops

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Evolutionary Developments

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FUTURE OF COMPRESSORS

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How Technology Develops...

Would this engineer

Material

nsumption?

ergy consumption?

vironmental

pact?

ansportation cost?

anuf.cost: ~2%?

Can you

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Creative Compressors…

http://www.fairchildcontrols.com/54mm-heli-rotor-compressor/

Oil-free Screw Compressor
~15,000 rpm

http://www.embraco.com/wisemotion/Default.aspx

Oil-free Linear Compressor Variable Capacity

Highest Power Density in Industry

http://www.aspencompressor.com/our-technology/

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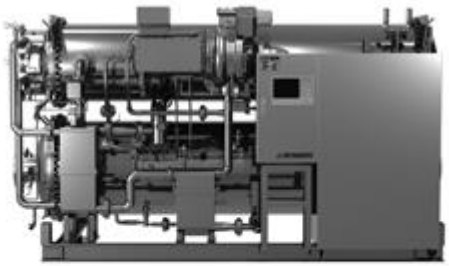
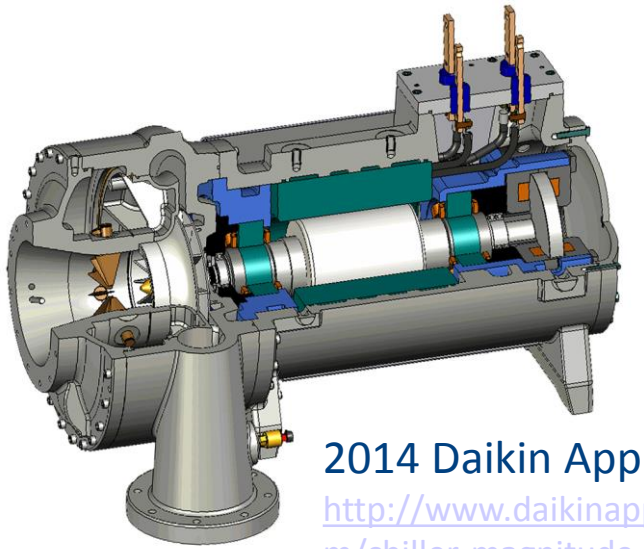
Oil-Free Centrifugal Compressor

York YMC² Water-Cooled Magnetic Centrifugal Chiller



Mitsubishi

Centrifugal chiller with magnetic bearing system "ETI-40MB/50MB"



2014 Daikin Applied

http://www.daikinapplied.com/chiller-magnitude-magnetic.php

Trane® Series S™ CenTraVac™ Chiller

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FUTURE OF HEAT EXCHANGERS

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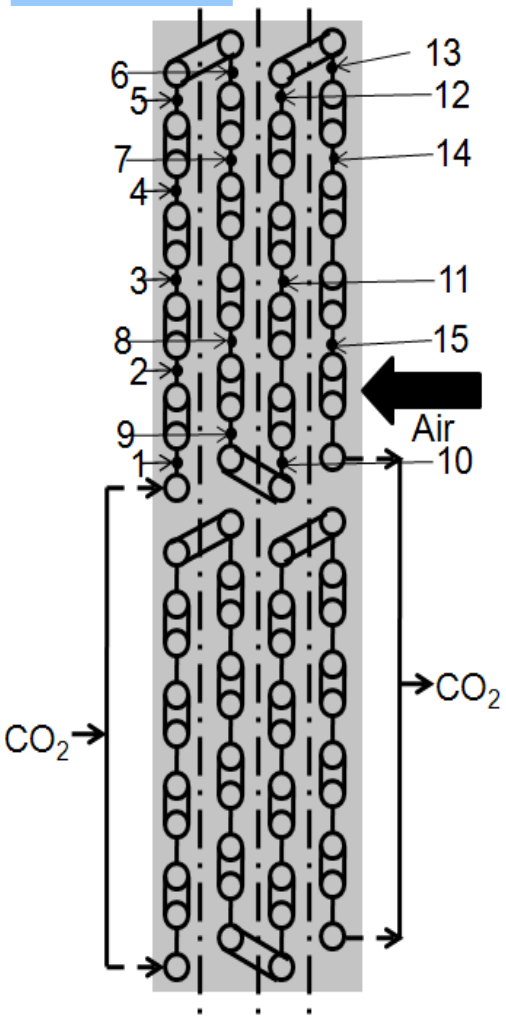
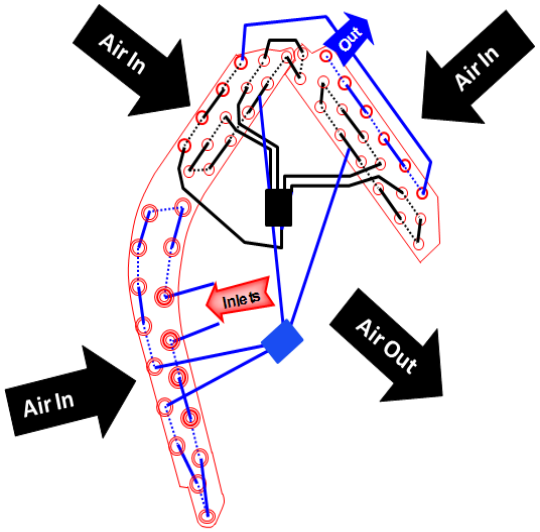
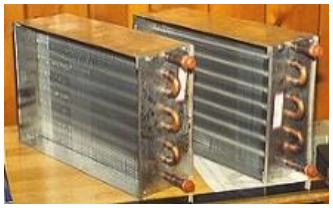
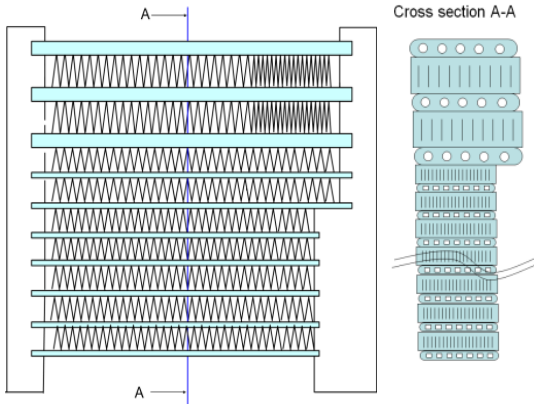
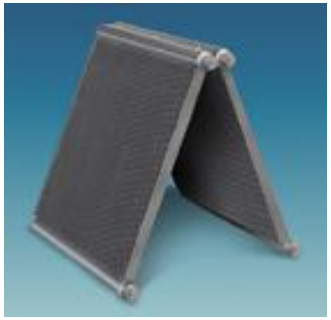
Air-to-Refrigerant Heat Exchangers











Standard configuration MCHX

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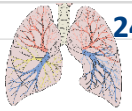
Future of Heat Exchangers



CEEE/DOE Research

Well investigated Micro/Mini-channel CoilDesigner®

CEEE Research Correlations/Tools

Well Investigated: Correlations/Tools CoilDesigner®

Compactness (cm²/cm³)

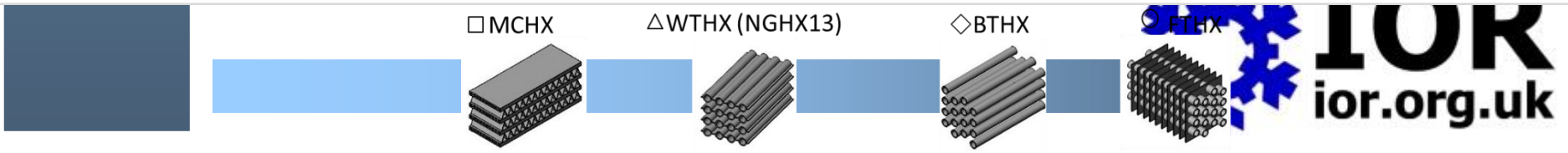
Material Utilization (cm²/cm³)

