Fan Industry: Facing Up to the Energy Challenges

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Session Topics

- **Part 1 - Overview of HVAC Energy Issues**
  - HVAC System Energy Consumption
  - HVAC System Energy Metrics
  - Fan Efficiency Metrics - FEG and FMEG

- **Part 2 - Draft Standard and Examples**
  - Draft AMCA 205
  - Fan Selection Implications/Examples

- **Questions/Discussion**
Energy Consumption

2008 Estimated US Energy Consumption

99 Quads (105 EJ)

\(^1\)LLNL / DOE / EIA 2009
Energy Consumption

Estimated U.S. Energy Use in 2008: ~99.2 Quads

Source: LLNL 2009. Data is based on DOE/EIA-0384(2009). June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports form for non-thermal resources (i.e., hydro, wind and solar) in EIA-regulation units by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 83% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-M-410527

LLNL / DOE / EIA 2009

AMCA :: AHR :: 2010
Energy Consumption - HVAC Systems

Estimated US HVAC Energy Consumption\(^2\)

- **1.9 Quads (2.0 EJ) Heating**
- **1.4 Quads (1.5 EJ) Fans + Pumps**
- **1.9 Quads (2.0 EJ) Cooling**

\(^2\)DOE 1999 - source energy
1) volumetric flowrate (design requirement)

2) system resistance (design result)
HVAC System

\[ P_t \text{ always decreases in absence of energy input} \]
System Energy Metrics

Total Energy = Kinetic Energy + Potential Energy

\[ P_t Q = P_v Q + P_s Q = \text{flow (air) power } (H_o) \]

- Energy rate to maintain air motion
- Energy rate to overcome resistance
System Energy Metrics

Electricity Generation (Source)

Shaft Power ($H_{sh}$)

Motor/Controls Input Power ($H_{dc}$)

Flow (air) Power ($H_o$)

Site Energy Rate
25” Belt Drive Airfoil DWDI Blower
Motor - 90% efficient, Drive - 90% efficient
Operating point: 16,800 cfm @ 6.5 in-wg (total)

Motor Input Power
(20,378 W, 100%)

Motor Output Power
(18,340 W, 90%)

Motor Loss
(2,038 W, 10%)

Drive Loss
(1,834 W, 9%)

Shaft Power
(13,246 W, 65%)

Aerodynamic Loss
(3,260 W, 16%)

Fan Bearing Loss
(815 W, 4%)

Acoustic Loss
(80 dB → 0.1 mW, <<1%)

Flow Power
(12,838 W, 63%)
System Energy Metrics - Example

25” Direct Drive Plenum Fan
Motor - 90% efficient, No Drive
Operating point: 9250 cfm @ 6.35 in-wg (total)

Motor Input Power
(10,154 W, 100%)

Motor Loss
(1,015W, 10%)

Shaft (Impeller) Power
(9,139 W, 90%)

Aerodynamic Loss
(2,335 W, 23%)

Flow Power
(6,905 W, 68%)

Acoustic Loss
(80 dB → 0.1 mW, <<1%)
System Energy Metrics

How do we reduced HVAC (airside) energy consumption?

**Flow resistance** (system design)
- Minimum duct resistance
- Low pressure drop components (coils, filter, dampers)

\[
\min \{ P_t Q \}
\]

**Flowrate** (application requirement)
- Minimum Q to achieve HVAC goal
- Minimize system leakage
System Energy Metrics

One approach...

