Air-to-Air Energy Recovery

Presenters: Ronnie Moffitt, Dennis Stanke, John Murphy, Jeanne Harshaw (host)
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With the increased focus on reducing energy use in buildings, more projects are considering the use of air-to-air energy recovery. And energy codes are evolving to require energy recovery in more applications. This ENL will discuss the various technologies used for air-to-air energy recovery and the importance of properly controlling these devices in various systems types.

Viewer learning objectives
1. Summarize how to design and control exhaust-air energy recovery to maximize the energy-saving benefits
2. Understand the various air-to-air energy recovery technologies
3. Understand the advantages and drawbacks of various air-to-air energy recovery technologies
4. Summarize how recent changes to energy codes impact the requirement for using exhaust-air energy recovery in buildings

Agenda
Welcome, introduction
Why recover energy?
  a) Reduce energy use (psychrometrics of EA energy recovery)
  b) Comply with energy codes (ASHRAE Standard 90.1, IECC)
  c) Review the definition of effectiveness
Discuss common technologies (advantages & drawbacks, typical performance)
  a) Coil loop
  b) Heat pipe
  c) Fixed-plate heat exchanger
  d) Fixed-membrane heat exchanger
  e) Total-energy wheel
  f) Comparison of technologies
Proper control and integration into HVAC systems
  a) Show colorful psych chart with hourly weather data
  b) Mild weather (turn device off when hOA < hEA or DBTOA < DBTEA)
  c) Cold weather (modulate capacity to prevent over-heating)
  d) Frost prevention during cold weather
  e) Review operating modes for a mixed-air VAV system
Suggestions for cost-effective application of energy recovery
  a) ASHRAE 90.1-2010 requires exhaust-air energy recovery in more applications
  b) Total-energy recovery devices transfer both sensible heat and water vapor (larger reductions in plant capacity, less susceptible to frosting)
  c) Centralize exhaust to better balance airflows and maximize recovery (DEER unit configuration, Std 62.1 and restroom exhaust)
  d) Minimize cross-leakage with proper fan placement
  e) Importance of proper control (include bypass dampers to enable economizing in mixed-air systems, modulate capacity to prevent over-heating, analyze frost prevention methods)
  f) Specify AHRI-certified components (introduce AHRI 1060 certification program)

Summary
Ronnie Moffitt | applications engineering | Trane
Ronnie joined Trane in 1996 and currently is an airside applications engineer whose responsibility is to aid design engineers and Trane sales personnel in the proper design and application of HVAC systems. His primary focus has been dehumidification and air-to-air energy recovery. This includes the development, design and control optimization of desiccants in commercial HVAC systems. He has several patents related to these subjects, and serves on related ASHRAE engineering committees. He is current chairman of the AHRI Air-to-Air Energy Recovery Ventilation Equipment section.

Ronnie led the development of the Trane CDQ system, a winner of the R&D 100 Award for The Most Technologically Significant New Products of 2005. He is a certified Energy Manager (CEM) by Association of Energy Engineers and received his B.S. in Aerospace Engineering from Syracuse University.

John Murphy | applications engineer | Trane
John has been with Trane since 1993. His primary responsibility as an applications engineer is to aid design engineers and Trane sales personnel in the proper design and application of HVAC systems. As a LEED Accredited Professional, he has helped our customers and local offices on a wide range of LEED projects. His main areas of expertise include energy efficiency, dehumidification, dedicated outdoor-air systems, air-to-air energy recovery, psychrometry, and ventilation.

John is the author of numerous Trane application manuals and Engineers Newsletters, and is a frequent presenter on Trane’s Engineers Newsletter Live series. He also is a member of ASHRAE, has authored several articles for the ASHRAE Journal, and has been a member of ASHRAE’s “Moisture Management in Buildings” and “Mechanical Dehumidifiers” technical committees. He was a contributing author of the Advanced Energy Design Guide for K-12 Schools and the Advanced Energy Design Guide for Small Hospitals and Health Care Facilities, a technical reviewer for the ASHRAE Guide for Buildings in Hot and Humid Climates, and a presenter on ASHRAE’s “Dedicated Outdoor Air Systems” webcast.

Dennis Stanke | staff applications engineer | Trane
With a BSME from the University of Wisconsin, Dennis joined Trane in 1973, as a controls development engineer. He is now a Staff Applications Engineer specializing in airside systems including controls, ventilation, indoor air quality, and dehumidification. He has written numerous applications manuals and newsletters, has published many technical articles and columns, and has appeared in many Trane Engineers Newsletter Live broadcasts.

