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Learning Objectives

- Understand how ventilation heat recovery systems work
- Identify the requirements for ventilation heat recovering as defined by ASHRAE 90.1
- Recognize typical situations that lead to cost-effective applications of ventilation heat recovery
Agenda

- Energy Recovery Types
- Standard 90.1 Requirements
- Costs & Benefits
- Typical Application Schematics & Control Sequences
Energy Recovery Types

- Rotary (wheel)
  - Sensible
  - Total (Enthalpy)

- Flat Plate
  - Sensible
  - Total (Enthalpy)

- Heat Pipe

- Run-around
Rotary Heat Exchanger
Enthalpy Wheel Desiccants

- **Lithium Chloride**
  - Salts dissolve, wash off.

- **Silica Gel**
  - Best water transfer characteristics.

- **Molecular Sieves**
  - Can be engineered to discriminate between species. Ideal for many process applications.
Flat Plate Heat Exchanger

Synthetic matrix embedded with ceramic desiccant capable of water diffusion
Heat Pipe Heat Exchanger
Run-Around Heat Exchanger

- **HOT AIR (WASTE HEAT STREAM)**
- **COOLED AIR**
- **AIR TO BE HEATED**
- **HOT AIR**
- **PIPING SYSTEM**
Heat Exchanger Cooling Performance

Outdoor air:
91°F DB
73°F WB

Leaving Sensible HX, 70% EFF:
82°F DB

Leaving Enthalpy Wheel, 70% EFF:
82°F DB
66°F WB

Exhaust air:
78°F DB
63°F WB
Heat Exchanger Ratings

- **ARI 1060**
  - Rotary
  - Flat Plate
  - Heat Pipe
  - Non-ARI Certified language
    - “Tested in accordance with ARI 1060”
    - “Independently tested in accordance with ASHRAE Standard 84 and ARI standard 1060”
    - “Independently certified in accordance to ARI 1060”
  - ARI Certified language
    - ARI 1060 certified and listed in the ARI 1060 Directory of Certified Air-to-Air Energy Recovery Ventilation Equipment
    - No seal – not certified!

- **ARI 410**
  - Run-around coils
Freezing/Frosting

![Graph showing the relationship between temperature and humidity ratio for different air intake and outlet conditions. The graph includes lines for outside air intake, exhaust air, outside air outlet, and preheated outside air.](image)
Frost Control

- Function of outdoor temperature and indoor RH
- Enthalpy wheel has the lowest frost threshold
- Pre-heat is preferred solution – maintains maximum recovery
- Usually not required in non-humidified buildings

### Frost Threshold Temperature (°F)

<table>
<thead>
<tr>
<th>Indoor Air RH (%)</th>
<th>Indoor Air Dry Bulb Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70° F</td>
</tr>
<tr>
<td>20</td>
<td>-14</td>
</tr>
<tr>
<td>30</td>
<td>-3</td>
</tr>
<tr>
<td>40</td>
<td>5</td>
</tr>
<tr>
<td>50</td>
<td>12</td>
</tr>
<tr>
<td>60</td>
<td>18</td>
</tr>
</tbody>
</table>
## Comparison of HX Types

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Rotary Wheel</th>
<th>Fixed Plate</th>
<th>Heat Pipe</th>
<th>Run-Around</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensible Effectiveness (equal flow)</td>
<td>60%-80%</td>
<td>60%-70%</td>
<td>30%-65%</td>
<td>45%-65%</td>
</tr>
<tr>
<td>Total Effectiveness (equal flow)</td>
<td>65%-80%</td>
<td>45%-65%</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Pressure drop (each side)</td>
<td>0.5 to 1.2 in.wg.</td>
<td>0.6 to 1.4 in.wg.</td>
<td>0.2 to 0.8 in.wg.</td>
<td>0.3 to 1.0 in.wg.</td>
</tr>
<tr>
<td>Susceptibility to frost</td>
<td>High (sensible)</td>
<td>Highest (sensible)</td>
<td>Modest</td>
<td>Modest</td>
</tr>
<tr>
<td>Lowest (total)</td>
<td>Low (total)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross-leakage</td>
<td>Modest</td>
<td>Slight</td>
<td>Slight</td>
<td>None</td>
</tr>
</tbody>
</table>

Adapted from Trane Heat Recovery Applications Manual
Typical Cost/Performance Ratio

from Trane Heat Recovery Applications Manual, 1997
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.

- Provision shall be made to bypass or control the heat recovery system to permit air economizer operation.

- **Note:** Addendum to toughen requirements recently out for public review but not likely to be approved as written.
Energy Recovery not required for:

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 systems in climate zones 1 through 3.

g) Cooling systems in climate zones 3c, 4c, 5b, 5c, 6b, 7, and 8.

h) Where the largest exhaust source is less than 75% of the design outdoor air flow.

i) Systems requiring dehumidification that employ energy recovery in series with the cooling coil.
ASHRAE 90.1 vs. Actual Effectiveness

\[ \varepsilon_{ARI} = \frac{\dot{m}_{oa} (h_{oaE} - h_{oaL})}{\dot{m}_{\text{min}} (h_{oaE} - h_{raE})} = \frac{\dot{m}_{oa} (h_{oaE} - h_{oaL})}{\dot{m}_{ea} (h_{oaE} - h_{raE})} \]

\[ \varepsilon_{90.1} = \frac{h_{oaE} - h_{oaL}}{h_{oaE} - h_{raE}} > 0.5 \]

