The Impact of Industrial Ventilation Systems on Energy Conservation

Michael J. Ellenbecker, Sc.D., CIH
Director, TURI
Presentation Overview

• Principles of ventilation design for contamination control
  – General exhaust ventilation
  – Local exhaust ventilation
• Impact of ventilation on energy use
  – HVAC systems used in industry
  – Energy costs associated with HVAC use
• Optimizing energy use while protecting workers and the environment
The Basics

• Ventilation is used as an end-of-pipe control to
  – Reduce worker exposures
  – Together with air pollution control devices, reduce environmental releases

• Every cubic foot of air that is exhausted from the plant will be replaced

• The replacement air must be conditioned
  – This talk will focus on heating replacement air
Types of Ventilation for Contaminant Control

• General exhaust ventilation (GEV)
  – Also called dilution ventilation
  – Simplest, but usually not the best choice

• Local exhaust ventilation (LEV)
  – More difficult to design, install and maintain than GEV
  – Usually preferred to GEV

• Replacement air systems
  – Also called make-up air
  – Largest source of energy use in ventilation systems
General Exhaust Ventilation
Typical Concentration Plot

- Alfentanil (n = 5): 0.5 mcg/kg/min
- ULTIVA (n = 6): 0.05 mcg/kg/min
Maximum Concentration

\[ C_{\text{max}} = (GK/Q) \times 10^6 \]

Where

- \( C_{\text{max}} \) = contamination concentration (ppm)
- \( G \) = contamination generation rate (ft\(^3\)/min)
- \( Q \) = GEV air flow (ft\(^3\)/min)
- \( K \) = mixing factor (dimensionless)
Estimation of Generation Rate

- Easiest case – solvent evaporation
- Need some estimate of solvent use over time – assume it all evaporates

\[ G \text{ (cfm)} = G(lb/min) \times 453 \text{ g/lb} \times 24.5 \text{ L/mole} \times \frac{MW \text{ (g/mole)}}{28.3 \text{ L/ft}^3} \]

\[ = 390 \text{ G (lb/min)} \times \frac{MW}{MW} \]
Estimation of Generation Rate, Cont.

\[ G \text{ (lb/min)} = G \text{ (pts/h)} \times 1.04 \text{ lb/pt} \times \text{s.g.} \times \frac{60 \text{ min/h}}{1 \text{ h/min}} \]

\[ = 0.017 \times \text{s.g.} \times G \text{ (pt/h)} \]
Local Exhaust Ventilation
Comparison of GEV v. LEV

• GEV only reduces contaminant concentration, while a properly designed LEV system can eliminate worker exposure

• GEV generally requires much more air flow than a properly designed LEV system

• People choose GEV because it is simpler and has lower capital costs, but usually GEV has much higher operating costs
Example – Vapor Degreaser

Assume:

• TCE used – TLV = 10 ppm
• G = 1 ft³/min TCE vapor
• K = 5
GEV Calculation

The air flow required to hold the maximum TCE calculation equal to its TLV is:

\[
Q = \frac{GK}{TLV} \times 10^6
= (1 \times \frac{5}{10}) \times 10^6
= 500,000 \text{ ft}^3/\text{min} !!!!!!
\]

AND – worker is still being exposed at the TLV!
GEV Variables

• GEV is dependent on both the contaminant generation rate and toxicity
  
  E.g., if the TLV is 100 ppm, $Q = 50,000 \text{ cfm}$
  
  TLV is 1000 ppm, $Q = 5,000 \text{ cfm}$

• Therefore, GEV makes more sense for low-toxicity exposures
But if You Use LEV.....

Assume the tank is 3 ft long (L) by 2 ft deep (x). Use a slot hood along the back side, assuming a capture velocity \((V_c)\) of 150 ft/min:

\[
Q = 2.8LxV_c \\
= 2.8 \times 3 \times 2 \times 150 \\
= 2,500 \text{ ft}^3/\text{min}
\]
But You have to Optimize the LEV System!