Air-to-Air Energy Recovery

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learning objectives
After today’s program you will be able to:

- Design and control exhaust-air energy recovery to maximize the energy-saving benefits
- Identify the advantages and drawbacks of various air-to-air energy recovery technologies
- Comply with recent changes to energy codes regarding the requirements for exhaust-air energy recovery
Today’s Presenters

John Murphy
Applications Engineer

Dennis Stanke
Applications Engineer

Ronnie Moffitt
Applications Engineer

Agenda

- Why implement exhaust-air energy recovery?
- Common air-to-air energy recovery technologies
- Proper control and integration into HVAC systems
- Suggestions for cost-effective application of energy recovery
Agenda

- Why implement exhaust-air energy recovery?
  - Reduce overall system energy use
  - Comply with energy codes
- Common air-to-air energy recovery technologies
- Proper control and integration into HVAC systems
- Suggestions for cost-effective application

Exhaust-Air Energy Recovery

air-to-air heat exchanger

OA → EA' → EA → OA'

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sensible-energy recovery
(Atlanta, Georgia)

total-energy recovery
(Atlanta, Georgia)
Why Use Exhaust-Air Energy Recovery?

**Operating Cost**
- Reduces cooling and heating energy use
  - Heating energy savings is generally greater than cooling energy savings
- Increases fan energy use

**Installed Cost**
- Allows downsizing of cooling and heating plants
  - Total-energy recovery typically allows for largest cooling plant reductions
- Added pressure loss may increase fan motor sizes
- May require additional exhaust ductwork
**Agenda**

- Why implement exhaust-air energy recovery?
  - Reduce overall system energy use
  - Comply with energy codes
- Common air-to-air energy recovery technologies
- Proper control and integration into HVAC systems
- Suggestions for cost-effective application

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**Why Recover Energy in Buildings?**

- Save energy and operating costs
- Comply with:
  - Energy codes (IECC), following either ASHRAE Standard 90.1 or ICC requirements
  - Green-building codes (IgCC-based), following either Standard 189.1 or ICC requirements
  - Energy label (ENERGY STAR) or building rating systems (LEED®)
- **IECC**—International Energy Conservation Code
- **ICC**—International Code Council (ICC) requirements
- **IgCC**—International green Construction Code

**how standards fit with Energy Codes**

- **Primary ASHRAE Standards**
  - **Std 90.1**
- **Other Sources**
  - Expertise
  - ANSI Stds
  - NFPA
- **Model Energy Code**
  - **90.1 Path**
  - **IECC**
  - **ICC Path**
- **Local Energy Code**
What is Standard 90.1?

- An ANSI standard in mandatory-language, co-sponsored by ASHRAE, USGBC, and IES, that:
  - Provides minimum design energy requirements for commercial and high-rise residential buildings
  - It does not apply to low-rise residential
  - It covers building envelope, HVAC, water heating, power and lighting

Standard 90.1-2007, Section 6.5.6.1
Exhaust-Air Energy Recovery

Individual fan systems that have both a design supply air capacity of 5000 cfm or greater and have a minimum outdoor air supply of 70% or greater of the design supply air quantity shall have an energy recovery system with at least 50% recovery effectiveness. Fifty percent energy recovery effectiveness shall mean a change in the enthalpy of the outdoor air supply equal to 50% of the difference between the outdoor air and return air at design conditions. Provision shall be made to bypass or control the heat recovery system to permit air economizer operation as required by Section 6.5.1.1.
Standard 90.1-2007, Section 6.5.6.1
Exhaust-Air Energy Recovery

- Must recover energy in any system with both:
  - Design supply airflow of 5,000 cfm or more
  - Minimum outdoor airflow 70% or more of design supply airflow

- Must meet “energy recovery effectiveness” ≥ 50% 
  (vent load-reduction ratio = (h_o – h_co)/(h_o – h_r) ≥ 0.50)

- Bypass or control requirements to avoid heat recovery during air economizer operation

defined by ASHRAE Standard 90.1
“Energy Recovery Effectiveness” (ERE)

ERE = \frac{(h_o - h_{co})}{(h_o - h_r)}

ERE = ventilation load-reduction ratio ≥ 0.50
Each fan system shall have an energy recovery system when the system’s supply air flow rate exceeds the value listed in Table 6.5.6.1 based on the climate zone and percentage of outdoor air flow rate at design conditions. Energy recovery systems required by this section shall have at least 50% energy recovery effectiveness. Fifty percent energy recovery effectiveness shall mean a change in the enthalpy of the outdoor air supply equal to 50% of the difference between the outdoor air and return air enthalpies at design conditions. Provision shall be made to bypass or control the energy recovery system to permit air economizer operation as required by 6.5.1.1.

