# ENGINEERING PRINCIPLES

## HEATING & VENTILATING WITH 100% OUTSIDE AIR

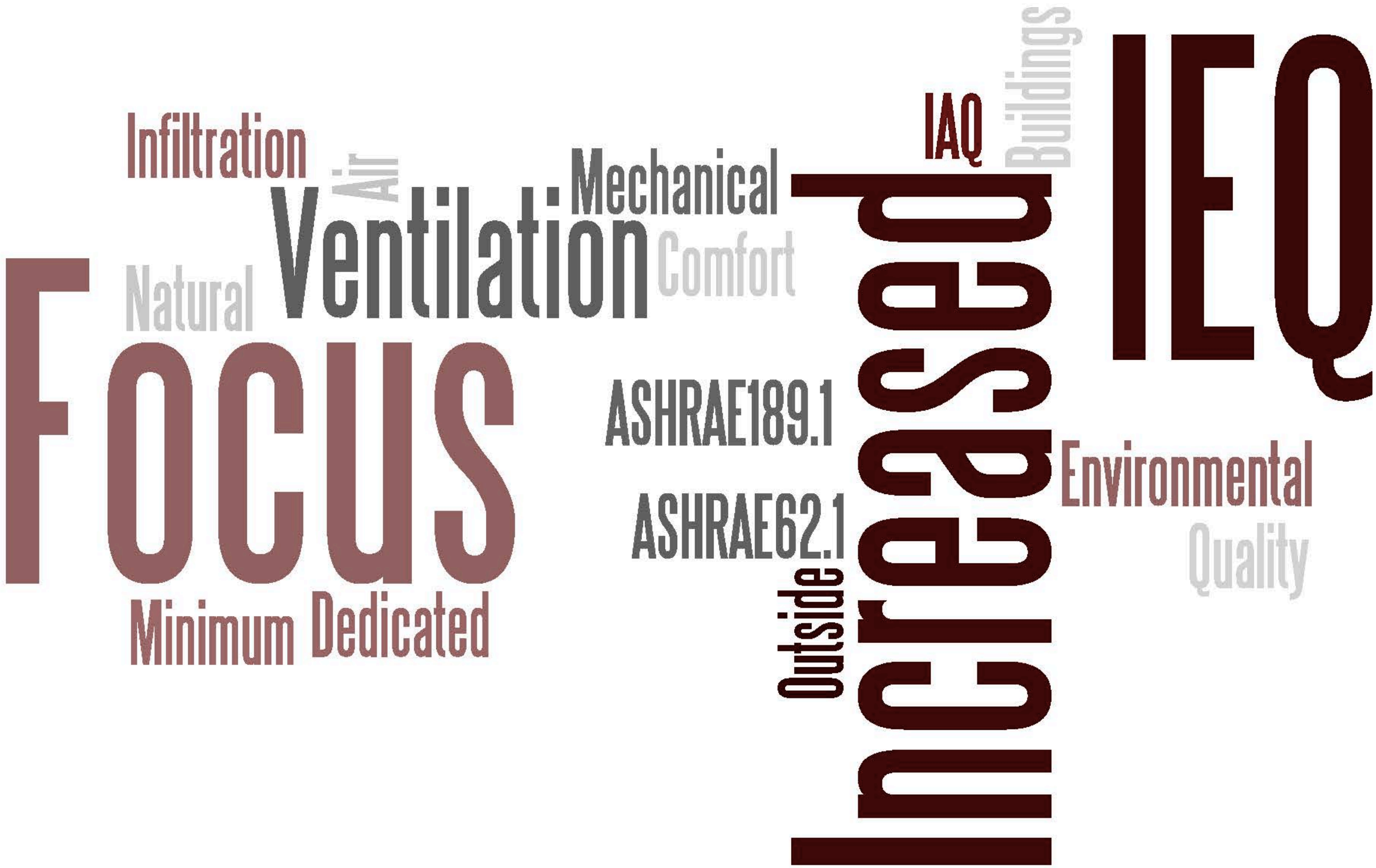
CAMBRIDGE® ENGINEERING INC

*More heat, less energy*

# Introductions

- Dave Binz
  - Cambridge Engineering
  - Director of Engineering
  - Chesterfield, MO

