Heat Pumps: The Past, Present and Future of this Transformative Technology

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HVAC Program Manager
Special Thanks

• Daikin – Naoki Fujita, Matt Lacey, Bill Paige
• DOE, BTO - Tony Bouza
• Fujitsu – Mike Psihoules
• Mitsubishi – Rick Nortz
1852 – Lord Kelvin
1856 – Peter von Rittinger
1902 Willis Carrier

- Inventor of modern air conditioning
- 1906 first installation of “Apparatus for Treating Air” at Cotton Mill in NC
1940s – Ground Source HP

- Hot water tank
- Heat pump
- Borehole heat exchanger
- Low-temperature underfloor heating
1950-72 – Slow Time for HP

- Dropping oil prices
- Heat Pumps stagnate
- Mostly just cooling in warmer climates
1973 – Oil Embargo

• ... and a repeat in 1979
• First massive intro of heat pumps
• From 800,000 globally to 4,000,000!
70s and 80s – Asia and Ductless

- Ductless, good for masonry
- Small living units
- Historically kerosene heaters and window AC
- Ductless HP a great solution!
Modern Innovations

- Refrigerants
- Microprocessors (80s)
- Electronic expansion valve (late 80s)
- Compressor technology (reciprocating to scroll to inverter)
- ECM fan motors
- Heat Exchangers (more efficient heat transfer with minimal surface area)
- Smaller, more efficient, quieter and more features
Market and Industry
Global Ductless Adoption

Source: Nortz (Mitsubishi Electric) and Psihoules (Fujitsu), NJCEP Presentation
Investment – Case Study
- $7B in US investments
- 2 other Parts Manufacturers have moved to US soil
Market Growth

- 2015 - 2016 US Growth
  - 20%
  - Ductless
- EVT Program
  - 1824 (2015)
  - 2243 (2016)
  - 23%
Performance and Diversity
How Low Can They Go?

• At least -13°F
• Below -13?  
• COP 2.0 @5°F
• 100% of nominal capacity @5°F

Pretty Low!
Performance

- HSPF 12-15
- SEER 20-30, as high as 38!
- But…are HSPF and SEER good indications of performance?
- New Testing Standards
  - CSA
  - Dynamic vs. Static Testing
Ductless – Single Zone

• EVT Supports 6 Manufacturers
• NEEP – 15 Manufacturers
• From 6,000-24,000 btu/h
Ductless – Multi-Zone

- EVT – 3 Manufacturers
- NEEP – 6 Manufacturers
- 18,000 – 48,000 btu/h

Source: Nortz (Mitsubishi Electric) and Psihoules (Fujitsu), NJCEP Presentation
Ductless – More Choices!

Source: Nortz (Mitsubishi Electric) and Psihoules (Fujitsu), NJCEP Presentation
Ducted
Ducted

- Standard Heat Pump
- Not a lot of cold climate options
- Performance not at level of ductless
- Fully Distributed heating/cooling
- Excellent Integration with Backup System
Ducted Ductless?

- Good for multiple small rooms
- Efficiency loss due to added fan energy
Air to Water - Altherma
Air to Water
Ground Source

- Seasonal COPs up to 5
- Whole home heating/cooling
- No backup necessary
- Market growth, but still prohibitively expensive for most
Commercial Heat Pumps

• VRF
  – Largest opportunity for growth in VT
• Hybrid Rooftop Units
  – Least involved option (direct swap-out)
Other Applications

• Domestic Water Heating
• Clothes Dryers
• Industrial Heat Recovery
  – Drying, Washing, Pasteurizing, etc.
Its All About Style…
Current Trends

• Growth
• Investment in US market
• Development of products for US market
• Diversity of product offering
• Viable for most climates and market sectors
System Impact & Integration
Modeled Electric Consumption

Exhibit 9-4. Composite Total Energy Study Modeled Electric Energy Use (TWh)

Improving “Emiciency”

Carbon Intensity of US Electric Sector Generation
2005-2030

- Energy efficiency of installed equipment is static over time
- Emissions Efficiency (“emiciency”) improves over time

Renewable Penetration

State Renewable Portfolio Standards for Class I or New Renewable Energy by 2020

Source: ISO-NE 2016 Regional Electricity Outlook
Renewable Penetration

State Renewable Portfolio Standards for Class I or New Renewable Energy by 2020

Source: ISO-NE 2016 Regional Electricity Outlook
75% by 2032
An Endangered Species

On the way out
More than 4,200 MW of the region’s nongas generating capacity has retired or plans to retire soon. This includes several oil- and coal-fired units, as well as two nuclear plants that were part of the region’s baseload generation. “At risk” for closing are another 6,000 MW from additional coal- and oil-fired generators, which are displaced from the electric energy market on most days by gas-fired units. But they are still critical for meeting the region’s demand in winter, particularly when natural gas supplies are limited. In total, about 30% of the region’s generating capacity could be gone by 2020. These retiring resources are likely to be replaced by more natural-gas-fired resources.