Standard 90.1-2010, Section 6.5.6.1
Exhaust-Air Energy Recovery

- Must recover energy in any system with good potential, which depends upon supply airflow, minimum outdoor airflow (≥30%) and climate, as shown in Table 6.5.6.1
- Must meet “energy recovery effectiveness” ≥ 50% (vent load-reduction ratio = (h_o - h_co)/(h_o - h_r) ≥ 0.50)
- Bypass or control requirements to avoid heat recovery during air economizer operation
## Standard 90.1-2010, Section 6.5.6.1
### Exhaust-Air Energy Recovery

### TABLE 6.5.6.1 Energy Recovery Requirement (I-P)

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>% Outdoor Air at Full Design Flow</th>
<th>Design Supply Fan Flow, cfm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≥10% and &lt;20%</td>
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<td>≥20% and &lt;30%</td>
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<td>≥60% and &lt;70%</td>
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<td>≥70% and &lt;80%</td>
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<tr>
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<td>≥80%</td>
<td></td>
</tr>
</tbody>
</table>

### 3B, 3C, 4B, 4C, 5B
- NR NR NR NR NR NR

### 1B, 2B, 5C
- NR NR NR ≥26000 ≥12000 ≥5000 ≥4000

### 6B
- ≥11000 ≥5500 ≥4500 ≥3500 ≥2500 ≥1500

### 1A, 2A, 3A, 4A, 5A, 6A
- NR NR ≥5500 ≥4500 ≥3500 ≥2000 ≥1000 ≥0

### 7, 8
- ≥2500 ≥1000 ≥0 ≥0 ≥0 ≥0

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## Standard 90.1-2013, expected Section 6.5.6.1
### Exhaust-Air Energy Recovery

### TABLE 6.5.6.1 Energy Recovery Requirement (I-P)

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>% Outdoor Air at Full Design Flow</th>
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<tr>
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<td>≥30% and &lt;40%</td>
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<td></td>
<td>≥40% and &lt;50%</td>
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<tr>
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<td>≥70% and &lt;80%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≥80%</td>
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</tbody>
</table>

### 3B, 3C, 4B, 4C, 5B
- NR NR NR NR NR NR

### 1B, 2B, 5C
- NR NR NR ≥26000 ≥12000 ≥5000 ≥4000

### 6B
- ≥28000 ≥26500 ≥11000 ≥5500 ≥4500 ≥3500 ≥2500 ≥1500

### 1A, 2A, 3A, 4A, 5A, 6A
- ≥26000 ≥16000 ≥5500 ≥4500 ≥3500 ≥2000 ≥1000 ≥0

### 7, 8
- ≥4500 ≥4000 ≥2500 ≥1000 ≥0 ≥0 ≥0 ≥0

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Standard 90.1-2010, Section 6.5.6.1

Exhaust-Air Energy Recovery Exceptions

a. Laboratory systems meeting 6.5.7.2.
b. Systems serving spaces that are not cooled and that are heated to less than 60°F.
c. Systems exhausting toxic, flammable, paint, or corrosive fumes or dust.
d. Commercial kitchen hoods used for collecting and removing grease vapors and smoke.
e. Where more than 60% of the outdoor air heating energy is provided from site-recovered or site-solar energy.
f. Heating energy recovery in climate zones 1 and 2.

Standard 90.1-2010, Section 6.5.6.1 (cont.)

Exhaust-Air Energy Recovery Exceptions

g. Cooling energy recovery in climate zones 3C, 4C, 5B, 5C, 6B, 7, and 8.
h. Where the largest source of air exhausted at a single location at the building exterior is less than 75% of the design outdoor air flow rate.
i. Systems requiring dehumidification that employ energy recovery in series with the cooling coil.
j. Systems expected to operate less than 20 hrs per week at the outdoor air percentage covered by Table 6.5.6.1
Standard 90.1-2010, Section 6.5.6.1
Exhaust-Air Energy Recovery

- Some exceptions to exhaust-air ER requirements:
  - a. Laboratory systems meeting 6.5.7.2 (e.g., certain VAV lab exhaust and supply systems)
  - e. Systems where site-recovered or site-solar heat provides >60% of the energy needed to heat outdoor air
  - g. Cooling energy recovery in cool, dry climates (zone 3C, 4C, 5B, 5C, 6B, 7, and 8)
  - i. Dehumidification systems using energy recovery in series with the cooling coil
What is Standard 189.1?

- An ANSI standard in mandatory-language, co-sponsored by ASHRAE, USGBC, and IES, that:
  - Provides minimum design requirements for high-performance green buildings (HPGB)
  - Applies to the same buildings as Std 90.1 and Std 62.1
  - It covers building site, water use, energy use, indoor environmental quality, environmental impact
7.4.3.6 Exhaust-Air Energy Recovery. The exhaust-air energy recovery requirements defined in Section 6.5.6.1 of ANSI/ASHRAE/IES Standard 90.1 shall be used except that the energy recovery effectiveness shall be 60% and the requirements of Table 7.4.3.6 shall be used instead of those of Table 6.5.6.1 of ANSI/ASHRAE/IES Standard 90.1.