ASHRAE 90.1 definition basically assumes equal exhaust and outdoor airflow rates
Effectiveness increases with unbalanced flow, but energy recovered does not!
Wintertime Sensible Effectiveness

Outdoor Air:
DB: 35F
WB: 33F
h: 12.2 Btu/lb

Exhaust Air:
DB: 45.5F
WB: 41.7F
h: 16.1 Btu/lb

Outdoor Air:
DB: 59.5F
WB: 46.2F
h: 18.4 Btu/lb

Exhaust Air:
DB: 70F
WB: 53.4F
RH: 30%
h: 30.0 Btu/lb

70% Sensible Effectiveness
100% Exhaust Airflow Rate

ASHRAE Effectiveness: 61%
Wintertime Sensible Effectiveness

Outdoor Air:
DB: 35F
WB: 33F
h: 12.2 Btu/lb

Exhaust Air:
DB: 45.5F
WB: 41.7F
h: 16.1 Btu/lb

Outdoor Air:
DB: 59.5F
WB: 46.2F
h: 18.4 Btu/lb

Exhaust Air:
DB: 70F
WB: 53.4F
RH: 30%
h: 30.0 Btu/lb

82% Sensible Effectiveness
70% Exhaust Airflow Rate

ASHRAE Effectiveness: 50%
**Summertime Sensible Effectiveness**

- **Outdoor Air:**
  - DB: 95F
  - WB: 78F
  - h: 41.9 Btu/lb

- **Exhaust Air:**
  - DB: 91F
  - WB: 68.5F
  - h: 33.0 Btu/lb

- **Outdoor Air:**
  - DB: 79F
  - WB: 73.6F
  - h: 37.6 Btu/lb

- **Exhaust Air:**
  - DB: 75F
  - WB: 63F
  - RH: 51%
  - h: 28.8 Btu/lb

**ASHRAE Effectiveness:** 33%
Conclusion

- Where 90.1 requires heat recovery for cooling:
  - Enthalpy heat exchanger required

- Where 90.1 requires heat recovery for heating:
  - If humidified (RH>~30%): Enthalpy heat exchanger required
  - If not humidified: Any style will work
Advantages

- Somewhat self-cleaning and easy to clean
- Low frost temperature limits
  - May eliminate preheat coil in non-humidified buildings
  - Increases heat recovered in cold weather
- Compact
- Highest effectiveness, sensible & total
- Lowest cost per unit of recovered energy
- “Free” winter humidification (recovers latent load)

Disadvantages

- Moving parts affect maintenance costs
- Leakage and carryover between airstreams
- Airstreams must be side-by-side (vs. run-around)
First Costs/Benefits

- **Costs**
  - Heat recovery device
  - Routing exhaust ducts (or run-around pipes) to intakes
  - Added fans (where applicable)
  - Increased fan motor HP of existing supply air and exhaust air fans

- **Benefits**
  - Downsizing heating/cooling systems
### Operating Costs/Benefits

**Costs**
- Increased maintenance (filters, coil/core cleaning, motor, bearings)

**Benefits**
- Reduced cycling due to smaller AC unit size for improved temperature and humidity control
  - No real humidity benefits from moisture transfer – it is the cooling system that removes the moisture
- Reduced cooling and heating loads
  - Offset partly by added fan energy
  - Net savings varies by application, design, and climate
Net Energy Savings
(School in Madison, WI. No summer classes)
Net Energy Savings
(Big Box Department Store, Iowa)
Most Cost Effective Applications

- High outdoor air rate
  - Densely occupied spaces
- Excess return air that would have to be exhausted anyway to prevent over-pressurizing building
  - Allows HR to be used without extra ductwork and without extra fan if there already is a relief fan
Typical Constant Volume AHU without Energy Recovery
Constant Volume AHU with Energy Recovery

- Outdoor Air
- Supply Air
- Exhaust Air
- Return Air
- Economizer
- Enthalpy Wheel
- Bypass Damper for Capacity Control
Variable Volume AHU
with Energy Recovery & Economizer

Economizer

Enthalpy Wheel

VFD

Bypass Damper for Capacity Control & Fan Energy Savings

Outdoor Air

Supply Air

Exhaust Air

Return Air
Control Logic

- Return Air Damper (high limit not shown)
- Exhaust HX Bypass Damper (high limit not shown)
- Economizer Outdoor Air Damper (high limit not shown)

HX Wheel On when Economizer Outdoor Air Damper is closed.
Bypass & Economizer Outdoor air damper closed, Return air damper open when outdoor air enthalpy > return air enthalpy
Wheel Operation
Madison, WI, 8am-8pm, 70% min OA

Wheel On Minimum OA HW Valve Modulated
Wheel On Minimum OA Bypass Modulated
Wheel Off Economizer Dampers & CHW Modulated
Wheel On Minimum OA CHW Valve Modulated
Summary & Tips

- Usually the optimum Energy Recovery type is:
  - Enthalpy Wheel in humid climates & cold climates with humidification
  - Flat Plat or Run-around for hot dry climates and no humidification
  - No heat recovery in mild climates
- Use ARI Certified products only
  - Ensures fair playing field, realistic load reduction estimates
- Keep pressure drops low to minimize fan energy losses
- Only apply to minimum outdoor air
  - Bypass HX for economizer outdoor air
- Take credit for reduced loads in heating/cooling equipment sizing
  - Necessary for cost effectiveness and control benefits
- Determine savings using annual energy program of actual system application
  - Manufacturer’s programs are often over-simplified and favor recovery
Questions?

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