Source: ISO-NE 2016 Regional Electricity Outlook
Enhanced Utilization of Renewables

- PV, Fuel Cells, and Battery Storage all operate using DC power
- Utilizing DC reduces losses due to:
  - Transmission/Distribution
  - Inversion
Thermal Storage

- Simple Water Storage, or
- Phase Change Materials (PCMs)
Smart and Well Connected

- Demand Response
- Remote Firmware Updates
- Site-specific operation
- Occupancy and other sensors
- Integrated Controls
Natural Refrigerants
ODP

- **Ozone Depletion Potential**
- Relative amount of ozone degradation compared to baseline R-11 (1.0)
GWP

- **Global Warming Potential**
- Relative amount of heat trapped in the atmosphere by a gas (refrigerant) compared to a CO2 baseline (1.0)

\[
1 \text{ kg of } \text{CH}_4 \quad = \quad 32 \text{ kg of } \text{CO}_2
\]
### GWP and ODP

#### Figure 2: ODP and GWP for Various Refrigerants

<table>
<thead>
<tr>
<th>REFRIGERANT</th>
<th>TYPE</th>
<th>ODP</th>
<th>GWP (100yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-12</td>
<td>CFC</td>
<td>0.820</td>
<td>10,600</td>
</tr>
<tr>
<td>R-22</td>
<td>HCFC</td>
<td>0.034</td>
<td>1,700</td>
</tr>
<tr>
<td>R-404A</td>
<td>HFC</td>
<td>0</td>
<td>3,800</td>
</tr>
<tr>
<td>R-410A</td>
<td>HFC</td>
<td>0</td>
<td>2,000</td>
</tr>
<tr>
<td>R-290 (Propane)</td>
<td>Natural</td>
<td>0</td>
<td>~20</td>
</tr>
<tr>
<td>R-717 (Ammonia)</td>
<td>Natural</td>
<td>0</td>
<td>&lt;1</td>
</tr>
<tr>
<td>R-744 (CO₂)</td>
<td>Natural</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>HFO-1234yf</td>
<td>HFO</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: Calm & Hourahan, 2001
Refrigerants

26% 

Source: DOE, EERE, July 2016 *The Future of Air Conditioning for Buildings*
R-32

*Source: Values for 100 year global warming potential (GWP) from IPCC Fourth Assessment Report. Comparative 100 year GWP: HFC410A, 2,090; HFC32, 675.
On a Mission

• Advancing Natural Refrigerants in order to shape a more sustainable future for refrigeration [and heat pumps!]
New Ways to Skin the Cat
The Pretty Sure Stuff

• Performance improving
• Smaller
• More features
• More options (manufacturer, delivery, etc.)
• More whole home
All-in-One CERV

- Heat pump integrated ERV
- Integrated “smart” controls
All-in-One
Nilan – Compact P

- Heat Recovery Ventilation
- DHW
- Heat Pump
All-in-One VICS

TEAM LEAD: STEVEN WINTER ASSOCIATES INC.—WASHINGTON, DC

Steven Winter Associates Inc. will develop a fully integrated, smart space conditioning and ventilation solution, referred to as VICS (a Ventilation Integrated Comfort System), for low-load dwellings (zero energy ready homes, multifamily apartments, etc.). This innovation is intended to address HVAC performance issues found in most low-load dwellings when space conditioning and whole-building ventilation are provided by separate mechanical systems. This lack of system integration can result in high equipment and installation costs, redundant components, and poorly or non-integrated controls. The VICS is intended to provide:

- A single device integrating an HRV or ERV with a low-capacity, split heat pump fan coil to provide efficient heating, cooling, dehumidification, and whole-house ventilation
- Filtration, heat recovery, conditioning, and distribution of outdoor air
- Installed cost savings of $1,000–$2,000 compared to separate, ducted ventilation and heating/cooling systems
- Separate control of supply and exhaust flows allowing for active makeup air for local exhaust fans
- Better humidity control by passing outdoor air through ERV and over a cooling coil.