- Must use recovery energy based on energy recovery potential, which depends on climate, outdoor airflow (≥10%) and supply airflow per Table 7.4.3.6
- Must meet “energy recovery effectiveness” ≥ 60% ([vent load-reduction ratio] = (h_o − h_{co})/(h_o − h_r) ≥ 0.60)
- Must include bypass or control requirements to avoid heat recovery during air economizer operation
Standard 189.1-2011 vs. Standard 90.1-2010
Exhaust-Air Energy Recovery

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>3B, 3C, 4B, 4C, 5B</th>
<th>1B, 2B, 5C</th>
<th>6B</th>
<th>1A, 2A, 3A, 4A, 5A, 6A</th>
<th>7, 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Outdoor Air at Full Design Flow</td>
<td>≥10% and &lt;20%</td>
<td>≥20% and &lt;30%</td>
<td>≥30% and &lt;40%</td>
<td>≥40% and &lt;50%</td>
<td>≥50% and &lt;60%</td>
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<tr>
<td>Design Supply Fan Flow, cfm</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
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<td>≥5000</td>
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<td>≥5000</td>
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<td>≥5500</td>
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<td></td>
<td>≥4000</td>
<td>≥4000</td>
<td>≥2500</td>
<td>≥1000</td>
<td></td>
</tr>
</tbody>
</table>

ASHRAE Standard 84
- Defines method of testing air-to-air heat exchangers

AHRI Standard 1060
- Defines conditions and procedures for rating and certifying performance
defined by ASHRAE Standard 84 and AHRI Standard 1060

Effectiveness

sensible effectiveness

$$\varepsilon_s = \frac{\dot{m}_{OA}}{\dot{m}_{\text{min}}} \times \frac{(T_1 - T_2)}{(T_1 - T_3)}$$

total effectiveness

$$\varepsilon_T = \frac{\dot{m}_{OA}}{\dot{m}_{\text{min}}} \times \frac{(h_1 - h_2)}{(h_1 - h_3)}$$

$$\dot{m}_{\text{min}} = \text{smaller of } \dot{m}_{OA} \text{ or } \dot{m}_{EA}$$

Equal Airflows

$$\varepsilon_T = \frac{10,000 \text{ cfm}}{10,000 \text{ cfm}} \times \frac{(38.4 - 33.6)}{(38.4 - 29.2)} = 52\%$$

$$Q_T = 4.5 \times 10,000 \text{ cfm} \times (38.4 - 33.6 \text{ Btu/lb}) = 216 \text{ MBh}$$
Unequal Airflows

\[ \varepsilon_T = \frac{10,000 \text{ cfm}}{7,500 \text{ cfm}} \times \frac{(38.4 - 34.0)}{(38.4 - 29.2)} = 64\% \]

\[ Q_T = 4.5 \times 10,000 \text{ cfm} \times (38.4 - 34.0 \text{ Btu/lb}) = 200 \text{ MBh} \]

Compared to 52% with equal airflows.

Sponge in large bucket of water
- More water absorbed
- Less effective
  (does not absorb all water in bucket)

Sponge in small puddle of water
- Less water absorbed
- More effective
  (absorbs all water in puddle)
ASHRAE 90.1-2010, Section 6.5.6.1
Exhaust-Air Energy Recovery

“Fifty percent energy recovery effectiveness shall mean a change in the enthalpy of the outdoor air supply equal to 50% of the difference between the outdoor air and return air enthalpies at design conditions.”

Equal Airflows

\[ \varepsilon_T = \frac{10,000 \text{ cfm}}{10,000 \text{ cfm}} \times \frac{(38.4 - 33.6)}{(38.4 - 29.2)} = 52\% \]

52% ventilation load reduction
Unequal Airflows

\[ \varepsilon_T = \frac{10,000 \text{ cfm}}{7,500 \text{ cfm}} \times \frac{(38.4 - 34.0)}{(38.4 - 29.2)} = 64\% \]

48% ventilation load reduction

"As-Applied" vs. "Rated" Effectiveness

- Be careful not to confuse the enthalpy reduction (or ventilation load reduction) required by ASHRAE 90.1 with "rated" effectiveness per ASHRAE 84 / AHRI 1060
- Strive for equal airflows
  - Bring back as much exhaust air as possible
Agenda

