Design and Operation of a Conditioning Energy Recovery Ventilator (CERV) for Passive Houses

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Motivation and Objectives

Combine our knowledge of HVAC systems with interest in energy efficient homes to create a niche product.

Coupled with highly efficient house construction (e.g., Passive House standards), efficient house conditioning systems lead to the ability to provide all home energy needs with solar energy in a cost effective manner.

The “CERV” is a primary component for efficient heating, cooling, and dehumidification of an energy efficient home.

Development of energy efficient house conditioning systems with the goal of constructing a “net zero energy” home for central Illinois and beyond.
Air Conditioning Experience

- refrigerators
- military aircraft cooling
- automotive
Presentation Outline

• House Energy Characteristics
• Building Conditioning Requirements

• Conditioning Energy Recovery Ventilator Description
• CERV Operation and Performance
Keeping Comfortable

Lots to consider!

Building construction, outside conditions, Interior components, and activities
2007 Solar Decathlon House

- The 2007 University of Illinois Solar Decathlon “elementhouse” is a “Net Zero” house in which all house energy is supplied by solar energy (solar electric with PV panels).

- The UI 2007 Solar Decathlon House is also designed to supply up to 10,000 miles of electric vehicle transportation per year.

- Zero energy house design significantly reduces the capacity requirements of its comfort conditioning system.

- Ventilation and moisture management become very important.

- While smaller, the comfort system must be more nimble and smarter than conventional systems.
2000 sq ft Home LifeCycleCost

Simple LifeCycleCost ~ $242,000

with 12 cm insulation = $20,500
and 27 m² PV = $20,200

Or, 10 cm insulation = $17,100
and 29.5 m² PV = $22,100

Or, 5 cm insulation = $8,500
and 45 m² PV = $33,800

Optimal solution is fairly “flat”
“Sensible” heat and “latent” heat refer to the transfer of energy into or out of a conditioned space where:

- **Sensible** refers to an energy transfer that you can “sense”
  - Temperature change of air

- **Latent** refers to an energy transfer that is hidden or not sensed
  - Moisture change of air

The energy needed to drop 70°F air from 60%rh to 40%rh is the same as the energy to heat air from 70°F to 85°F.
Conventional vs. Efficient

• Conventional homes are dominated by the exterior conditions
  – Leaky envelope means unwanted ventilation
  – Larger capacity required because of free air movement
  – Free exchange of conditioned/unconditioned air without recovery of energy
  – Little moisture control

• Efficient homes balanced more towards interior loads
  – Ventilation and moisture are controlled
  – Small energy loads make energy recovery significant
Typical House Conditioning System

Illinois Weather

• Conventional home air conditioner ~3 “tons” (36,000 Btu/hr ~ 10,000 watts)
  – Designed for ~2/3 sensible and ~1/3 latent loads

• Conventional gas furnace ~80,000 Btu/hr ~ 22,000 watts

• Efficient capacity control of conventional systems difficult
  – Conventional construction requires large span of capacity control
Base Case House

So, what capacity is needed to keep a high efficiency residence comfortable? How many tons, BTUH, watts, liters per day…..?

- 2000 sq ft, single story house (~45’ x 45’)
- 50 sq ft, south facing windows, U=0.5W/m^2-K
  - High performance, triple/quadruple glazed
- UAwall + UAroof = 65W/K (~R22 wall, R44 roof)
- Ventilation = 50 cfm (0.2 ACH) => ASHRAE 62.2 standard
- 4 people (75W/person heat; 75W/person moisture)
- 200W internal generation (refrigerator, TV, computer, lights, etc)

ICF (insulated concrete form) home in Urbana IL
Comfort is a squishy concept

2000 sq ft Home Comfort

- Heating and dehumidification
- Cooling and dehumidification
- Heating and humidification

66-76F
30-60%rh

Qlatent (watts)
Qsensible (watts)
2000sq ft “Conventional” Home

- Heating and dehumidification
- Cooling and dehumidification
- Heating and humidification

- 3 x vent, 3 x UA
- 100 sqft windows

- Qsensible (watts)
- Qlatent (watts)
CERV
Conditioning Energy Recovery Ventilator

Low temperature heat pump air conditioning system:

Cold side air

Hot side air

evaporator

compressor

condenser
CERV Features

- Small capacity, self-contained, modular system
- Plug and play modules are added to reach required building capacity
- Air source heat pump with a variable speed compressor to adjust to load
- Provides heating, cooling, dehumidification, and ventilation
## Refrigerant Overview

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Systems</th>
<th>*ODP (Ozone Depletion Potential)</th>
<th>*GWP (Global Warming Potential)</th>
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</thead>
<tbody>
<tr>
<td>R12</td>
<td>automotive</td>
<td>1</td>
<td>8100</td>
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<tr>
<td>R22</td>
<td>residential and light commercial air conditioning, refrigerators, and freezers</td>
<td>0.05</td>
<td>1700</td>
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<tr>
<td>R134a</td>
<td>residential and light commercial air conditioning, refrigerators, freezers, and automotive</td>
<td>0</td>
<td>1300</td>
</tr>
<tr>
<td>R410A</td>
<td>residential and light commercial air conditioning replacing R22</td>
<td>0</td>
<td>1890</td>
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<tr>
<td>R744 (CO2)</td>
<td>In development for automotive</td>
<td>0</td>
<td>1</td>
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<tr>
<td>HFO 1234 yf</td>
<td>Preliminary tests as a 134a “drop in”</td>
<td>0</td>
<td>4</td>
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</tbody>
</table>