Port Hydraulic Diameter (mm)

0 20 40 60 80 100 120

0 200 400 600 800 1,000

0 1 2 3 4 5 6 7 8 9 10



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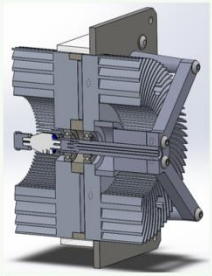
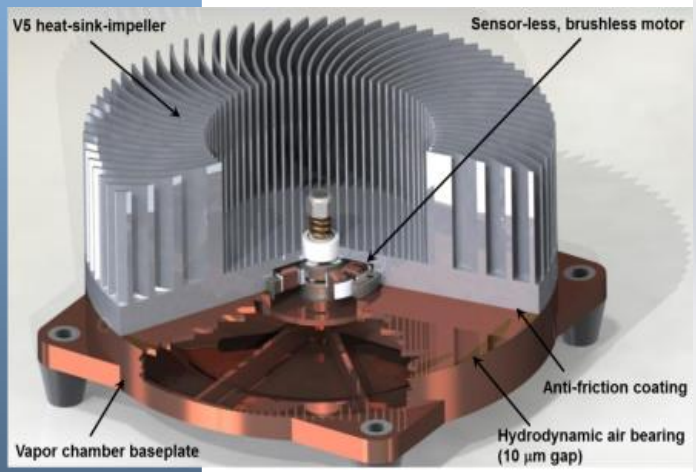
Air Bearing Condenser (SNL)

- **Conv. air-refrigerant heat exchanger: Large volume (HX + Fan)**
- **Sandia Cooler**
  - **HX combines “fan” and “fin”, compact**
  - **Air-bearing maintains 5-10 micrometer air gap**
  - **Quiet and efficient**

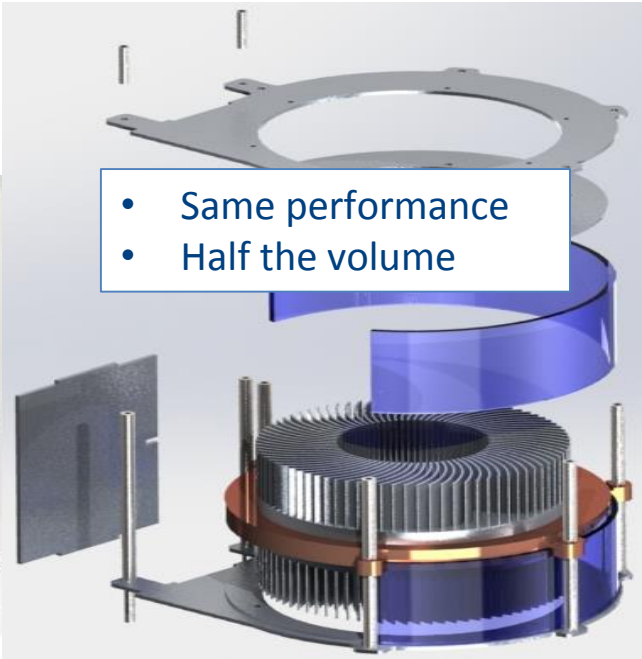


Cross-section of Sandia Cooler device concept

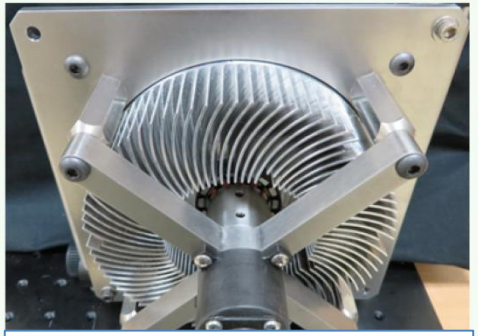
Laird Baseline Unit



http://energiaoldal.hu/csendes-es-hatekony-szamitogep-hutes/



- Same performance
- Half the volume



- Reduced Volume
- Increased COP

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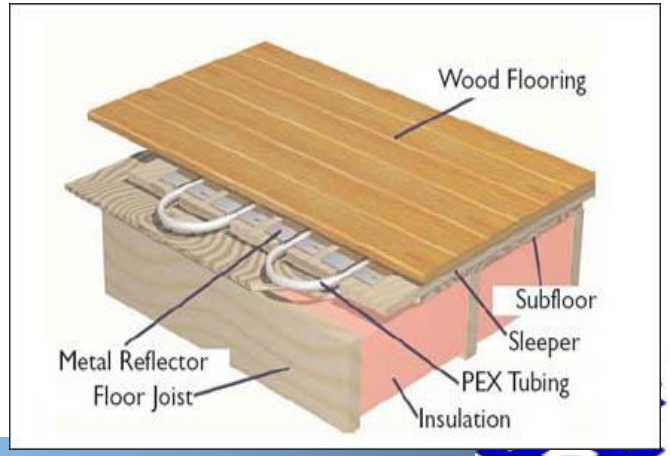
Floor Heating – Chilled Ceilings

http://www.cmhc-schl.gc.ca/en/co/renoho/images/ce-04-1.jpg



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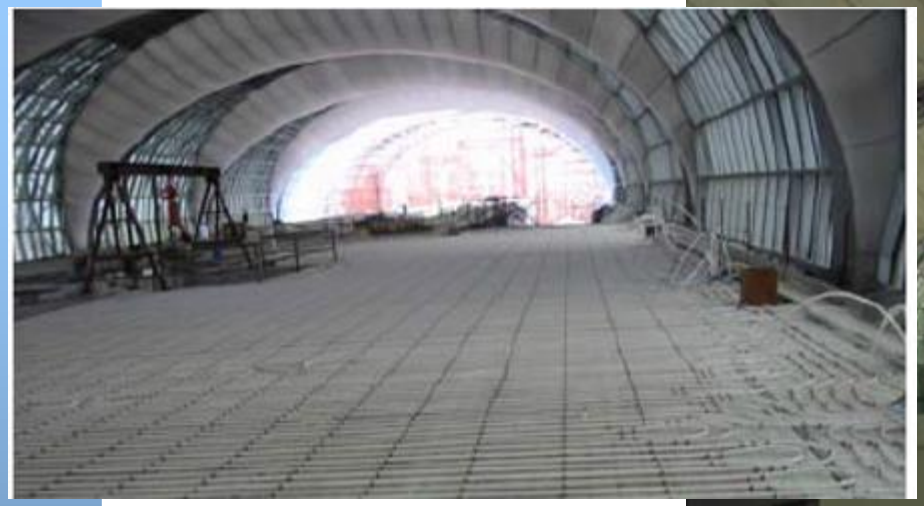
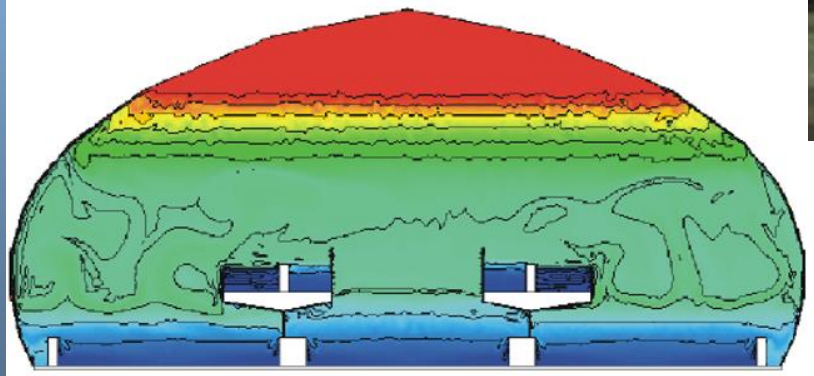
Examples