- Why implement exhaust-air energy recovery?
- Common air-to-air energy recovery technologies
  - Coil loop
  - Heat pipe
  - Fixed-plate heat exchanger
  - Fixed-membrane heat exchanger
  - Total-energy wheel
- Proper control and integration into HVAC systems
- Suggestions for cost-effective application

Energy Recovery Technology Comparison

- Coil loop
- Heat pipe
- Fixed-plate heat exchanger
- Fixed-membrane heat exchanger
- Total-energy wheel
coil loop

**Typical Applications**

- When need to totally isolate ventilation from exhaust air
- No cross contamination
- Hospitals or labs with high ventilation/exhaust rates (8760 hours/year)
- Greater benefits in heating-dominated climates
coil loop
How Much Energy Recovered

Typical Coil Loop
Sensible Effectiveness
35% to 55% sensible heat recovered

- Ethylene glycol (30%)
- Turbulators inside 5/8" tubes

 coil loop
Energy Recovery At What Cost

Typical Coil Loop
Air Pressure Drop per Coil

- 4 rows = 10 ft. H₂O
- 6 rows = 15 ft. H₂O
- 8 rows = 19 ft. H₂O
- Additional losses (valves, pipes, run)
Coil Loop Considerations

- Sensible recovery only, no stream-to-stream leakage, ducts may be separated
- Ventilation load-reduction is usually **too low**
  - 10-20% in moist climates, 35-55% in dry & cold climates
- Std 90.1 exceptions may allow coil loops, e.g.:
  - Exception c: Systems exhausting toxic fumes
  - Exception h: Systems with multiple small exhaust paths

Heat Pipe

- Capacity modulation via bypass dampers or tilt control
- Very low cross-leakage
- No pumps
heat pipe

How Much Energy Recovered

Heat Pipe
Sensible Effectiveness

30% to 52% sensible heat recovered

heat pipe

Energy Recovery At What Cost

Typical Coil Loop
Air Pressure Drop per Coil
Heat Pipe Considerations

- Sensible recovery only, some leakage possible, ducts must be adjacent
- Ventilation load-reduction is too low
  - 10-20% in moist climates, 30-50% in dry & cold climates
- Std 90.1 exceptions may allow use of heat pipes, e.g.:
  - Exception b: Uncooled spaces, heated to <60°F

Fixed-Plate Heat Exchanger

- Cross-flow aluminum plates
- Dimpled or channeled plates
- Handle high pressure up to 10” diff
- High temperatures
- Corrosion resistant
- Capacity modulation using face-and-bypass dampers
- Little or no cross-leakage
- Most susceptible to frosting
fixed-plate heat exchanger

Example AHU Layouts

- Face-and-bypass dampers
- Center bypass
- Drain pans
fixed-plate heat exchanger
Non-Uniform Temperature Across Exchanger

- OA: 20°F
- RA: 70°F, 30% RH (37°F DPT)

cold corner

37°F
42°F
47°F
54°F

Which Face Velocity Matters?

- exchanger face area
- air handler face area
fixed-plate heat exchanger
How Much Energy Recovered

Air-to-Air Plate Exchanger Sensible Effectiveness 60% to 70% sensible heat recovered

Energy Recovery At What Cost

Air-to-Air Plate Exchanger Air Pressure Drop
Fixed-Plate Considerations

- Sensible recovery only, some leakage possible, ducts must be adjacent
- Ventilation load-reduction varies over wide range
  - 20% to 30% in moist climates is too low
  - 55% to 70% in dry & cold climates is high enough
- Std 90.1 exceptions may allow fixed-plate exchangers
  - Exception j: Systems that operate less than 20 hours per week at design minimum OA flow

Fixed-Membrane Heat Exchanger

- Membrane material in layers
- Water vapor permeable
- Capacity modulation using external bypass dampers
- Little cross-leakage
Fixed-Membrane Heat Exchanger

- Smaller cores only (500 cfm range)
- Limited fan arrangements
- Low pressure differential (2 to 4 in. H₂O maximum)
- Large footprint required
- Transitions add another 1.0 to 1.5 in. H₂O pressure loss (> 2000 cfm)

fixed-membrane heat exchanger
How Much Energy Recovered

Bank of Membrane Exchangers
Sensible & Latent Effectiveness

Sensible: 62-70%
Latent: 45–54%

10,000 cfm Air Handler Example
Air Handler Face Velocity (FPM)
Fixed-Membrane Considerations

- Total energy recovery, low leakage, adjacent ducts
- Ventilation load-reduction varies widely
  - 35% to 60% in moist climates
  - 55% to 70% in dry & cold climates
- Probably meet Std 90.1 (50%) in most locations and
  Std 189.1 (60%) in some locations
- Low core airflows limit unit size
Total-Energy Wheel