Same example, but use a canopy hood located 3 ft (H) over the degreasing tank:

The perimeter around the tank (P) = 10 ft

\[
Q = 1.4PHV_c \\
= 1.4 \times 10 \times 3 \times 150 \\
= 6,300 \text{ ft}^3/\text{min}
\]
Replacement Air Systems
Gas Fired Replacement-air Units

**Figure 12.2** Gas-fired replacement-air units: The indirect-fired unit is equipped with a burner chamber and heat exchanger, so the replacement air stream and gas combustion process are separate. These units are equipped with recirculating dampers. The products of combustion of the direct-fired gas units are delivered to the workplace. If air is recirculated from the workplace, it must be introduced downstream of the burner; otherwise, fugitive air contaminants will be thermally degraded in the burner and delivered to the space. The direct-fired replacement air units are equipped with elaborate controls which permit their safe operation.
By-pass Steam System

FIGURE 7-9 BY-PASS STEAM SYSTEM
Annual Heating Cost

\[ C = \frac{0.154Qd_g t c_f}{\eta H_f} \]

Where

- \( C \) = heating cost, $/year
- \( d_g \) = annual degree days at your location
- \( t \) = hours/week replacement air system operates
- \( c_f \) = cost of fuel
- \( \eta \) = efficiency of heating unit
- \( H_f \) = heat content of the fuel
<table>
<thead>
<tr>
<th>City</th>
<th>Albany</th>
<th>Boston</th>
<th>Chicago</th>
<th>Cleveland</th>
<th>Detroit</th>
<th>Minneapolis</th>
<th>NY</th>
<th>Philadelphia</th>
<th>Pittsburgh</th>
<th>St. Louis</th>
<th>Wash., DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Temp (F) Dec-Feb</td>
<td>24</td>
<td>22.4</td>
<td>25</td>
<td>28</td>
<td>25.9</td>
<td>16</td>
<td>33.2</td>
<td>33.3</td>
<td>29</td>
<td>32.2</td>
<td>33.4</td>
</tr>
<tr>
<td>Discharge Air Temp (F)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>11782</td>
<td>10409</td>
<td>10613</td>
<td>11343</td>
<td>10959</td>
<td>13176</td>
<td>9284</td>
<td>9652</td>
<td>10797</td>
<td>8943</td>
<td>8422</td>
</tr>
<tr>
<td>79</td>
<td>11425</td>
<td>10049</td>
<td>10277</td>
<td>10982</td>
<td>10605</td>
<td>12826</td>
<td>8937</td>
<td>9300</td>
<td>10436</td>
<td>8624</td>
<td>8089</td>
</tr>
<tr>
<td>78</td>
<td>11062</td>
<td>9690</td>
<td>9940</td>
<td>10621</td>
<td>10256</td>
<td>12478</td>
<td>8595</td>
<td>8954</td>
<td>10076</td>
<td>8310</td>
<td>7764</td>
</tr>
<tr>
<td>77</td>
<td>10709</td>
<td>9242</td>
<td>9610</td>
<td>10265</td>
<td>9914</td>
<td>12135</td>
<td>8265</td>
<td>8619</td>
<td>9726</td>
<td>8003</td>
<td>7446</td>
</tr>
<tr>
<td>76</td>
<td>10356</td>
<td>8994</td>
<td>9283</td>
<td>9915</td>
<td>9581</td>
<td>11797</td>
<td>7938</td>
<td>8285</td>
<td>9379</td>
<td>7702</td>
<td>7139</td>
</tr>
<tr>
<td>75</td>
<td>10009</td>
<td>8652</td>
<td>8972</td>
<td>9570</td>