# Trend #1 - Ventilation

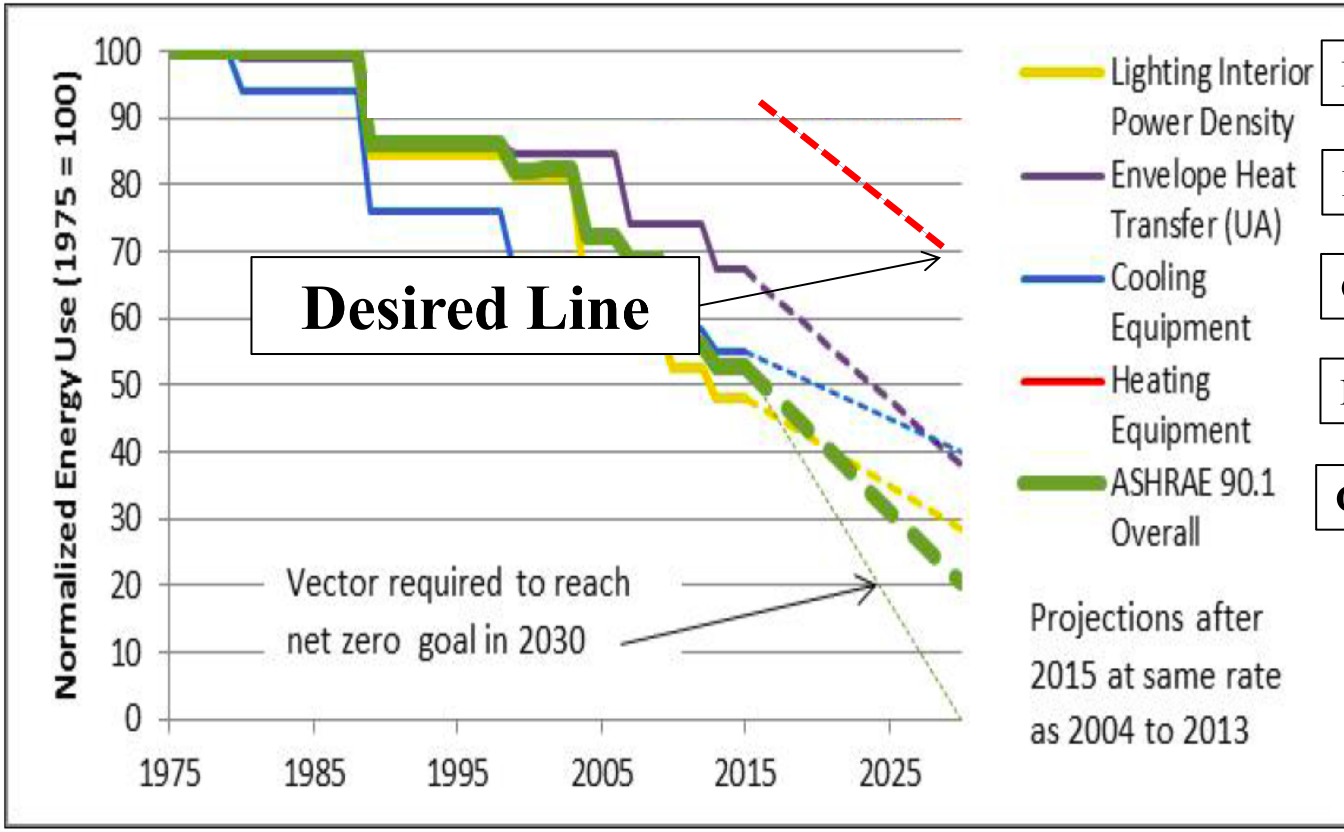


# Trend #2 - Energy

# Ventilation Efficiency Conflict

# Why Focus on Heating Systems?

**25 Years**




**Lighting – 44% Improvement**

**Envelope – 21% Improvement**

**Cooling – 27% Improvement**

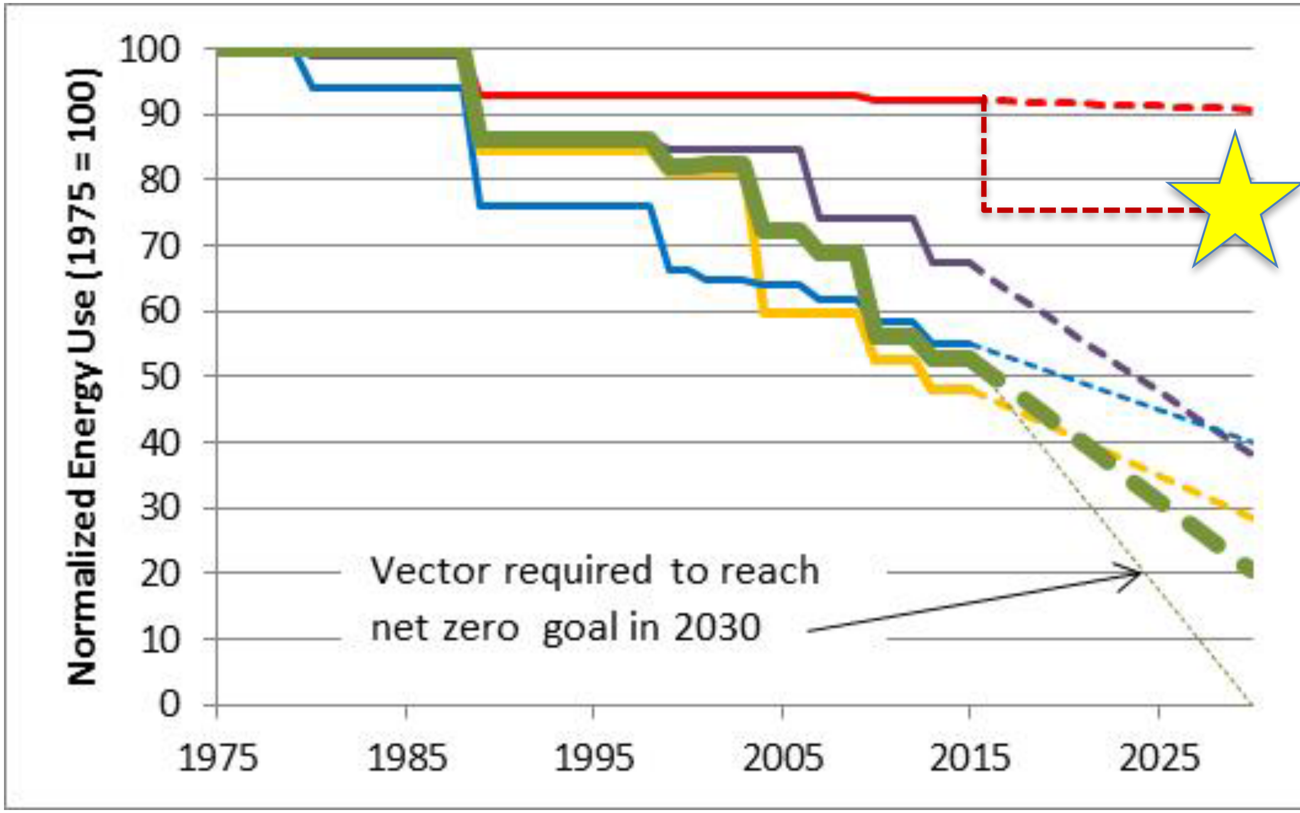
**Heating – 1% Improvement**

**Overall – 37% Improvement**

**Source: End Use Opportunity Analysis from Progress Indicator Results for ASHRAE Standard 90.1-2013**
**Pacific Northwest National Laboratory**

# Energy Savings Goal

- To reach the energy savings goals for the whole building, heating system efficiency must improve




