Building Energy Technologies

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## Building Energy Technologies

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- Advanced system concepts  
  - CCHP: co-gen power and cooling  
  - Compact distributed systems  
  - Desiccant cooling  
  - Concentrated solar cooling  
  - Energy recovery ventilator  | - Wavelength-selective coatings  | - Heat pump dryer  
  - Heat pump water heater  | - PV – solution deposition  
  - Fuel cell technologies  
  - Energy storage - batteries  |

- Established technology and/or capability  
  - Has been proposed  
  - Potential application of microtechnology
Heating, Ventilation and Air Conditioning
Heat-Activated Heat Pumps
Heating, Ventillation, and Air Conditioning (HVAC)
Heat-Activated Heat Pumps

• Use heat to provide cooling, heating, and power
  – Burn a fuel, such as H₂, natural gas, propane, or military fuel
  – Waste heat source—engine exhaust, fuel cell reject heat, etc…
  – Solar thermal—need >100°C, preferably >170°C

• Three systems under development
  – Expander/Compressor cycle—coupled ORC and vapor compression
    • Can provide power, cooling, and/or heating
    • 1.5 ton demonstration system currently in testing (U.S. Army)
  – Absorption heat pump—ammonia-water cycle
    • Can provide cooling and/or heating
    • 1.5 ton demonstration system scheduled for Summer, 2010 (U.S. Army)
  – Adsorption heat pump—ammonia carbon
    • Can provide cooling and/or heating
    • Rapid cycle thermal swing modeling showing COP_{cool} > 1.1 and COP_{heat} > 2.4
HVAC: Heat-Activated Heat Pump
Expander/Compressor Cycle

- **Concept**
  - Coupled organic Rankine cycle (ORC) and vapor compression.
  - Mechanical linkage of expander, compressor, and motor/generator allows for any combination of cooling, heating, or power.
  - Co-fired with heat and electric power for highly flexible load-following system.

- **Progress & Status**
  - System models project COP>1.1 at military conditions of 50°C ambient.
  - Developed high performance scroll expander technology (see below).
  - Incorporated advanced microchannel heat exchangers to improve performance.
  - Developed 5.3 kW (~1.5 tons) cooling system, currently in testing.

- **Point of Contact**
  - Prof. Rich Peterson, richard.Peterson@oregonstate.edu
HVAC: Expander/Compressor Cycle
Technology Development – Scroll Expanders

- Based on commercial, high volume production scroll technology.
- Measured near 100% volumetric efficiency in preliminary testing (no blow-by of working fluid).
- Measured isentropic efficiency and power output in test rig show efficiencies approaching 80%.

- Packaging and housing
  - Provides output shaft to measure power and to connect to compressor unit.
  - Fully sealed to allow pressurized working fluid.
HVAC: Heat-Activated Heat Pump
Expander-Compressor Cycle Heat Pump

- **Competition**
  - Commercial electric heat pumps
  - Absorption (solution) cycle heat pumps
  - No commercial heat pumps in U.S. for residential and smaller heat-activated cooling

- **Advantages**
  - High-efficiency, compact equipment
  - Flexible co-generation of power and cooling/heating
  - Utilize growing supply of natural gas reserves

- **Next steps**
  - Test system at designed outdoor temperature of 120 °F
  - Replace current oil heater loop with heat recovered from the exhaust of a diesel engine

- **Intellectual Property**
  - Patent application in final stages of review by the U.S. patent office.
    Most claims accepted.

Assembled 5.3-kW E/C system viewed from cool air discharge side

Dimensions are 34”x32”x24”
**HVAC: Heat-Activated Heat Pump**

**Absorption Cycle Heat Pump**

- **Concept**
  - Natural gas or solar heat pump for air conditioning, space heating, and water heating.
  - High energy efficiency obtained through extensive heat integration and heat recuperation—COP > 0.6 projected at military conditions (50°C ambient).
  - Compact system is achieved through microchannel absorber, desorber, and heat exchanger technologies.