Olesen B., 2009, Low temperature radiant heating – high temperature radiant cooling, ASHRAE, Louisville

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Vapor Compression Cycle Improvements

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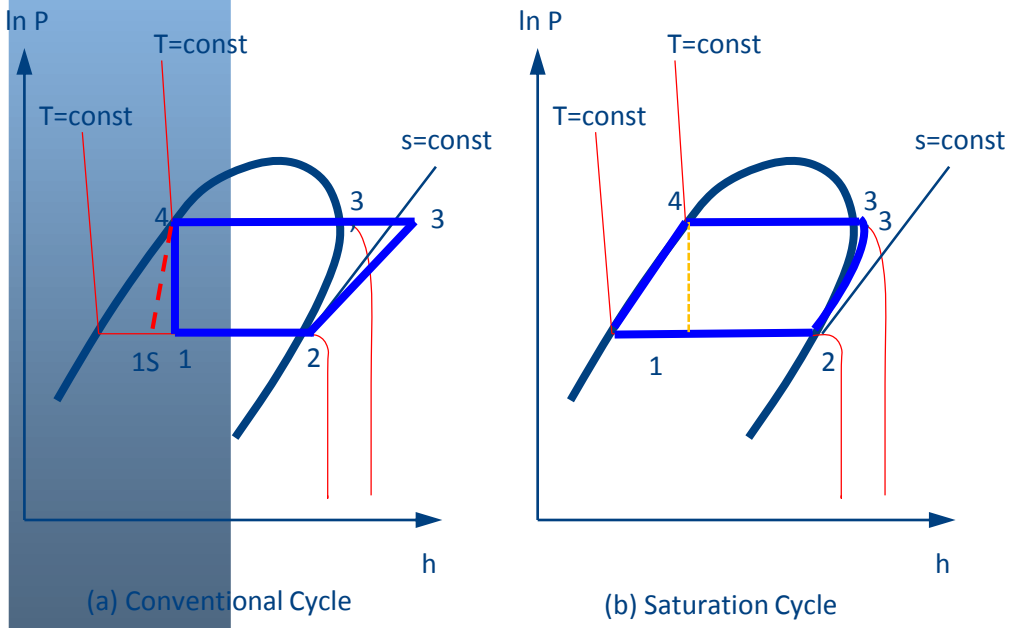
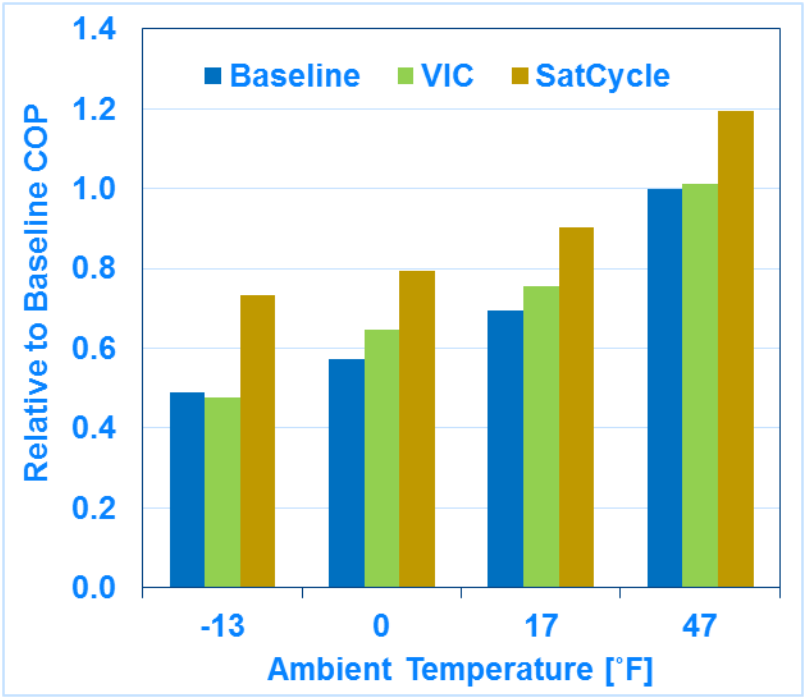
Ultra Efficient Vapor Compression

Saturation Cycle

- **First concept**
- **22% ↑ 35°C cooling COP**
- **53% ↑ -25°C heating COP**





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System Integration Benefits

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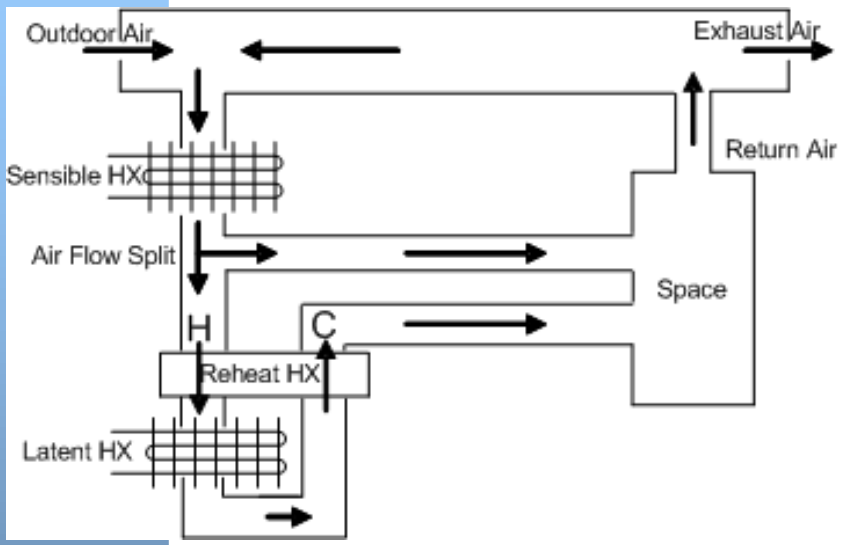
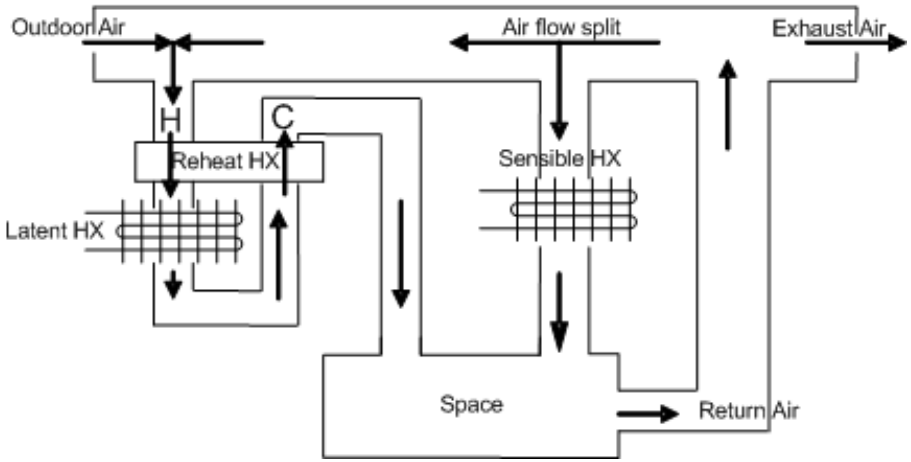
Introduction-SSLC Configurations