- Desiccant rotor rotating 20-60 rpm between exhaust and outdoor air
- Capacity modulation using bypass dampers
- Some cross-leakage
- Self cleaning (dry particles)
- Less susceptible to frosting than sensible-recovery technologies

<table>
<thead>
<tr>
<th>Media Types</th>
<th>Aluminum</th>
<th>Synthetic fiber</th>
<th>Polymer</th>
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<tr>
<td>Weight</td>
<td>heaviest</td>
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<td>Bearing maintenance</td>
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<td>Desiccant loading</td>
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<tr>
<td>Corrosion resistance</td>
<td>good</td>
<td>best</td>
<td>better</td>
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<tr>
<td>Common depth</td>
<td>6”, 8”, 12”</td>
<td>4”, 6”</td>
<td>1.5”, 3”</td>
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</table>
total-energy wheel
How Much Energy Recovered
AHRI 1060 Directory Data

Sensible & Latent Effectiveness

**Sensible:** 60-76%
**Latent:** 55-71%
Energy Recovery At What Cost

**Energy Wheel**
Air Pressure Drop

<table>
<thead>
<tr>
<th>Face Velocity (FPM)</th>
<th>Air Pressure Loss (in w.g.)</th>
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<tbody>
<tr>
<td>300</td>
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<td>700</td>
<td>1.0</td>
</tr>
<tr>
<td>800</td>
<td>1.2</td>
</tr>
<tr>
<td>900</td>
<td>1.4</td>
</tr>
<tr>
<td>1000</td>
<td>1.6</td>
</tr>
</tbody>
</table>

**Motor Power**

<table>
<thead>
<tr>
<th>Media type</th>
<th>Motor horsepower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>1/3—5 hp</td>
</tr>
<tr>
<td>Synthetic fiber</td>
<td>1/4—2 hp</td>
</tr>
<tr>
<td>Polymer</td>
<td>1/80—1/3 hp</td>
</tr>
</tbody>
</table>
total-energy wheel: at what cost

Cross Leakage

[Diagram showing cross leakage with symbols and arrows indicating airflow and pressure differences.]
Outside Air Correction Factor
Ratio of outdoor air flow to supply air flow

$$OACF = \frac{OA \text{ cfm}}{SA \text{ cfm}}$$

Exhaust Air Transfer Ratio
The percentage of supply air that is exhaust air

- 1.4
- 1.45
- 1.5

Total-energy wheel Cross-Leakage Measurements
Total Energy Wheel Considerations

- Total energy recovery, must manage leakage, adjacent ducts
- Ventilation load-reduction (60% to 80% in all climates) meets Std 90.1 (50%) and Std 189.1 (60%)
- Proper fan placement can control pressures to reduce potential leakage

Comparison of Energy-Recovery Technologies

Reduction in Ventilation Cooling Load:
Region A “Moist”
Comparison of Energy-Recovery Technologies

Reduction in Ventilation Heating and Cooling Load:
Region B “Arid”

% Reduction Ventilation Load

Comparison of Energy-Recovery Technologies

Recovery Efficiency Ratio

recovery efficiency ratio (RER): a ratio of the energy recovered divided by the energy expended in the energy recovery process*

BTUH / W (cooling) or W / W (heating)

<table>
<thead>
<tr>
<th>Power required</th>
<th>Coil loop</th>
<th>Heat pipe</th>
<th>Plate exchanger</th>
<th>Membrane cores</th>
<th>Energy wheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan: Pressure Loss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan: Leakage/Purge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component: Motor or Pump</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*RER is defined by ASHRAE Std 84-2008 and AHRI Guideline V
Comparison of Energy-Recovery Technologies

RER Cooling: Region A “Moist”

Based on 10,000 cfm 95°F / 78°F OA 75°F 55%RH RA

RER btuh / W

Air Handler Face Velocity (fpm)

Comparison of Energy-Recovery Technologies

RER Cooling: Region B “Arid”

Based on 10,000 cfm 105°F OA 75°F 55% RH RA

RER btuh / W

Air Handler Face Velocity (fpm)
Comparison of Energy-Recovery Technologies

COP Coefficient of Performance: Heating

Based on
10,000 cfm
10°F OA
70°F no frosting

Installed Price Addition (AHU)

Heating Only or Cooling: Region B “Arid”
Conclusion: Which technology?

- Is cross leakage a concern?
  - Toxic, fume hoods, isolation rooms, etc.
    - Coil loop
  - Animal laboratory, natatorium
    - Fixed-plate HX, coil loop, heat pipe
Conclusion: Which technology?