- Full ventilation and space conditioning
- Designed for low load homes
Complete Replacement

- No need for backup heating system
- Possible today in low load buildings
- Within 10 years (maybe 5!)
Objective 1: Near-Term
- Improve efficiency of current technologies
- May include cost reduction activities

Objective 2: Next Generation
- Longer-term
- Potential to “leapfrog” existing technologies
- Entirely new approaches

Objective 2: Next Generation
- e.g., Non-Vapor Compression

Legend
- Red: Current Status
- Green: DOE Objective

Source: Refined from BTO Presentation: energy.gov/sites/prod/files/2014/05/f15/HVAC_Overview_Bouza_042314_and_042414.pdf
Compressors
The Heart and Soul of Heat Pumps

• Reciprocating, rotary vane, and screw
• Scroll currently used in efficient systems
• What’s next? **Centrifugal**
• Used in Chillers
• Natural Refrigerant friendly
• Oil Free
Compressors
The Heart and Soul of Heat Pumps

• Non-mechanical compression?
• Electro-chemical compressors
  – “Noiseless”
  – Low GWP refrigerants
  – Hydrogen combines with H2O and ammonia
  – Pressures up to 10,000 psi
Non Vapor Compression
Absorption

- Cyclical absorption/desorption of refrigerant in secondary fluid
- Runs on Electricity or combustible fuels
- No compressor!
- Natural refrigerant
- New? - smaller and less expensive
Non Vapor Compression
The really far-out stuff

- Thermo-electric
- Magneto-caloric
- Electro-caloric
- Elastic-caloric
- Thermo-acoustics
Thermo-electric

- Current induces temperature differential across 2 different materials ("peltier effect")
- Solid State Heat Pump
Magneto-caloric

- Some materials gain and lose heat when exposed to a magnetic field
Electro-caloric

- Materials show a temperature change when exposed to an electric field
Thermo-elastic

• Materials that give off heat when physically stressed
• Potential for COP ~11!
Thermo-acoustics

- Acoustic oscillations induce compression and expansion of a working gas (refrigerant)
Conclusions
100
SEER
Conclusions

It's All About the Money

• Economics have driven innovations and adoption
  – Rittinger and Salt Brine
  – Oil Embargo
  – Disappearance of Altherma
  – Next Gen Tech
## Conclusions

Its All About the Money – Or Is It?

<table>
<thead>
<tr>
<th>Type of Energy</th>
<th>BTU/unit</th>
<th>Typical Efficiency</th>
<th>$/unit</th>
<th>$/MMBtu</th>
<th>High Efficiency</th>
<th>$/MMBtu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Oil, gallon</td>
<td>138,200</td>
<td>80%</td>
<td>$2.23</td>
<td>$20.14</td>
<td>95%</td>
<td>$16.96</td>
</tr>
<tr>
<td>Kerosene, gallon</td>
<td>136,600</td>
<td>80%</td>
<td>$2.80</td>
<td>$25.65</td>
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<td></td>
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<tr>
<td>Propane, gallon</td>
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<td>$29.17</td>
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<td>*</td>
<td>$14.88</td>
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<td>Electricity, kWh (resistive)</td>
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<td>$0.15</td>
<td>$43.46</td>
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<td></td>
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<tr>
<td>Electricity, kWh (heat pump)</td>
<td>3,412</td>
<td></td>
<td>$0.15</td>
<td>#</td>
<td>240%</td>
<td>$18.32</td>
</tr>
<tr>
<td>Wood, cord (green)</td>
<td>22,000,000</td>
<td>60%</td>
<td>$227</td>
<td>$17.21</td>
<td>^</td>
<td></td>
</tr>
<tr>
<td>Pellets, ton</td>
<td>16,400,000</td>
<td>80%</td>
<td>$275</td>
<td>$20.96</td>
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Source: November 2016 VT Fuel Price Report
Conclusions
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Source: November 2016 VT Fuel Price Report
Conclusions
Its All About the Money – Or Is It?

• Why?
  – Carbon footprint, being “green”
  – Comfort/Convenience - AC/Heat out of same install
  – Make use of solar (63% in EVT evaluation)
  – Getting away from bulk delivery
  – “Cool Gadget” high-tech thing
Thank You!