SSLC Serial Configuration



SSLC Parallel Configuration

Outside condition	Standard	Humid	Hot & Dry	Hot & Humid
Energy savings	30%	27%	37%	26%

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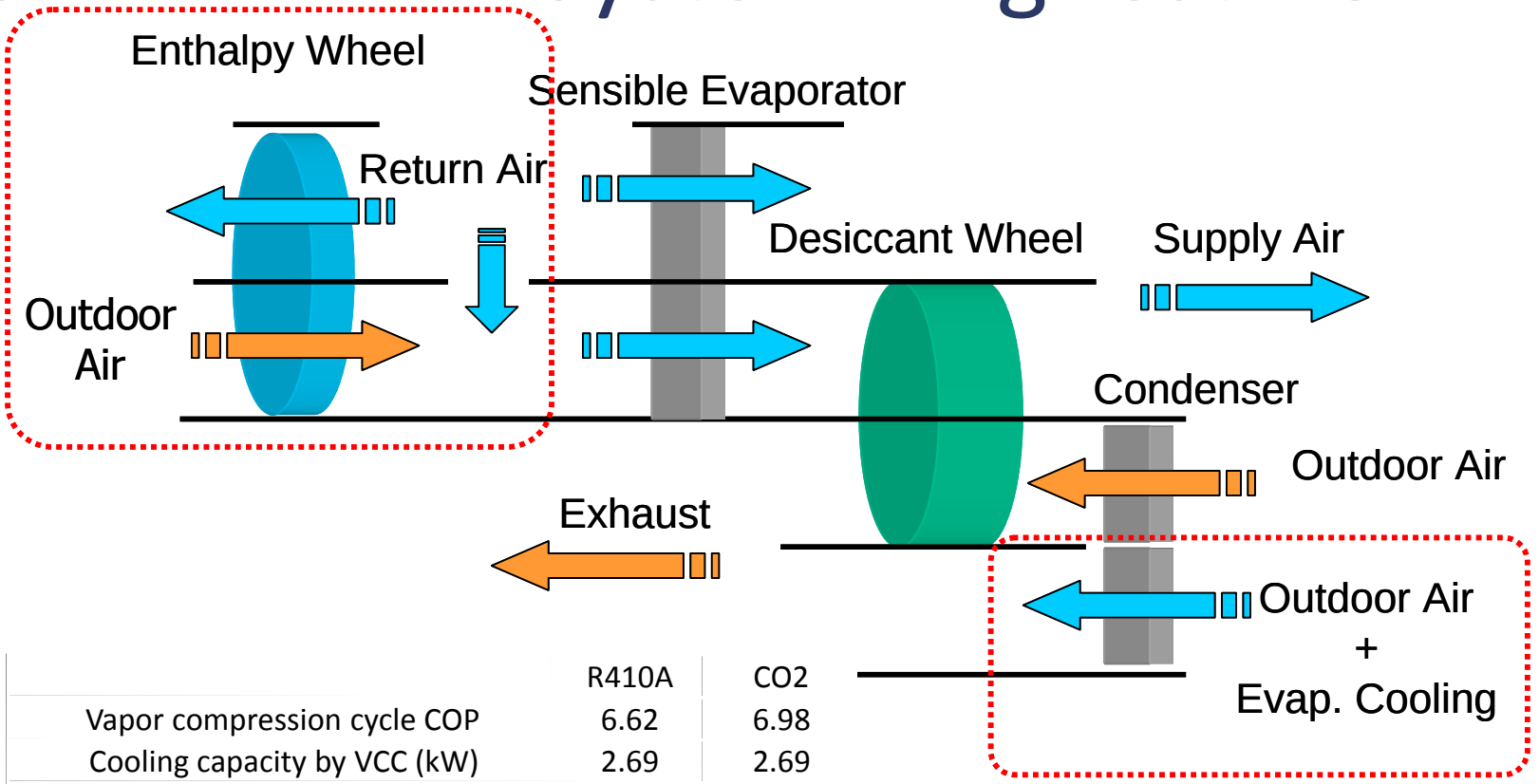
SSLC-EW-DW System: Highest COP



	R410A	CO2
Vapor compression cycle COP	6.62	6.98
Cooling capacity by VCC (kW)	2.69	2.69
System COP	8.62	9.09
System cooling capacity (kW)	3.50	3.50
Power input (kW)	0.41	0.39
System COP improvement from EW	73.00%	68.00%
Enthalpy wheel capacity (kW)	1.32	1.32
Enthalpy wheel latent capacity (kW)	0.67	0.67

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Solar Decathlon 2011

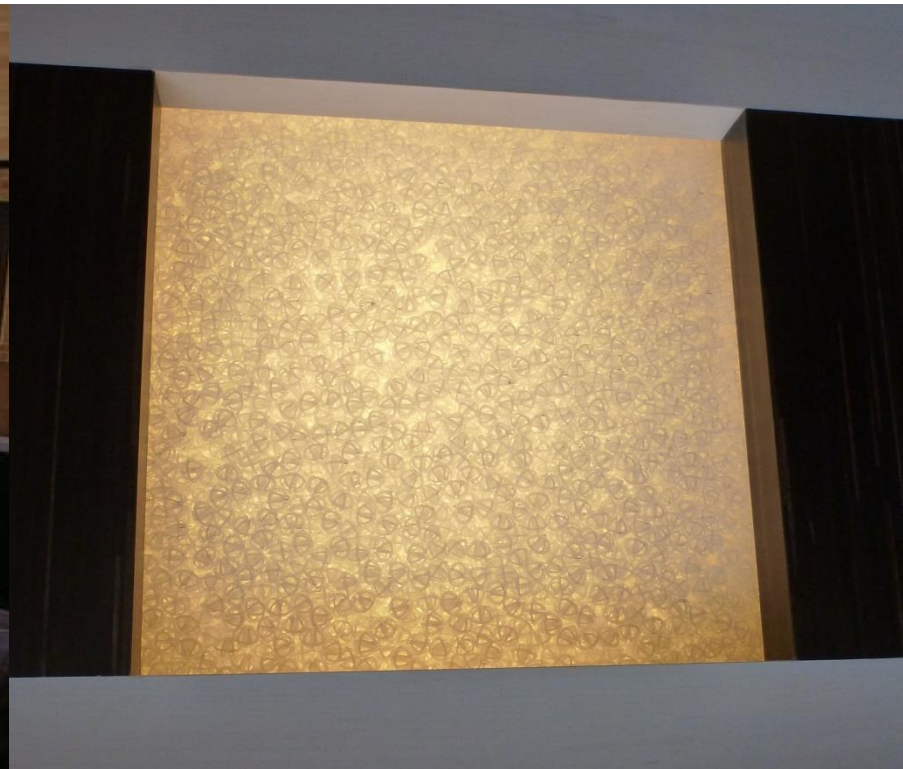
- US DOE Sponsored Competition
- 20 Universities competing
- UMD won 1st Place, October 2011