- Comfort cooling/heating application
  - Dry or arid climate
    - Fixed-plate heat exchanger
  - Humid or mixed climate
    - Total-energy wheel
  - Reduced footprint required
    - Coil loop, heat pipe

Agenda

- Why implement exhaust-air energy recovery?
- Common air-to-air energy recovery technologies
  - Proper control and integration into HVAC systems
    - On/off
    - Capacity modulation
    - Frost prevention
- Suggestions for cost-effective application
Control During Mild Weather

- EA: 7,000 cfm
- RA: 70°F
- RRA: 20,000 cfm
- OA: 10,000 cfm, 55°F
- SA: 30,000 cfm, 55°F
- Cooling coil ON (438 MBh)
Control During Mild Weather

- EA: 7,000 cfm, 70°F
- wheel OFF
- cooling coil ON (308 MBh)
- RRA
- OA: 10,000 cfm, 55°F
- SA: 30,000 cfm, 55°F

Control During Mild Weather

- EA: 27,000 cfm, 70°F
- wheel OFF
- cooling coil OFF (0 MBh)
- RRA
- OA: 30,000 cfm, 55°F
- SA: 30,000 cfm, 55°F

Airside economizing
## On/Off Control Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Control Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil loop</td>
<td>Turn off pump</td>
</tr>
<tr>
<td>Heat pipe</td>
<td></td>
</tr>
<tr>
<td>Fixed-plate heat exchanger</td>
<td>Face-and-bypass dampers</td>
</tr>
<tr>
<td>Fixed-membrane heat exchanger</td>
<td></td>
</tr>
<tr>
<td>Total-energy wheel</td>
<td>Turn off wheel</td>
</tr>
</tbody>
</table>

**Diagram:**
- **face-and-bypass dampers**
- **center bypass**
- **EA**
- **OA**
On/Off Control Methods

- **Coil loop**
  - Turn off pump

- **Heat pipe**
  - Face-and-bypass dampers
  - Some use solenoid valve(s)

- **Fixed-plate heat exchanger**
  - Face-and-bypass dampers

- **Fixed-membrane heat exchanger**
  - Face-and-bypass dampers

- **Total-energy wheel**
  - Turn off wheel

Control During Heating

- **EA** 7,000 cfm
- **RA** 70°F
- **wheel ON (full capacity)**
- **RRA** 8,000 cfm
- **cooling coil ON (87 MBh)**
- **OA** 10,000 cfm 40°F
- **60°F**
- **64°F**
- **18,000 cfm**
- **SA** 60°F (SAT reset)
Control During Heating

- EA: 7,000 cfm, 70°F
- RRA: 8,000 cfm, heating coil ON (131 MBh)
- OA: 10,000 cfm, 40°F
- SA: 18,000 cfm, 60°F (SAT reset)

Wheel OFF

- Both coils OFF

Control During Heating

- EA: 7,000 cfm, 70°F
- RRA: 8,000 cfm
- OA: 10,000 cfm, 40°F
- SA: 18,000 cfm, 60°F (SAT reset)

Modulate EA bypass dampers

- Wheel ON (partial capacity)
- Both coils OFF
Capacity Modulation Methods

Coil loop
- Three-way mixing valve
- Vary pump speed

Heat pipe
- Face-and-bypass dampers
- Some use solenoid valve(s)
- Tilt mechanism

Fixed-plate heat exchanger
- Face-and-bypass dampers

Fixed-membrane heat exchanger
- Face-and-bypass dampers

Total-energy wheel
- Exhaust-side bypass damper
- Vary wheel speed

Comparison of Capacity Control Methods

<table>
<thead>
<tr>
<th>%VFD Speed or % Bypass Closed</th>
<th>Bypass control</th>
<th>Speed control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Speed / Position</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Cost ✓
- Control ✓
- Energy ✓
- Motor duty ✓
Frosting

water vapor condensing on exhaust-side coil

sensible-energy recovery

OA  OA'  dry-bulb temperature, F

Total- vs. Sensible-Energy Recovery

OA  OA'  total-energy recovery

sensible-energy recovery

dry-bulb temperature, F
### Frost Prevention Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coil loop</strong></td>
<td>Three-way mixing valve</td>
</tr>
<tr>
<td><strong>Heat pipe</strong></td>
<td>Face-and-bypass dampers</td>
</tr>
<tr>
<td><strong>Fixed-plate heat exchanger</strong></td>
<td>Frost damper</td>
</tr>
<tr>
<td><strong>Fixed-membrane heat exchanger</strong></td>
<td>Face-and-bypass dampers</td>
</tr>
<tr>
<td><strong>Total-energy wheel</strong></td>
<td>Supply-side bypass damper</td>
</tr>
</tbody>
</table>