Specific Fan Power (SFP)

\[
SFP \equiv \frac{\text{Fan Input Power}}{\text{Flowrate}} \equiv \frac{H_{dc}}{Q}
\]
System Energy Metrics

Specific Fan Power (SFP)

\[
SFP = \frac{H_{dc}}{Q} = \frac{P_t}{\eta_{dc}}
\]

- \(H_{dc}\): System Total Pressure
- \(Q\): Required Flowrate
- \(P_t\): Input Power \(\rightarrow\) Air Power
- \(\eta_{dc}\): Efficiency
System Energy Metrics

Efficiency - including motor, drives, fan:

\[ \eta_{dc} \equiv \frac{H_o}{H_{dc}} = \frac{P_t Q}{H_{dc}} \]
System Energy Metrics

$\eta_{dc}$ - combination of component efficiencies:

$$SFP = \frac{P_t}{\eta_c \eta_m \eta_d \eta_t}$$

System resistance

controls, motor, drive, fan
System Energy Metrics

Placing upper limit on SFP:

Example:

If $\text{SFP} < 700 \text{ W/kcfm (0.94 HP/kcfm)}$

- Places upper limit on $P_t = 6 \text{ in-wg (1,500 Pa)}$
- $P_t < 6 \text{ in-wg for } \eta_{dc} < 100\%$

Effective means to assure efficient system design
System Energy Metrics

Reducing Energy Consumption

- Minimize $P_t$ for given flow requirement (SFP)
  - Duct/System designer responsibility
- Maximize motor/control/drive efficiency ($\eta_m, \eta_c, \eta_d$)
  - Motor/Control/drive supplier responsibility
- Maximize fan efficiency ($\eta_t$)
  - Fan manufacturer responsibility

Next: Focus on fan efficiency
Fan Energy Metrics

Fan Efficiency \( \frac{\text{air energy rate out}}{\text{shaft energy rate in}} \) = \( \frac{\text{air power out}}{\text{shaft power in}} \)

\[ H_{sh} \]  
\[ H_o \]
Fan Energy Metrics

Efficiency - fan (without drives):

\[ \eta_t \equiv \frac{H_o}{H_{sh}} = \frac{P_t Q}{H_{sh}} \]

Fan input power
Fan Efficiency

Proposed Fan Energy Grading Metric

Goals

- Simple to implement
- Grading system applies to fan model range
- Provide simple means to compare fan designs
- Based on total fan energy (total pressure)
- Provide tool for regulative bodies
Fan Efficiency

Two Proposed Metrics:

**Fan Motor Efficiency Grade (FMEG)**
- Input at motor/control electrical mains
- Suitable for fans sold with integral motorized impeller
- Based on overall fan efficiency
- Function of motor/control input power

**Fan Efficiency Grade (FEG)**
- Input at fan shaft/impeller
- Suitable for fans sold less drive/motor
- Based on fan peak total efficiency
- Accounts for the effects of impeller diameter
Fan Efficiency Grades

Typical Direct Drive Fan

Motor

Fan

FMEG

FEG
Fan Efficiency

Practical Considerations (FEG)

- Efficiency varies with fan operating point
- Peak efficiency varies with
  - Fan type
  - Fan tip speed
  - Fan size
Fan Efficiency

Effect of impeller diameter for geometrically similar fans at same tip speed

Total Efficiency, $\eta_t$

Flowrate, Q

$\eta_t$ - large diameter

$\eta_t$ - small diameter
Fan Efficiency

Geometric/Aerodynamic Similarity?

- Reasonable manufacturing tolerances
- Low Reynolds number performance degradation
- Mechanical losses don’t follow fan laws
Fan Efficiency

Envelopes of Fan Peak Efficiencies of US Fans by Fan Type

Source: John Cermak
Fan Efficiency

Fan Efficiency Grade (FEG)

Peak Total Efficiency, pTE (%)

Impeller Diameter (in)

FEG 85
FEG 80
FEG 75
FEG 71
FEG 67
FEG 63
FEG 60
FEG 56
FEG 53
FEG 50
Fan Efficiency

Fan Efficiency Grade (FEG)

pTE = 67%
D = 15” (381 mm)
FEG = 75
Fan Efficiency

Fan Efficiency Grade (FEG)