<td>9247</td>
<td>11475</td>
<td>7620</td>
<td>7959</td>
<td>9036</td>
<td>7413</td>
<td>6835</td>
</tr>
<tr>
<td>74</td>
<td>9669</td>
<td>8317</td>
<td>8656</td>
<td>9229</td>
<td>8920</td>
<td>11142</td>
<td>7308</td>
<td>7641</td>
<td>8702</td>
<td>7121</td>
<td>6538</td>
</tr>
<tr>
<td>73</td>
<td>9333</td>
<td>7790</td>
<td>8349</td>
<td>8898</td>
<td>8599</td>
<td>10816</td>
<td>7004</td>
<td>7328</td>
<td>8372</td>
<td>6839</td>
<td>6250</td>
</tr>
<tr>
<td>72</td>
<td>9007</td>
<td>7668</td>
<td>8046</td>
<td>8557</td>
<td>8291</td>
<td>10496</td>
<td>6706</td>
<td>7028</td>
<td>8050</td>
<td>6560</td>
<td>5974</td>
</tr>
<tr>
<td>71</td>
<td>8682</td>
<td>7354</td>
<td>7750</td>
<td>8248</td>
<td>7981</td>
<td>10180</td>
<td>6421</td>
<td>6728</td>
<td>7740</td>
<td>6289</td>
<td>5703</td>
</tr>
<tr>
<td>70</td>
<td>8364</td>
<td>7046</td>
<td>7468</td>
<td>7928</td>
<td>7678</td>
<td>9870</td>
<td>6146</td>
<td>6436</td>
<td>7429</td>
<td>6023</td>
<td>5438</td>
</tr>
<tr>
<td>69</td>
<td>8255</td>
<td>6749</td>
<td>7183</td>
<td>7617</td>
<td>7383</td>
<td>9567</td>
<td>5871</td>
<td>6158</td>
<td>7127</td>
<td>5767</td>
<td>5179</td>
</tr>
<tr>
<td>68</td>
<td>7750</td>
<td>6458</td>
<td>6905</td>
<td>7313</td>
<td>7100</td>
<td>9269</td>
<td>5606</td>
<td>5886</td>
<td>6333</td>
<td>5523</td>
<td>4929</td>
</tr>
<tr>
<td>67</td>
<td>7452</td>
<td>6175</td>
<td>6635</td>
<td>7016</td>
<td>6816</td>
<td>8975</td>
<td>5349</td>
<td>5618</td>
<td>6546</td>
<td>5277</td>
<td>4690</td>
</tr>
<tr>
<td>66</td>
<td>7152</td>
<td>5903</td>
<td>6373</td>
<td>6722</td>
<td>6543</td>
<td>8887</td>
<td>5101</td>
<td>5360</td>
<td>6272</td>
<td>5053</td>
<td>4455</td>
</tr>
<tr>
<td>65</td>
<td>6881</td>
<td>5633</td>
<td>6122</td>
<td>6445</td>
<td>6278</td>
<td>8410</td>
<td>4858</td>
<td>5109</td>
<td>5997</td>
<td>4822</td>
<td>4229</td>
</tr>
<tr>
<td>64</td>
<td>6607</td>
<td>5370</td>
<td>5875</td>
<td>6165</td>
<td>6020</td>
<td>8131</td>
<td>4521</td>
<td>4864</td>
<td>5734</td>
<td>4595</td>
<td>4014</td>
</tr>
<tr>
<td>63</td>
<td>6340</td>
<td>5118</td>
<td>5638</td>
<td>5897</td>
<td>5772</td>
<td>7858</td>
<td>4394</td>
<td>4628</td>
<td>5483</td>
<td>4379</td>
<td>3798</td>
</tr>
<tr>
<td>62</td>
<td>3081</td>
<td>4873</td>
<td>5399</td>
<td>5636</td>
<td>5533</td>
<td>7590</td>
<td>4176</td>
<td>4397</td>
<td>5234</td>
<td>4168</td>
<td>3588</td>
</tr>
<tr>
<td>61</td>
<td>5829</td>
<td>4643</td>
<td>5164</td>
<td>5331</td>
<td>5290</td>
<td>7339</td>
<td>3957</td>
<td>4172</td>
<td>5006</td>
<td>3963</td>
<td>3383</td>
</tr>
<tr>
<td>60</td>
<td>5586</td>
<td>4399</td>
<td>4936</td>
<td>5140</td>
<td>5054</td>
<td>7086</td>
<td>3747</td>
<td>3952</td>
<td>4769</td>
<td>3761</td>
<td>3182</td>
</tr>
</tbody>
</table>
**Read the Globe**