Watershed 2011

Leafhouse 2007

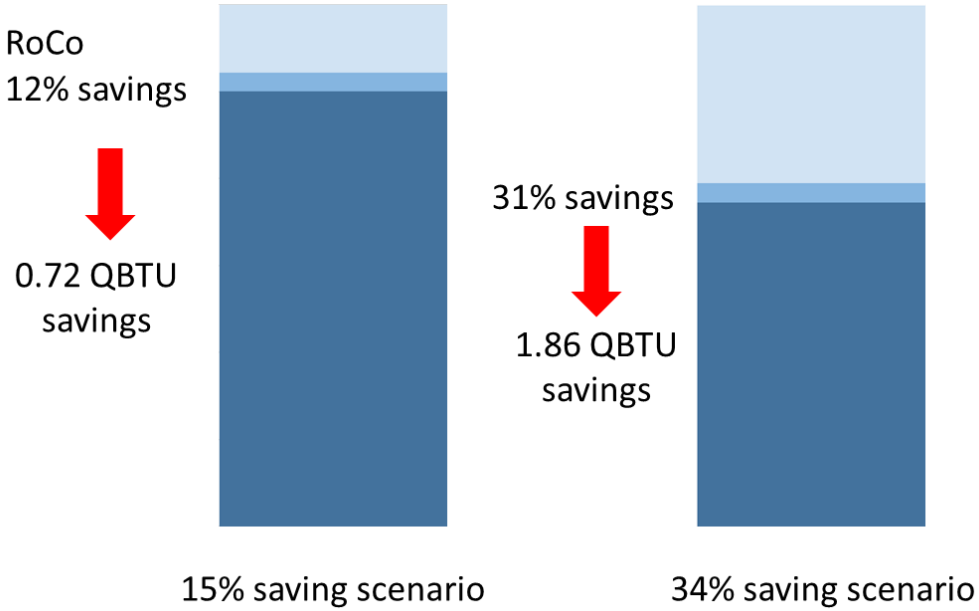
Liquid Desiccant ‘Water Fall’

- Architectural feature
- $CaCl_2$ Solution
- Solar hot water regeneration
- Solution storage tank
- Split system AC
- Now basis for start-up company



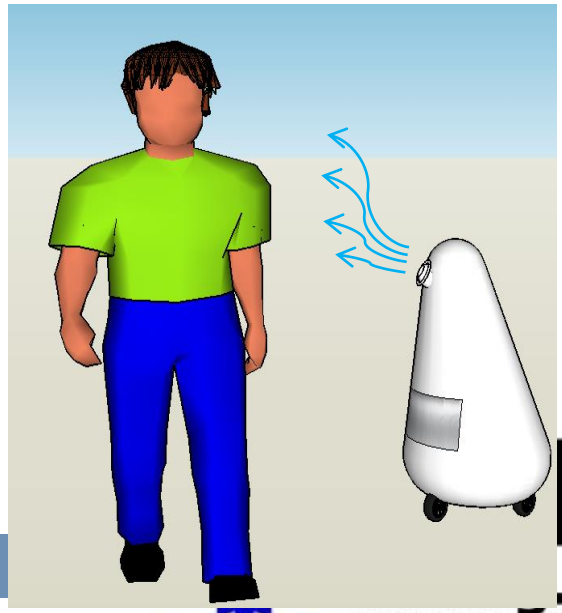
Roving Comforter, RoCo

- RoCo Technology
  - Personal ‘attendant’ for thermal comfort
  - Cooling and heating through one or more robotically controlled air nozzles
  - Follows a person
  - Integrates thermal storage
  - Many implementation and cost options



UMD/CEEE | ORNL | RoCo Team | GE | Sandia

To be marketed through firstbuild



SYSTEMATIC EXPLORATION OF DESIGN SPACE AND WHAT IT MAY LEAD TO

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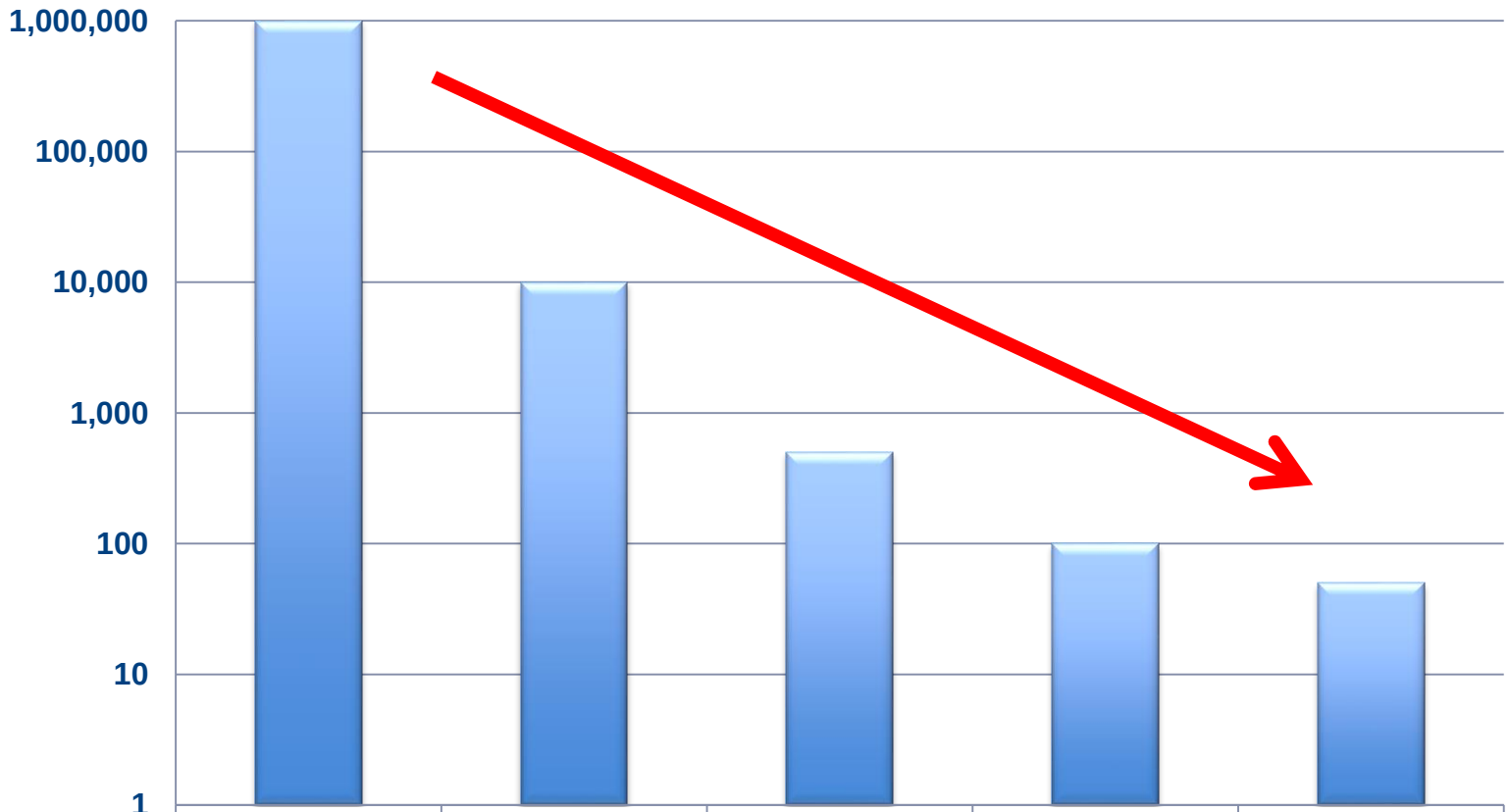
Fast Ways of Exploring Design Space