- Grade labels in preferred numbers (R40)
- Reference diameter: 40 in (1016 mm)
- Minimum defined diameter: 5 in (125 mm)
- Fans >40 in use reference diameter Grade
- Formula defined - for electronic calculation
Part 2
Draft Standard AMCA 205 & Selection Examples
Fan Efficiency

Standards Activity

- DIS/ISO I2759 Fans - Efficiency Classification for Fans
- AMCA 205 (draft) Energy Efficiency Classification for Fans

- Fan Efficiency Subcommittee appointed by AMCA Fan Committee - SEP 2008
- Draft AMCA 205 approved by the AMCA Fan Efficiency Subcommittee - OCT 2009
- Draft AMCA 205 approved by the AMCA Fan Committee - OCT 2009
- Draft AMCA 205 out for approval to AMCA Members - DEC 2009
- Next Steps: Development of a FEG/FMEG AMCA Certification Program
Fan Efficiency Grade (FEG)

- The Fan Efficiency Grade FEG is an indicator of the capacity of a Fan to convert Fan shaft power $H_{sh}$ to Fan air power $H_o$.

- The FEG is defined as a function of the Fan Total Peak Efficiency (pTE) and Fan size (impeller diameter).

- Specifications of Minimum FEG shall include a requirement that the Fan Total Efficiency at the actual point of operation be within 10 points of the Fan Total Peak Efficiency.
Draft AMCA 205

Fan Efficiency Grade (FEG)

- Applies to fans driven by motors > 1/6 HP (125 W)
- Applies to fans consuming more than 1000 kWh annually
Fan Selection - Practical Considerations

- **Minimum FEG specification**
  - Would limit available fan ranges
  - Does not guarantee reduced energy consumption

- **Select within I0 pt pTE**
  - Assures selections close to pTE
  - How restrictive?

**Next:**

- ✓ Survey various fan types
- ✓ Selection examples
## Fan Selection

### Achievable Peak Total Efficiency

<table>
<thead>
<tr>
<th>Fan Type</th>
<th>pTE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Centrifugal</strong></td>
<td></td>
</tr>
<tr>
<td>Airfoil</td>
<td>88</td>
</tr>
<tr>
<td>Backward Curved</td>
<td>84</td>
</tr>
<tr>
<td>Backward Inclined</td>
<td>80</td>
</tr>
<tr>
<td>Forward Curved</td>
<td>70</td>
</tr>
<tr>
<td><strong>Axial</strong></td>
<td></td>
</tr>
<tr>
<td>Vaneaxial</td>
<td>85</td>
</tr>
<tr>
<td>Tubeaxial</td>
<td>75</td>
</tr>
<tr>
<td>Propeller</td>
<td>55</td>
</tr>
<tr>
<td><strong>Mixed Flow</strong></td>
<td>75</td>
</tr>
<tr>
<td><strong>Tangential</strong></td>
<td>25</td>
</tr>
</tbody>
</table>

1. Radgen, et. al. 2008
Fan Selection

Flowrate

Total Pressure, Total Efficiency

$P_t$, $pTE$, $\eta_t$, $P_v$

10 pts

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## Selection Example

Range: DWDI AF FEG80
Application: 20 Ton RTU
Target Flow: 8000 CFM (13,600 m³/h)
ISP + ESP: 3 in-wg (750 Pa) \( P_t \)

<table>
<thead>
<tr>
<th>Size</th>
<th>( H_{sh} ) (HP)</th>
<th>( N ) (RPM)</th>
<th>TE</th>
<th>EAE* (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25”</td>
<td>5.70</td>
<td>1198</td>
<td>66.4%</td>
<td>45987</td>
</tr>
<tr>
<td>22”</td>
<td>5.24</td>
<td>1324</td>
<td>72.2%</td>
<td>42276</td>
</tr>
<tr>
<td>20”</td>
<td>5.04</td>
<td>1490</td>
<td>75.0%</td>
<td>40662</td>
</tr>
<tr>
<td>18”</td>
<td>5.16</td>
<td>1733</td>
<td>73.3%</td>
<td>41630</td>
</tr>
<tr>
<td>16”</td>
<td>5.63</td>
<td>2090</td>
<td>67.2%</td>
<td>45422</td>
</tr>
</tbody>
</table>