- **ODP** – Ozone depletion potential compared to CFC-11 (1)
- **GWP** – contribution to global warming compared to same mass of CO2 (1)
Refrigerant and Regulations

- R12 banned in 1994 – replaced with R134a

- Montreal Protocol – international treaty to phase out ozone depleting substances – eliminates sale of R22 equipment starting in 2010, allocation of acceptable producers for service use of existing equipment

CERV Refrigeration System

• Use 134a phase into 1234 yf as it becomes available
  – no ozone depletion
  – very low global warming potential

• Hermetically sealed system
  – small refrigerant charge
  – eliminates onsite charging, line sets, fittings
  – sealed for lifetime of unit
  – refrigerant can be recovered
CERV Modes of Operation and Test Results

- heating
- cooling
- heating with ventilation
- cooling with ventilation
- ventilation only

integrated controls to determine most efficient conditioning mode
Heating without ventilation:

- **Outside**
  - Temperature (T) cold: -1.2°C
  - Relative Humidity (RH%) cold: 90.7%

- **Inside**
  - Temperature (T) hot: 32.2°C
  - Relative Humidity (RH%) hot: 27.5%

- **Inlet**
  - Temperature (T) cold: 5.2°C
  - Relative Humidity (RH%) cold: 84.6%

- **Outlet**
  - Temperature (T) hot: 18.1°C
  - Relative Humidity (RH%) hot: 64.5%

**Energy Efficiency**

- **Compressor Power**: 377 W
- **Total Heating Capacity**: 1165 W

**Additional Information**

- **COP**: 3.1
- **EER**: 11.1 Btu/W-hr

*Energy Efficiency Ratio*
Winter day just below freezing, air flow ~100cfm
Very cold day ~2°F, long operation, no defrost needed

“drop in” mode lowers comp power
Operation at 0°F, also performed at -17°F with reduced capacity data not shown.
Coefficient of Performance (heat mode)

Time (seconds)

COP heating
Cooling without ventilation:

- **outside**
  - $T_{\text{hot in}} = 37.7^\circ C$
  - $RH\%_{\text{in}} = 29.0\%$
  - $T_{\text{hot out}} = 55.4^\circ C$
  - $RH\%_{\text{out}} = 12.7\%$

- **inside**
  - $T_{\text{cold out}} = 22.6^\circ C$
  - $RH\%_{\text{out}} = 64.0\%$
  - $T_{\text{cold in}} = 31.5^\circ C$
  - $RH\%_{\text{in}} = 39.0\%$

- Compressor power = 450 W
- COP = 2.4
- EER = 8.6 Btu/W-hr
- Total cooling capacity = 1079 W
- Lat. = 133 W
- Sens. = 947 W
Heating with ventilation:

- **T hot in = 14.1 C**
  - RH% in = 71.5%
- **T hot out = 32.0 C**
  - RH% out = 28.6%
- **T cold out = 14.1 C**
  - RH% out = 71.5%
- **T cold in = 20.2 C**
  - RH% in = 58.6%

- **compressor power = 335 W**
- **total heating capacity = 1803 W**
- **COP = 5.4**
- **EER = 19.3 Btu/W-hr**
**Cooling with ventilation:**

- **outside**
  - **T cold in** = 36.7°C
  - **RH% in** = 26.7%
  - **T hot out** = 36.7°C
  - **RH% out** = 26.7%

- **CERV**

- **inside**
  - **T cold out** = 25.1°C
  - **RH% out** = 48.0%
  - **T hot in** = 21.6°C
  - **RH% in** = 61.5%

- **compressor power** = 381 W
- **total cooling capacity** = 1342 W
- **COP** = 3.5
- **EER** = 12.7 Btu/W-hr
- **lat.** = 231 W
- **sens.** = 1110 W
Ventilation only:

CERV in dehumidification mode
- tests show water removal rate of 0.5 liters/hr
- with compressor power of 300 W gives 1.5 l/kW-hr
- EnergyStar dehumidifier standard for this size is >1.0 l/kW-hr
- could be coupled with a ventless clothes drier
Future Testing

Many initial tests have been performed, but ...many remain.

Test matrices quickly expand!

4 temperatures x 4 air flows x 4 humidities x 4 compressor speeds
= 256 points

results look promising so far
Additional Future Options:

CERV with heat pump water heater
- heats water with a COP of 2-3 (electric water heater COP is 1)
- added benefit of cooling and dehumidifying house
- with COP of 3 and 15% efficient PV panels = 45% efficiency equivalent to solar thermal without added complexity
Other Considerations

• Evaporator Defrosting
  – Frost buildup on air source heat pump when heating in cold weather

• Condensate removal
  – can possibly be used to improve condenser efficiency

• moisture/mold/odor prevention

• end of life recycle ability
Thanks

Questions?