	Exhaustive Search	MOGA	Offline Approximation	Online Approximation	New Global/Local Search
Computational Time	1000000	10000	500	100	50

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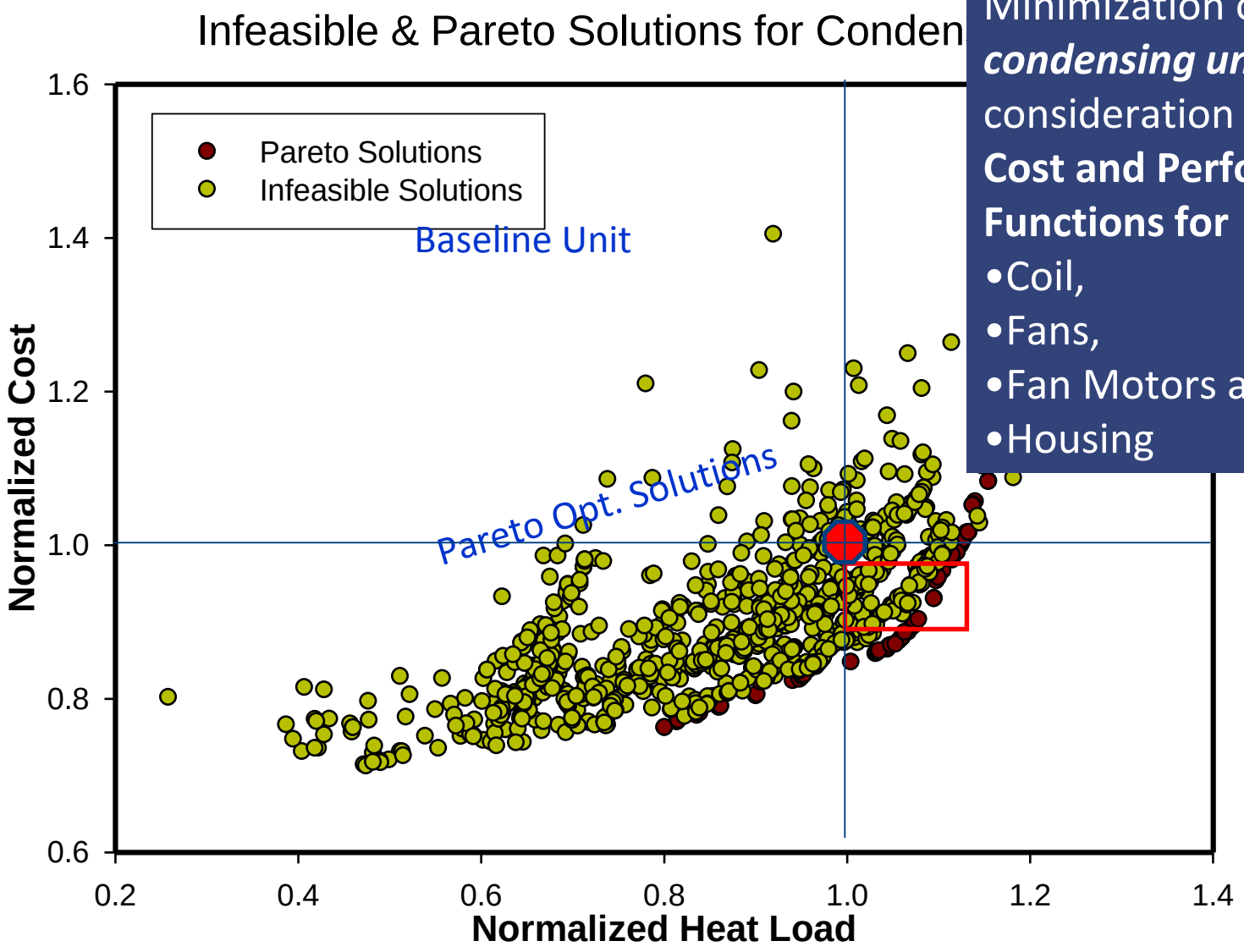
Cost Minimization Example: Condensing Unit



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

Cost and Performance Functions for

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

NGHX Methodology

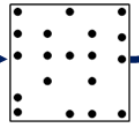
20%+ Better

Concept Heat Exchanger

Parameterize Geometry

Approximation

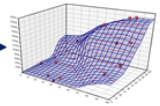
DOE



CFD, FEM etc.

PPCFD

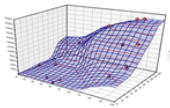
Air ΔP / HTC



Optimization

Optimizer

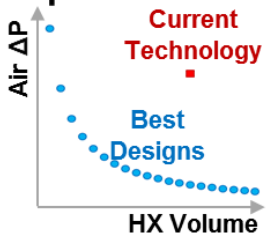
New Design



Assemble HX (CoilDesigner®)

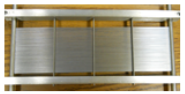
Air ΔP, Volume, Matl', Heat Load,…

Optimized HX



Manufacturing Constraints

Optimized HX



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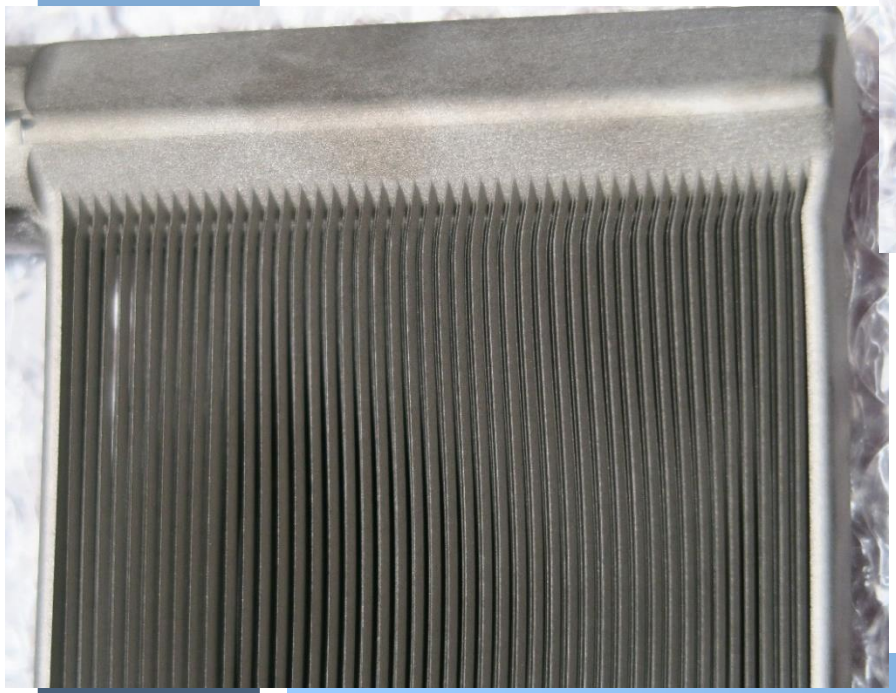
Heat Exchang

