Saving energy, staying healthy: ventilation in cold climates

Martin Kotol, PhD
• Born in Czech Republic
• M.Sc. ”Mechanical Ventilation in Cold Climates”
• Ph.D. ”Energy Use and IAQ in Cold Climates”
• Mostly in Greenland
• Internship at CCHRC
• Currently a Postdoc at ARTEK
• HVAC in Cold Climates
Agenda

- Indoor Air Quality and Health
- IAQ in Cold Climates
- Ventilation systems
- IAQ renovation in Greenland
- HRV tour & questions
Indoor Air Quality

• Moisture
• Mold
• Dust mites
• Volatile Organic Compounds (VOC)
• Environmental Tobacco Smoke (ETC)
• Candle light
• Carbon monoxide (CO)
• Carbon dioxide (CO₂)
• Too low RH = problem
• Too high RH = problem
Moisture

Absolute vs. Relative humidity

Relative humidity [%]

Absolute moisture lb/lb_{DRY}

68 °F

57 °F

32 °F

23 °F

0.005 0.010 0.015 0.020 0.025 0.030 0.035 0.040 0.045 0.050
Mold

• Feed on death organic matter
• Can live of many materials found at homes
• Thrive best at high water activity
• Many are harmful (so are the cleaning agents)
Dust mites

- 0.008 - 0.012 in
- Feeding on skin flakes
- Living in bedrooms (mattresses, carpets, bedding)
- Thrive best at higher RH
- Associated with asthma and allergy
VOC

- Organic chemicals that vaporize at room T
- From paints, waxes, varnishes, cleaning agents
- Trichlorethylene – Childhood leukemia
- Toluene – Retarded growth of fetus
- Xylenes – Birth defects
- Benzene – Human carcinogen
• Secondhand smoke
• Asthma, irritation, respiratory illnesses, SIDS, miscarriage,…
• Group A carcinogen
• 3000 deaths/year
Candle light

• Paraffin based candles - toluene and benzene
• Allergies, asthma, cancer, ...
• Bees wax and soy is a better alternative
• Still produce CO and soot
• Not always 100%
• Combustion pollutant
• Leading cause of poisoning deaths (430/y in USA)
• Odorless, colorless
• Fatigue and chest pain in low exposure
• Flulike symptoms in higher exposure
• Combustion, fermentation and respiration
• 400 ppm (0.04 %) in the atmosphere
• Effects human performance, perception of IAQ
• Used as an IAQ indicator
• ASHRAE 62.1 – 700 ppm AO
• ASTM D6245 – 650 ppm AO
• EN 15251 – 500 ppm AO
• Commonly referred - 1000 ppm
2 days bedroom CO₂
Effects of poor IAQ

- Quality of sleep
- Concentration and performance
- Sick Building Syndrome
- Asthma
- Allergies
- Mucous membranes irritation
- Cancer
- Poisoning
VENTILATION

Fresh air **IN**

Stale air **OUT**
Requirements

Health based minimum ventilation

8 CFM/pers

EU requirements

15 CFM/pers

ASHRAE 62.2

0.01 \cdot \text{floor area} + 7.5 \cdot (\#\text{bedrooms}+1)

BEES 2012

0.01 \cdot \text{floor area} + 10 \cdot (\#\text{bedrooms}+1)

CONTINUOUSLY!
Example

House 2000 ft$^2$; 3 bedrooms; 4 people

**ASHRAE 62.2**

$$(0.01 \cdot 2000 + 7.5 \cdot (3+1)) = 50 \text{ CFM} \ (12.5 \text{ CFM/pers})$$

**BEES 2012**

$$(0.01 \cdot 2000 + 10 \cdot (3+1)) = 60 \text{ CFM} \ (15.0 \text{ CFM/pers})$$
Situation in Greenland

- 23,112 dwellings (50% apartments)
- 33% of dwellings built before 1970
- Poor technical and environmental conditions
- Extreme climate
- 14 MMBtu/(ft²·year)
- Savings lead to lower ACH
- Long lasting cooking
- Drying clothes inside
Sisimiut study