**How can we utilize today's technology to improve heating system efficiency?**

Rosenberg et al. 2015. "Roadmap for the Future of Commercial Energy Codes." Pacific Northwest National Laboratory. January 2015.

# Session Objectives

**At the end of the session, we will be able to:**

1. Understand how a building can meet its space heating and ventilation needs through ***100% outside air direct fired heating technology***

2. Understand the differences between draw through (**MAU**) and blow through (**HTHV**) technologies

3. Understand  the **inherently safe design** of MAU & HTHV direct-fired, heating and ventilation technologies with focus on ventilation

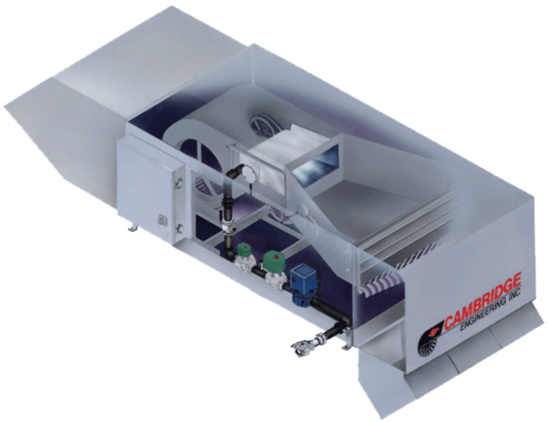
4. Understand the engineering calculations behind **delivering the most btus/cfm** or the most energy efficient way to heat a building