Validation

Energy Balance ±2.5%

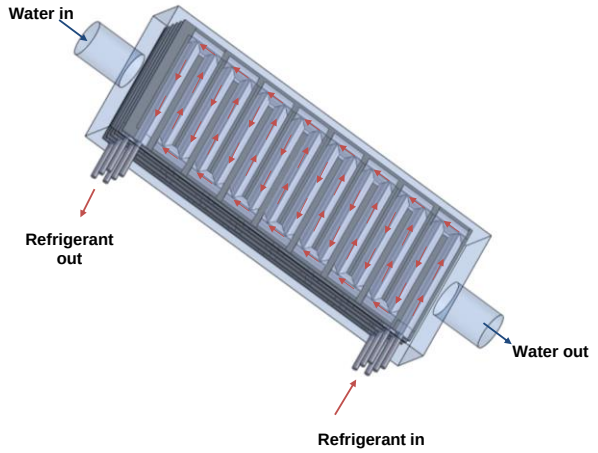
Heat Capacity ±7%

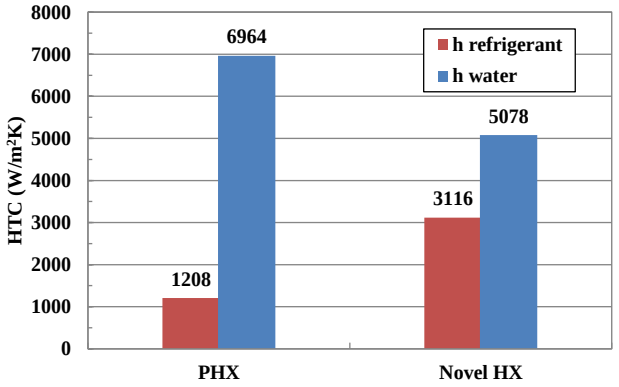
Air-side pressure drop ±12%



Novel Plate HX Example

- Fused Al sheets for flexible compatibility
- Independent water- and refrigerant-side spacing
- UA-value doubled
- @ same or lower dP





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Revolutionary Developments

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Magnetic Cooling: GE Appliances Prototype

- Refrigerator/freezer
- 80 F temperature lift
- Using 50 stages cascade cycle
- 20-25% more efficient than current vapor compression based refrigerator

http://www.ge.com/research/live/

http://www.gereports.com/post/75911607449/not-your-average-fridge-magnet

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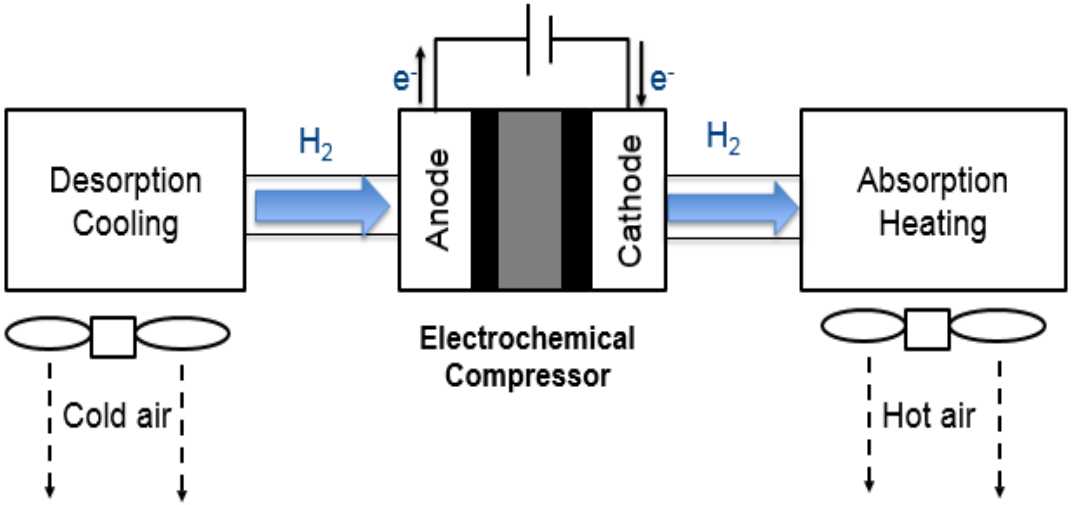
Electrochemical Compressor Driven MH Heat Pump



- **Mechanical compressor is replaced by electrochemical compressor**
- **System contains pure hydrogen**
- **Comparable or higher compression efficiency than mechanical compressor**
- **No moving parts**
- **Hydrogen flow direction can reversed by switching the anode and cathode, simplifying design**

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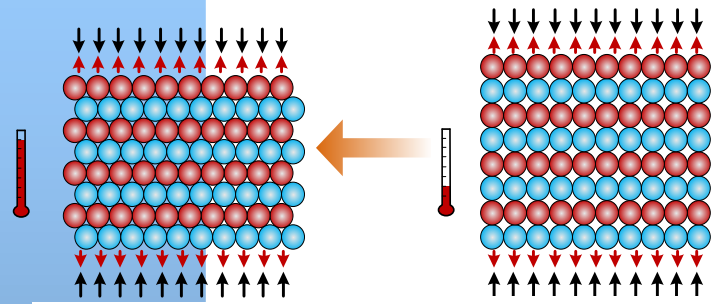
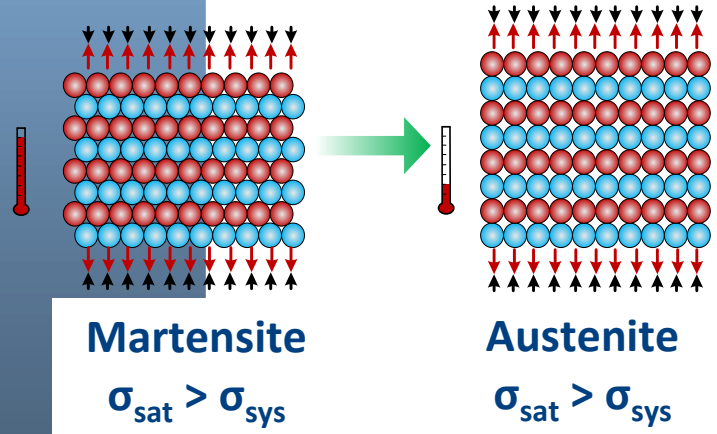
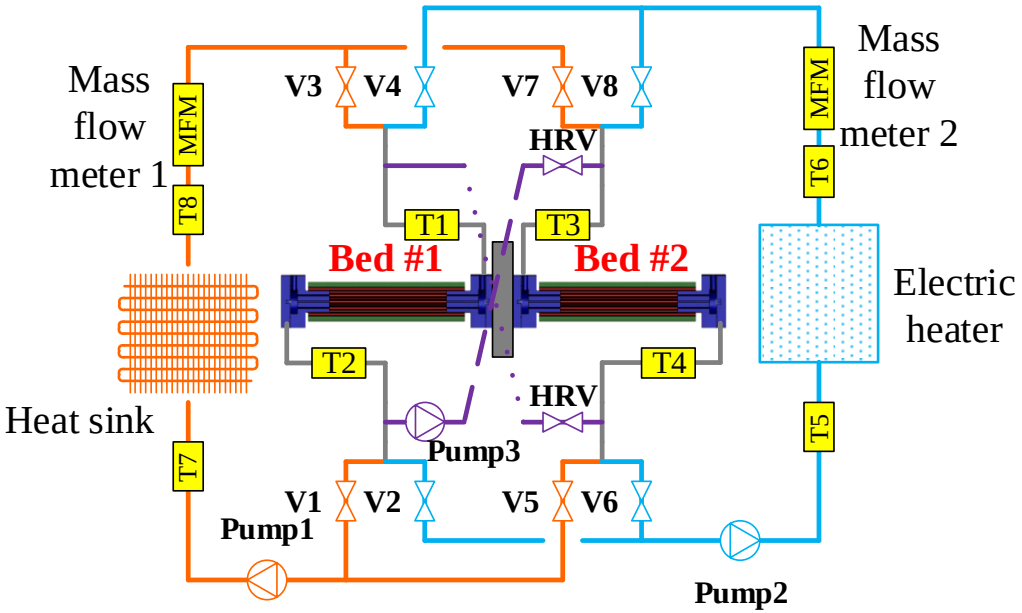
Thermoelastic Cooling