- **Progress & Status**
  - 300W-scale breadboard used as test bead for new concepts and subscale prototype demonstration.
  - COP > 0.6 projected at military conditions of 50°C ambient temperature.
  - 5.3 kW system designed and being assembled for Summer 2010 demonstration.
  - Substantial investment being made in low-cost manufacturing.

- **Point of Contact**
  - Dale King, dale.king@pnl.gov

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5kW-scale military system
HVAC: Heat-Activated Heat Pump
Absorption Cycle Heat Pump

➢ Competition
  ➢ Commercial electric heat pumps
  ➢ No commercial heat pumps in U.S. for residential and smaller heat-activated cooling

➢ Advantages
  ➢ High-efficiency, compact equipment
  ➢ Scalable from <1 ton up to commercial building
  ➢ Utilize growing supply of natural gas reserves
  ➢ Reduce electricity demand growth by offloading cooling during peak demand.

➢ Next steps
  ➢ Demonstrate 5.3 kW military system

➢ Intellectual Property
  ➢ Advance wick patent application pending.
  ➢ Integrated desorber patent application pending.
HVAC: Heat-Activated Heat Pump
Adsorption Cycle Heat Pump

- **Concept**
  - Natural gas or solar heat pump for air conditioning, space heating, and water heating.
  - High energy efficiency obtained through effective heat recuperation using a patented multi-bed system.
  - Compact system is achieved through:
    - integrated microchannel heat exchange for rapid thermal cycling, and
    - monolithic carbon sorbent having high capacity and high thermal conductivity.

- **Progress & Status**
  - Detailed models predicting compressor performance at specified conditions.
  - COP > 1 projected for residential cooling at standard conditions with >180°C heat.
  - COP > 2.4 projected for residential space heating with >180°C heat.
  - Progress made in aluminum joining for interleaved microchannel sorbent beds

- **Point of Contact**
  - Ward TeGrotenhuis, ward.tegrotenhuis@pnl.gov
HVAC: Heat-Activated Heat Pump
Adsorption Cycle Heat Pump

- **Competition**
  - Commercial electric heat pumps
  - Absorption (solution) cycle heat pumps
  - No commercial heat pumps in U.S. for residential and smaller heat-activated cooling

- **Advantages**
  - High-efficiency, compact equipment
  - Scalable from <1 ton up to commercial building
  - Utilize growing supply of natural gas reserves
  - Low corrosivity enabling aluminum construction
  - No solution pump

- **Next steps**
  - Bed fabrication and system demonstration
  - Multi-port valve development

- **Partners**
  - ATMI (carbon monolith sorbents)

- **Intellectual Property**
Heating, Ventilation and Air Conditioning
Advanced Heat Transfer
HVAC: Advanced Heat Transfer
Nano-Scale Coatings for Enhanced Boiling

- **Concept**
  - Nano-textured surfaces can enhance boiling heat transfer coefficient by about an order of magnitude.
  - Surface created by cost-effective micro-assisted nano-deposition (MAND™) process.

- **Progress & Status**
  - Proof-of-principle testing demonstrating higher heat transfer coefficient and higher critical heat flux.

- **Advantages**
  - Enhance HVAC coefficient of performance
  - Lighter, more compact evaporators

- **Next Step**
  - Demonstrate prototype scale device

- **Intellectual Property**
  - U.S. Pat. App. 12/709,266, Filed 2/2010 (OSU/PNNL)
  - U.S. Pat. App. (MAND™) (OSU)

- **Point of Contact**
  - Terry Hendricks, terry.hendricks@pnl.gov
HVAC: Advanced Heat Transfer

Air-side Heat Transfer

- **Concept**
  - Dramatically reduce gas heat transfer resistance

- **Progress and Status**
  - Demonstrated 44% reduction in gas heat transfer resistance at comparable pressure drop relative to straight fins.
  - Series resistance model indicates substantial further improvement possible.