EAE = Estimated Annual Energy Usage
- 90% motor efficiency
- 90% drive efficiency
- 100% duty cycle
Selection Example

Range: DWDI AF FEG85
Application: Size 50 AHU
Target Flow: 25,000 CFM (42,500 m³/h)
ISP + ESP: 6 in-wg (1,500 Pa) Pt

Fan Selections

<table>
<thead>
<tr>
<th>Size</th>
<th>( \eta_t )</th>
<th>( \eta_{pTE} )</th>
<th>( \eta_{pTE-H_{sh}} )</th>
<th>Meets the 10 pt limit</th>
<th>Drive Power ( H_{dc} ) (HP)</th>
<th>Specific Fan Power ( H_{dc} ) (HP/1000 cfm)</th>
<th>Duty Cycle</th>
<th>EAE (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>32&quot;</td>
<td>0.86</td>
<td>0.86</td>
<td>0</td>
<td>Yes</td>
<td>30.8</td>
<td>1.23</td>
<td>24 h/day</td>
<td>201141</td>
</tr>
<tr>
<td>28&quot;</td>
<td>0.81</td>
<td>0.84</td>
<td>3</td>
<td>Yes</td>
<td>32.7</td>
<td>1.31</td>
<td>24 h/day</td>
<td>213558</td>
</tr>
<tr>
<td>25&quot;</td>
<td>0.76</td>
<td>0.83</td>
<td>7</td>
<td>Yes</td>
<td>34.8</td>
<td>1.39</td>
<td>24 h/day</td>
<td>227607</td>
</tr>
<tr>
<td>22&quot;</td>
<td>0.67</td>
<td>0.82</td>
<td>15</td>
<td>No</td>
<td>39.5</td>
<td>1.58</td>
<td>24 h/day</td>
<td>258281</td>
</tr>
</tbody>
</table>

EAE = Estimated Annual Energy Usage
- 94% motor efficiency
- 95% drive efficiency
Selection Example

Range: DWDI AF FEG85
Application: Size 50 AHU
Target Flow: 25,000 CFM (42,500 m³/h)
ISP + ESP: 6 in-wg (1,500 Pa) $P_t$

Energy Usage and Cost Estimate

<table>
<thead>
<tr>
<th>Size</th>
<th>EAE (kWh)</th>
<th>Annual Cost</th>
<th>Annual Cost (rel. 32&quot;)</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>32&quot;</td>
<td>201141</td>
<td>$22,126</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28&quot;</td>
<td>213558</td>
<td>$23,491</td>
<td>$1,365</td>
<td>$2,730</td>
<td>$4,095</td>
<td>$5,460</td>
<td>$6,825</td>
<td>$8,190</td>
<td>$9,555</td>
</tr>
<tr>
<td>25&quot;</td>
<td>227607</td>
<td>$25,037</td>
<td>$2,911</td>
<td>$5,822</td>
<td>$8,733</td>
<td>$11,644</td>
<td>$14,555</td>
<td>$17,466</td>
<td>$20,377</td>
</tr>
<tr>
<td>22&quot;</td>
<td>258281</td>
<td>$28,400</td>
<td>$6,274</td>
<td>$12,548</td>
<td>$18,822</td>
<td>$25,096</td>
<td>$31,370</td>
<td>$37,644</td>
<td>$43,918</td>
</tr>
</tbody>
</table>

EAE = Estimated Annual Energy Usage
- 94% motor efficiency
- 95% drive efficiency

Electricity cost: $0.11 / kWh
### Selection Example

**Range:** Direct Drive Plenum FEG80  
**Application:** Size 25 AHU  
**Target Flow:** 12,000 CFM (20,350 m³/h)  
**ISP + ESP:** 5 in-wg (1,250 Pa) \( P_s \)