- Sisimiut, Greenland
- Questionnaire with 13.4% response rate (270)
- 80 dwellings selected
- T, RH, and CO$_2$ as IAQ indicator
- 1 week in summer 2011
- 1 week in winter 2012
Comfort

Percentage of respondents

- Very often
- Often
- Not so often
- Almost never
- Never
- I don't know or missing

- Mold
- Cold draft
- Cold floor
- Noise
- Too hot in summer
- Too cold in winter
- Too little daylight
- Condensation on windows
- Sick building syndrome
Smoking

- **Kids**
  - Smokers: 26
  - Non-smokers: 64

- **No Kids**
  - Smokers: 56
  - Non-smokers: 95
The younger the worse

![Graph showing CO2 concentration for Adults only, Kids only, and Adults + kids for Summer and Winter. The x-axis represents categories: Adults only, Kids only, Adults + kids. The y-axis represents Average CO2 concentration. The graph indicates that the CO2 concentration is higher for Adults + kids compared to Adults only and Kids only. There is a significant increase in CO2 concentration during Winter compared to Summer.]
The newer the worse

<table>
<thead>
<tr>
<th>Year</th>
<th>Concentration [ppm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1970</td>
<td>1083 ppm</td>
</tr>
<tr>
<td>Before 1970 W</td>
<td>1273 ppm</td>
</tr>
<tr>
<td>1970 - 1990</td>
<td>1045 ppm</td>
</tr>
<tr>
<td>1970 - 1990 W</td>
<td>1243 ppm</td>
</tr>
<tr>
<td>After 1990</td>
<td>1333 ppm</td>
</tr>
<tr>
<td>After 1990 W</td>
<td>1488 ppm</td>
</tr>
</tbody>
</table>
Despite requirements, the IAQ remains poor.
Sustainable Village

- Built in 2012 in Fairbanks

- 4 homes x 4 students x 4 solutions

- Foundations
- Envelopes
- Heating systems
- Ventilation systems
Percentage of night time with $\text{CO}_2 > 1100$ ppm

- Willow
- Spruce
- Birch
- Tamarack

Ventilation rate [CFM]
How is the IAQ in this room?
CCHRC addition
10 minutes brake
Natural ventilation

Mechanical ventilation
• Passive (no electric parts)
• Uses stack effect or wind pressure
• None or limited heat recovery
• Limited controllability
• Poor energy efficiency
• Poor air change
• Causes discomfort
Proved not to work!
• Active (use of fans to move air)
• Good controllability
• Air heating/cooling
• Heat recovery (sensible/latent)
• Air filtration/purification
• Requires maintenance
• Higher investment
Ventilation units

HRV & ERV
Effectiveness

\[ \varepsilon = \frac{q}{q_{\text{max}}} \]

\[ q_{\text{max}} = c_{\text{min}} \cdot (T_{h,i} - T_{c,i}) \]

\[ q = c_h \cdot (T_{h,i} - T_{h,o}) = c_c \cdot (T_{c,o} - T_{c,i}) \]

\[ c_h = c_{p,h} \cdot \frac{dm_h}{dt_h} \quad c_c = c_{p,c} \cdot \frac{dm_c}{dt_c} \]

If mass flows are identical:

\[ \varepsilon_{\text{supply}} = \frac{T_{\text{supply}} - T_{\text{outside}}}{T_{\text{return}} - T_{\text{outside}}} \]

\[ \varepsilon_{\text{exhaust}} = \frac{T_{\text{return}} - T_{\text{exhaust}}}{T_{\text{return}} - T_{\text{outside}}} \]
Example