### Boston's recent climate

<table>
<thead>
<tr>
<th></th>
<th>Degree days</th>
<th>Heat</th>
<th>Cool</th>
<th>April readings</th>
<th>Actual</th>
<th>Norm.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yesterday</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High/low</td>
<td>35/29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Departure from normal</td>
<td>-14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Departure for month</td>
<td>-64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Departure for year</td>
<td>-391</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 p.m. rel. humidity</td>
<td>61%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>April total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monthly total</td>
<td>5464</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season total</td>
<td>4939</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Last year to date</td>
<td>4174</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 24 Hr. Precipitation

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yesterday</strong></td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precip days in April</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Climate data are compiled from National Weather Service records and are subject to change or correction.
# Fuel Sources

<table>
<thead>
<tr>
<th>Fuel</th>
<th>BTU/unit</th>
<th>Typical Efficiency (%)</th>
<th>Available BTU/unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>12,000 BTU/lb</td>
<td>50</td>
<td>6,000</td>
</tr>
<tr>
<td>Oil</td>
<td>142,000 BTU/gal</td>
<td>75</td>
<td>106,500</td>
</tr>
<tr>
<td>Gas – Direct Fired</td>
<td>1,000 BTU/ft³</td>
<td>90</td>
<td>900</td>
</tr>
<tr>
<td>Gas – Indirect Fired</td>
<td>1,000 BTU/ft³</td>
<td>80</td>
<td>800</td>
</tr>
</tbody>
</table>
Assume Oil in Boston

- Cost = $3.50/gal
- Degree days = 5633 @ 65 F
- Full-time operation (168 h/wk)

\[ C = \frac{0.154Qd_gtc_f}{\eta H_f} \]

\[ C = 0.154(5633 \text{ dd})(168 \text{ h/wk})(3.50 \text{ /gal})(Q)/106,500 \]

\[ \text{BTU/gal} \]

= $4.80 per cfm per year to heat replacement air in Boston

For 40 hours/week, ~ $1/\text{cfm/year}
Let’s Revisit our TCE Example

• Assume 40 h/week operation, $1/cfm/year

GEV - $500,000 per year

LEV – canopy hood - $6,300 per year

LEV – slot hood - $2,500 per year
Payback Period

- Assume that the LEV system with a slot hood cost $20,000 more than the GEV system

\[
PP = \frac{20,000}{(500,000 - 2,500/\text{year})}
\]

\[= 0.04 \text{ years} = 2 \text{ weeks}\]
Another Example – Fume Hoods for Nanoparticles
Breathing Zone - Conventional Hood

Transferring 100g $\text{Al}_2\text{O}_3$

Pouring 100g $\text{Al}_2\text{O}_3$

Note: Background concentration was subtracted.
Airflow Pattern

Outside hood


Inside hood

Reference: C Pathanjali and M Rahman, IEEE 1996
Alternatives to Conventional Hoods

• Biological safety cabinets
  – Work well, but still high air flow

• “Nano” hoods
  – Specifically designed for handling NPs
  – Very low air flow
  – Very high containment efficiency
Optimizing energy use while protecting workers and the environment

• Use TUR to eliminate the need for exhaust ventilation
• If you must use exhaust ventilation, use LEV instead of GEV whenever possible
• When using LEV, have a knowledgeable ventilation engineer design the best system
• Optimize your replacement air system
• Pay attention to maintenance!
Thank You!

Contact information:

Mike Ellenbecker
ellenbec@turi.org

www.turi.org