### Fan Performance Table

<table>
<thead>
<tr>
<th>Size</th>
<th>( P_t )</th>
<th>( \eta_t )</th>
<th>( \eta_T )</th>
<th>( \eta_{TE} )</th>
<th>( Hi ) (HP)</th>
<th>Meets 10 pts limit</th>
<th>( \eta_m )</th>
<th>Drive Power ( H_{dc} ) (HP)</th>
<th>Specific Fan Power HP/1000 cfm</th>
<th>Duty Cycle</th>
<th>EAE (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25&quot;</td>
<td>5.55</td>
<td>0.79</td>
<td>0.79</td>
<td>0 pt</td>
<td>13.3</td>
<td>Yes</td>
<td>0.93</td>
<td>14.3 HP</td>
<td>1.19</td>
<td>24 h/day</td>
<td>93,352</td>
</tr>
<tr>
<td>22&quot;</td>
<td>5.90</td>
<td>0.73</td>
<td>0.78</td>
<td>5 pt</td>
<td>15.3</td>
<td>Yes</td>
<td>0.93</td>
<td>16.4 HP</td>
<td>1.37</td>
<td>24 h/day</td>
<td>107,396</td>
</tr>
<tr>
<td>20&quot;</td>
<td>6.55</td>
<td>0.66</td>
<td>0.77</td>
<td>11 pt</td>
<td>18.8</td>
<td>No</td>
<td>0.93</td>
<td>20.2 HP</td>
<td>1.68</td>
<td>24 h/day</td>
<td>131,873</td>
</tr>
<tr>
<td>16&quot; x 3</td>
<td>5.31</td>
<td>0.74</td>
<td>0.75</td>
<td>1 pt</td>
<td>13.6</td>
<td>Yes</td>
<td>0.90</td>
<td>15.1 HP</td>
<td>1.26</td>
<td>24 h/day</td>
<td>98,528</td>
</tr>
</tbody>
</table>

**EAE** = Estimated Annual Energy Usage  
- variable motor efficiency
Selection Example

Range: DWDI AF FEG75
Baseline: 25,000 cfm @ 6 in-wg ($P_t$)
VAV System Control: 0.75 in-wg

Load Profile

Fan Range
Selection Example

Typical VAV System Curve

Flowrate

Total Pressure, Total Efficiency

N

N_{\text{max}}

P_v

P_t

VAV Pressure Control Point
Energy consumption must include contribution from each operating point on the VAV schedule

\[ EAE = H_{dc1}\Delta t_1 + H_{dc2}\Delta t_2 + H_{dc2}\Delta t_2 + \ldots \]
Selection Example

Effect of baseline pressure

<table>
<thead>
<tr>
<th>Fan Size (in)</th>
<th>Annual Energy Consumption (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>400,000</td>
</tr>
<tr>
<td>25</td>
<td>300,000</td>
</tr>
<tr>
<td>27</td>
<td>200,000</td>
</tr>
<tr>
<td>30</td>
<td>100,000</td>
</tr>
<tr>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>36</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
</tr>
</tbody>
</table>

Effect of baseline pressure:
- $p_t = 8$ in-wg
- $p_t = 6$ in-wg
- $p_t = 4$ in-wg
- $p_t = 2$ in-wg

Estimated Annual Energy Usage:
- 90% motor efficiency
- 90% drive efficiency
- 100% duty cycle

Best TE
- Acceptable
- Unacceptable

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Summary

Serious efforts to reduce HVAC energy consumption

System wide approach:
✓ Minimize flow restriction in achieving HVAC goal (greatest impact)
✓ Maximize motor/control/drive efficiency
✓ Maximize fan efficiency

Rating fans for efficiency capability:
✓ FEG - fan grade based on shaft/impeller power
✓ FMEG - packaged fan/motor/drives

✓ Effective only if selection are made close to pTE (10 pts)
Questions