Calculate the temperature of the exhaust air $T_{\text{exhaust}}$

$\varepsilon = 70 \%$; $T_{\text{inside}} = 70 ^\circ \text{F} = T_{\text{return}}$; $T_{\text{outside}} = -40 ^\circ \text{F}$

$$
\varepsilon_{\text{exhaust}} = \frac{T_{\text{return}} - T_{\text{exhaust}}}{T_{\text{return}} - T_{\text{outside}}}
$$

$$
T_{\text{exhaust}} = T_{\text{return}} - \varepsilon \cdot (T_{\text{return}} - T_{\text{out}})
$$

$$
T_{\text{exhaust}} = 70 - 0.7 \cdot (70 + 40)
$$

$$
T_{\text{exhaust}} = -7 ^\circ \text{F}
$$

What does it mean?
Freezing

Absolute moisture lb/lb_{DRY}
• Preheating
Frost protection

- Preheating
- By-passing
Frost protection

- Preheating
- By-passing
- Flow reduction

20% from cracks
Frost protection

- Preheating
- By-passing
- Flow reduction
- Recirculation
Frost protection

- Preheating
- By-passing
- Flow reduction
- Recirculation
- Effectiveness regulation
Control

• Simple
  – Step control
  – Defrosting ON/OFF
  – Heating ON/OFF

• Advanced
  – VAV or DCV
  – Defrosting modulating
  – Central control system communication
  – GSM communication
Energy savings

\[ E = m \cdot c \cdot (T_i - T_o) \]

- Sep – May \( T_o = 8.4 \) °F
- \( T_i = 70 \) °F
- \( m = 60 \) CFM = 4.5 lb/m
- \( c = 0.24 \) Btu/lb \( \cdot \) °F

- \( E = 66.5 \) Btu/m = 25.9 MMBtu in 9 months
- 219 gal of fuel
- 770 $
Energy savings

- Effectiveness of 70%
- $770 \rightarrow 231$
- $539$ saved in 9 months
- Investment $6,000$
- Running costs $3$/month
- ROI 11 years
Lifebreath & Venmar

- Made in Canada
- Simple and compact
- Lower costs
- Simple control
- Recirculation as a defrosting strategy
Recirculation reduction

R² = 0.8997

Ventilation rate [CFM]
HRV vs ERV

- Willow
- Spruce
- Birch
- Tamarack

Average RH [%] vs Ventilation rate [CFM]
• Made in Germany
• Counter flow
• Electric preheating / by-pass / flow reduction
• EC motors
• 0-10 V input
• Ground loop
- Made in Scandinavia
- Rotary or counter flow HE
- Demand control
- ModBUS connectivity
- Preheating / flow reduction/ rotor speed
- Range hood connection
- Moisture recovery
Air Terminals

- Avoid noise
- Avoid draught
- Allow good mixing
Intakes

- Prevent snow intake
- Prevent insects intake
- Avoid short circuiting
Ductwork

- Noise
- Pressure loss
- Heat loss
- Cleaning
Ductwork
Filters

- G1 – G4, F5 – F9 (< 95 %)
- High Efficiency Particulate Air (HEPA) (< 99.999 %)
- Ultra Low Penetration Air (ULPA) (< 99.999995 %)
- Carbon
- Fat
Case Study - Sisimiut

FA - FRESH AIR VALVES  EA - EXHAUST AIR SHAFT/RANGE HOOD
Layout

GROUND FLOOR

SA - SUPPLY AIR VALVES

EA - EXHAUST AIR VALVES

RH - RANGE HOOD

1ST FLOOR
Ducts
Before installation

After installation
Humidity

Before installation

After installation

Average before

Average after

77%
Humidity

Relative humidity [%]

RH - after installation

RH - before installation
Findings

• Improvement of IAQ
  – Measured
  – Experienced

• Reasonable costs
  – Installation 9.300 USD
  – Running 300 USD/a
  – Savings 670 USD/a
  – ROI 14 years

• Mold prevention

• Comfort improvement
General conclusions

• Insufficient ventilation in Arctic dwellings
• Including new dwellings
• Natural ventilation is not an option
• Mechanical ventilation proved to work
  – Commercial systems have limitations
  – Frost and snow issues always need to be addressed
  – High quality design and control is essential
• Moisture recovery beneficial for higher RH
Arctic is a harsh place...

...but there is something in the outside air...

The only missing thing is to bring that air inside!

...what makes people happy.