---

**fixed-plate heat exchanger**

**Frost Prevention**

**Frost Avoidance Damper**

- RA 70°F, 30% RH (37 F DPT)
- OA 20°F
- Cold corner: < 32°F
- 31°F, 36°F, 41°F
- 54°F
- DAMPER
- 43°F, 45°F, 47°F
- 45°F
- OA 20°F
- RA 70°F, 30% RH (37 F DPT)
fixed-plate heat exchanger
Frost Prevention

- Fixed-plate (sensible) heat exchangers begin to experience frosting when entering OA drops < 25°F
- Use frost damper to minimize frosting (keeps higher temperature in the “cold corner”)

Frost Prevention Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Preheat Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil loop</td>
<td>Three-way mixing valve</td>
</tr>
<tr>
<td></td>
<td>OA or EA preheat</td>
</tr>
<tr>
<td>Heat pipe</td>
<td>Face-and-bypass dampers</td>
</tr>
<tr>
<td></td>
<td>OA or EA preheat</td>
</tr>
<tr>
<td>Fixed-plate heat exchanger</td>
<td>Frost damper</td>
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<td>OA or EA preheat</td>
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<tr>
<td>Fixed-membrane heat exchanger</td>
<td>Face-and-bypass dampers</td>
</tr>
<tr>
<td></td>
<td>OA or EA preheat</td>
</tr>
<tr>
<td>Total-energy wheel</td>
<td>Supply-side bypass damper</td>
</tr>
<tr>
<td></td>
<td>OA or EA preheat</td>
</tr>
</tbody>
</table>
Total-Energy Wheel in a Mixed-Air VAV System

wheel on (cooling)
wheel off
bypass dampers closed
bypass dampers open

to avoid overheating

wheel on (heating)

wheel on (cooling)
bypass dampers closed

humidity ratio, grains/lb of dry air

Sensible- or total-energy recovery
Mixed-air or dedicated OA system
Constant- or variable-air volume
DBT- or enthalpy-based control
Airside economizers
Energy recovery capacity control
Frost prevention
Agenda

- Why implement exhaust-air energy recovery?
- Common air-to-air energy recovery technologies
- Proper control and integration into HVAC systems
- Suggestions for cost-effective application

Suggestions

- ASHRAE 90.1-2010 (and 189.1-2011) requires exhaust-air energy recovery in more applications
- Total-energy recovery transfers both sensible heat and water vapor (latent heat)
  - Allows for larger cooling plant reductions
  - Less susceptible to frost, so greater heating energy savings
Suggestions
- Maximize energy recovery effectiveness
  - Centralize exhaust to better balance airflows and maximize recovery
  - Minimize cross-leakage with fan placement

Dual Exhaust Energy Recovery
- Toilet exhaust air is isolated from return air
- Divider panel divides toilet and system exhaust air
- Toilet exhaust enters the first portion of the energy wheel
- System exhaust enters second portion of wheel
- System exhaust air purges wheel of toilet exhaust air

Toilet Exhaust Air Flow = Fixed amount set by code requirements
System Exhaust Air Flow = Varies to meet building pressure requirements
DEER Damper Control

Exhaust Fan
Fan speed modulates to control building pressure

Toilet Damper
Traq damper modulates to maintain code required toilet exhaust air flow

Balancing Damper
When toilet damper is 100% open, balancing damper modulates from minimum position to close to maintain toilet exhaust air flow

ASHRAE Standard 62.1-2010, Section 5.16.3.2.5
Recirculation of Toilet Exhaust

“Class 2 air [which includes air from restrooms] shall not be recirculated or transferred to Class 1 spaces.

Exception: When using an energy recovery device, recirculation from leakage, carryover, or transfer from the exhaust side of the energy recovery device is permitted. Recirculated Class 2 air shall not exceed 10% of the outdoor air intake flow.”
### Exhaust Air Transfer Ratio (EATR)

- Defined by ASHRAE Standard 84
- Certified by AHRI Standard 1060

\[ EA \quad X_4 \quad X_3 \quad EATR \leq 10\% \quad OA \quad X_1 \quad X_2 \]

### Suggestions

- Proper control is very important
  - Turn device OFF during mild weather to avoid wasting energy
  - Modulate capacity during cold weather to prevent over-heating
  - Include bypass dampers to enable economizing in mixed-air systems
  - Don’t forget about frost prevention
Suggestions

- Specify/purchase AHRI-certified components
  - Trustworthy performance data, fewer third-party or field performance tests
  - More accurate sizing for improved design and application of air-handling equipment

Where to Learn More

references for this broadcast

www.trane.com/EN
Past program topics include:

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American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).  

American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE).  

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).  

Trane Application Manual


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Trane Air-Conditioning and Economics (TRACE™ 700). Available at www.trane.com/TRACE