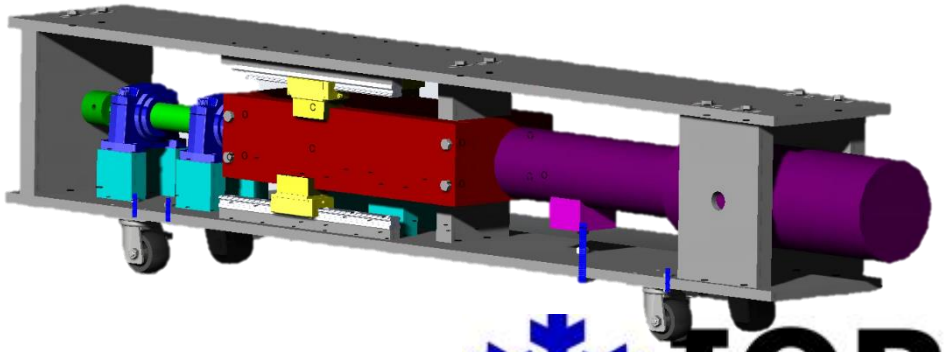


Apply stress to the system



Remove stress from the system





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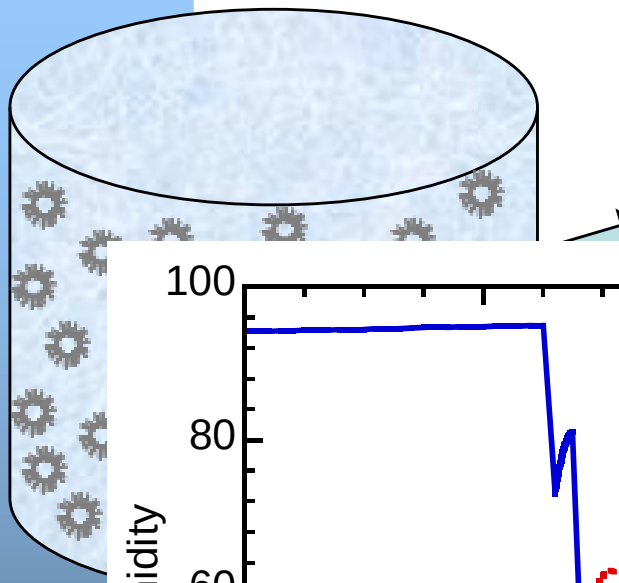
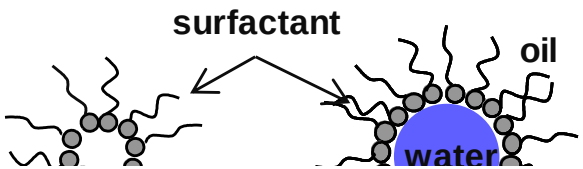
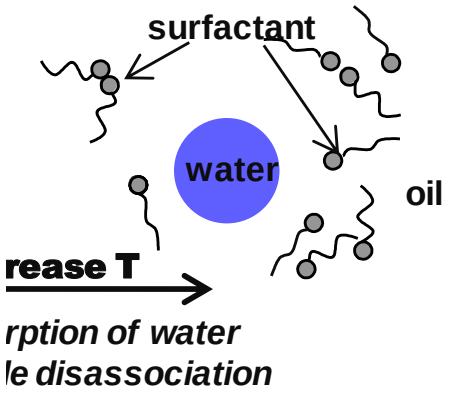
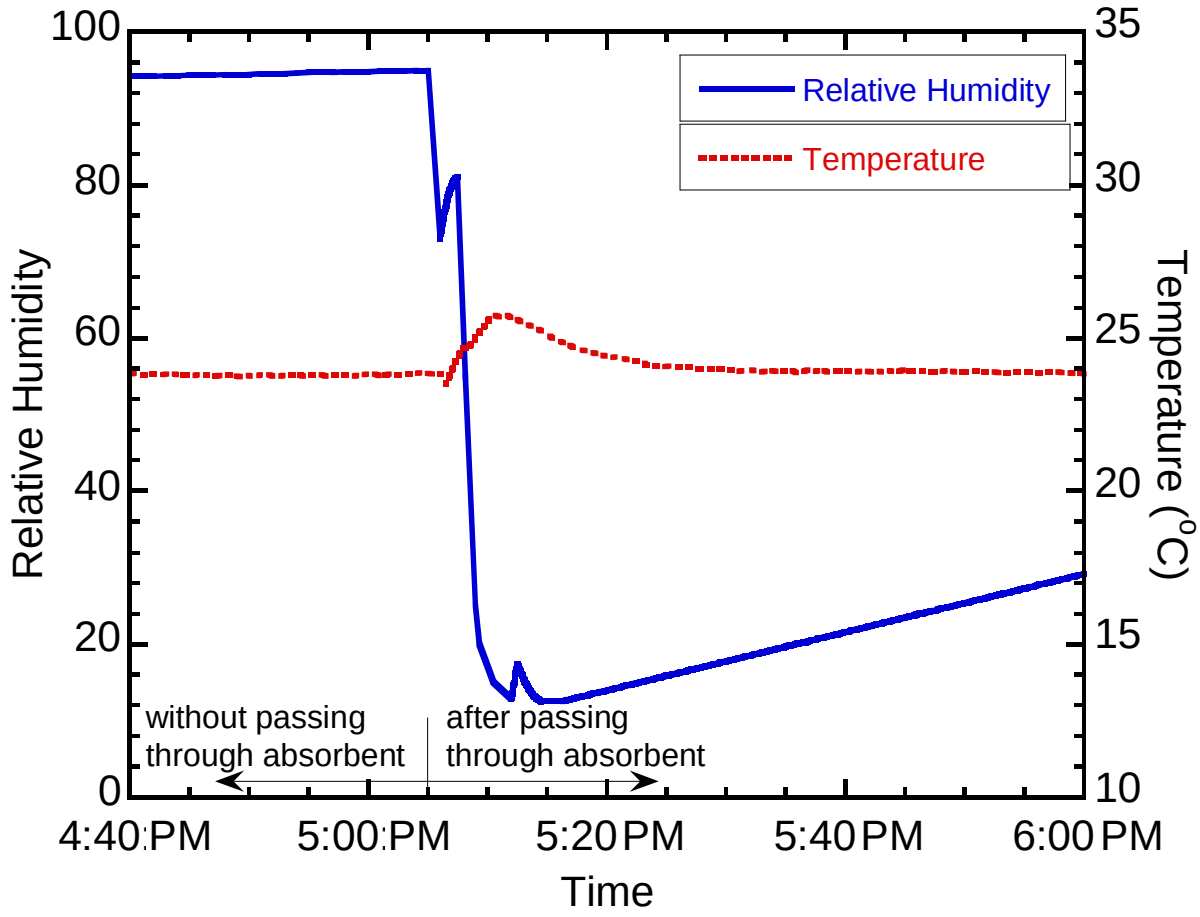
Novel Microemulsion Absorbent









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Outlook

- Increasing energy efficiency -> smaller products sold
- Ventilation and hot water larger portion of business
- Renovation is much larger market, more difficult to address = huge opportunity
- The nature of Innovation is changing rapidly

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Thank You

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We hope you enjoyed this webinar from the Institute of Refrigeration

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