- **Advantages**
  - Enhanced HVAC coefficient of performance
  - Lighter, more compact, higher performing evaporators and condensers

- **Next Steps**
  - Demonstrate prototype scale device
  - Second generation testing

- **Intellectual Property**
  - Invention disclosure filed

- **Point of Contact**
  - Ward TeGrotenhuis, ward.tegrotenhuis@pnl.gov

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**Figure:**

![Graph showing thermal resistance vs. velocity for different channel types: Empty Channel, Straight Porous Fin, Half Corrugation Porous Fin.](image)
HVAC: Advanced Heat Transfer  
Air-side Heat Transfer with 3-D Periodic Structures

- **Concept**
  - Use unique 3-D periodic microstructures to reduce gas heat transfer resistance by 45% compared to standard fin-plate structures.
  - Cost-effective manufacturing approaches identified.

- **Progress and Status**
  - Concept stage with in-house expertise

- **Advantages**
  - Enhanced HVAC coefficient of performance
  - Lighter, more compact, higher performing evaporators and condensers

- **Next Steps**
  - Proof-of-concept manufacturing
  - Demonstrate prototype-scale device
  - Develop intellectual property

- **Point of Contact**
  - Terry Hendricks, terry.hendricks@pnl.gov
Heating, Ventilation and Air Conditioning
Advanced Systems Concepts
Advanced System Concepts
CCHP: Co-Functional Power / Cooling Systems

Concept
- Produce combined power and cooling utilizing waste heat or by combusting fuel.
- Integrate a thermoelectric generator (TEG) power module as a topping cycle with a heat-activated cooling technology as a bottoming cycling.
- Heat coming from the TEG combined with hot exhaust gas is used to run the cooling system—effectively achieves 100% energy conversion efficiency in the TEG. Potentially saves 20 to 30% in fuel usage in forward deployed applications.

Progress and Status
- Being developed for battlefield applications, stationary and mobile, with various heat waste heat sources including diesel generator exhaust.
- Currently developing co-functional integration of 3 power & cooling technologies:
  - Advanced thermoelectric (TE) power system
  - Organic Rankine cycle (ORC) cooling system
  - Microchannel heat exchangers
- Currently testing a demonstration system designed for ~100 W power generation & 5.3 kW cooling capacity

Point of Contact
- Terry Hendricks, terry.hendricks@pnl.gov
Military Co-Functional Power / Cooling Systems

- TEG Power System Uses MicroChannel Heat Exchangers
  - Stainless Steel Air HX on Hot-Side
  - Aluminum R245fa HX on Cold-Side
  - 16-22 TE Modules

- ORC Boiler Uses MicroChannel Heat Exchangers
  - High-Temperature Bi$_2$Te$_3$ Modules
  - First-Ever 320°C Bi$_2$Te$_3$ Modules

- System Size
  - Microtechnology Enables Smaller System
  - Dimensions: 30” X 30” X 19”
  - Weight: ~100 kgs

- Next Steps
  - System Testing
Other ‘Drawing Board’ Concepts

- **Distributed Heat-activated Heat Pumps**
  - Distributed HVAC replaces a single large central HVAC unit with zonal or distributed HVAC units.
  - Advantages: reduces ducting and associated with central system cycling losses, enables zonal heating and cooling, lower building capital cost (no ducts will reduce a story height by 1 m)

- **Integrated Heat-activated Heat Pump and Desiccant Dehumidification**
  - Utilize waste heat from a heat-activated heat pump to regenerate the desiccant of a dehumidification system—heat pump topping cycle and desiccant bottoming cycle.
  - Advantages: No need to cool air to desired dew point allows higher evaporator temperature, higher heat pump Carnot efficiency, and increased energy efficiency.

- **Concentrated Solar HVAC**
  - Leverage MBI heat actuated HVAC technologies and partner to obtain affordable single-axis solar trough collectors leveraging low-cost technology currently marketed for solar heating.
  - Advantages: Increasing solar heat temperature increases HVAC efficiency and reduces HVAC and solar collector size and cost.