5. Understand how one might engage Cambridge Engineering, Inc. team to **support your valuable work with your clients**

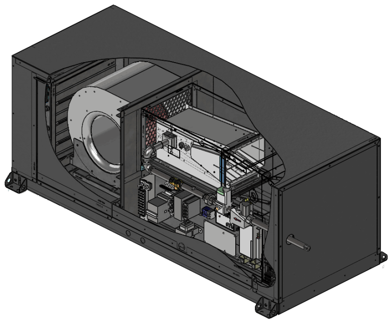
# Cambridge Engineering, Inc.


**A Leader in Energy Efficient Heating & Ventilation Technologies**

# CAMBRIDGE Product Lines

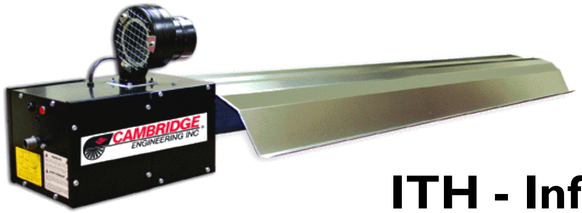



**S-Series – Blow Thru**
**<u>HTHV</u>**
**400-3200 MBH**



**SA-Series – Blow Thru**
**<u>HTHV</u>**
**250-350 MBH**

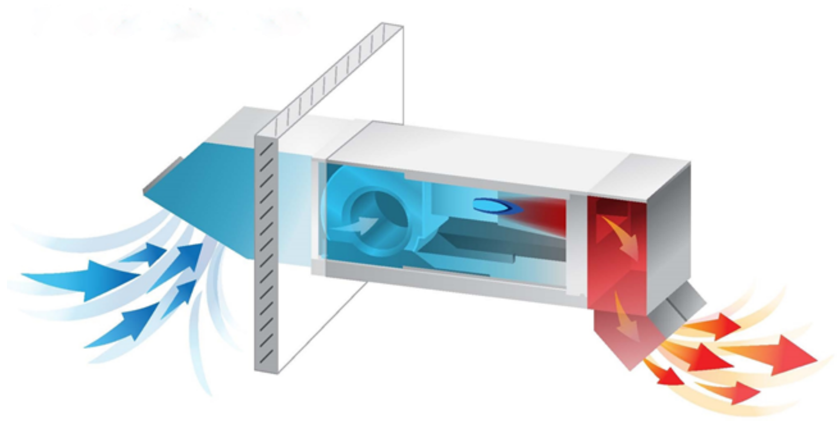
**M-Series – Draw Thru**
**Make Up Air**
**1800-75000 CFM**




**ITH - Infrared**

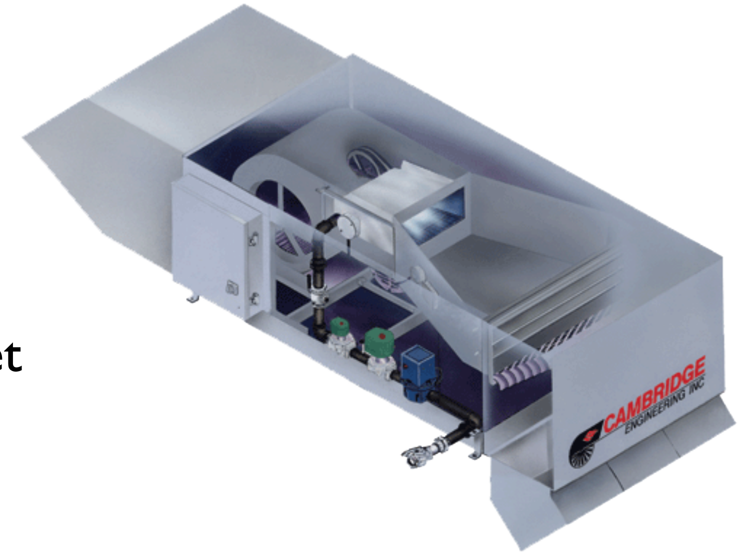
# What is HTHV?

- High-Temperature Heating & Ventilation units
  - 100% Outside Air, Direct-Fired Heater
  - Greater than 140 degree temp rise
  - Greater than 150 degree discharge temp
  - Fully Modulating Temperature Controls to meet both ventilation & space heating requirements



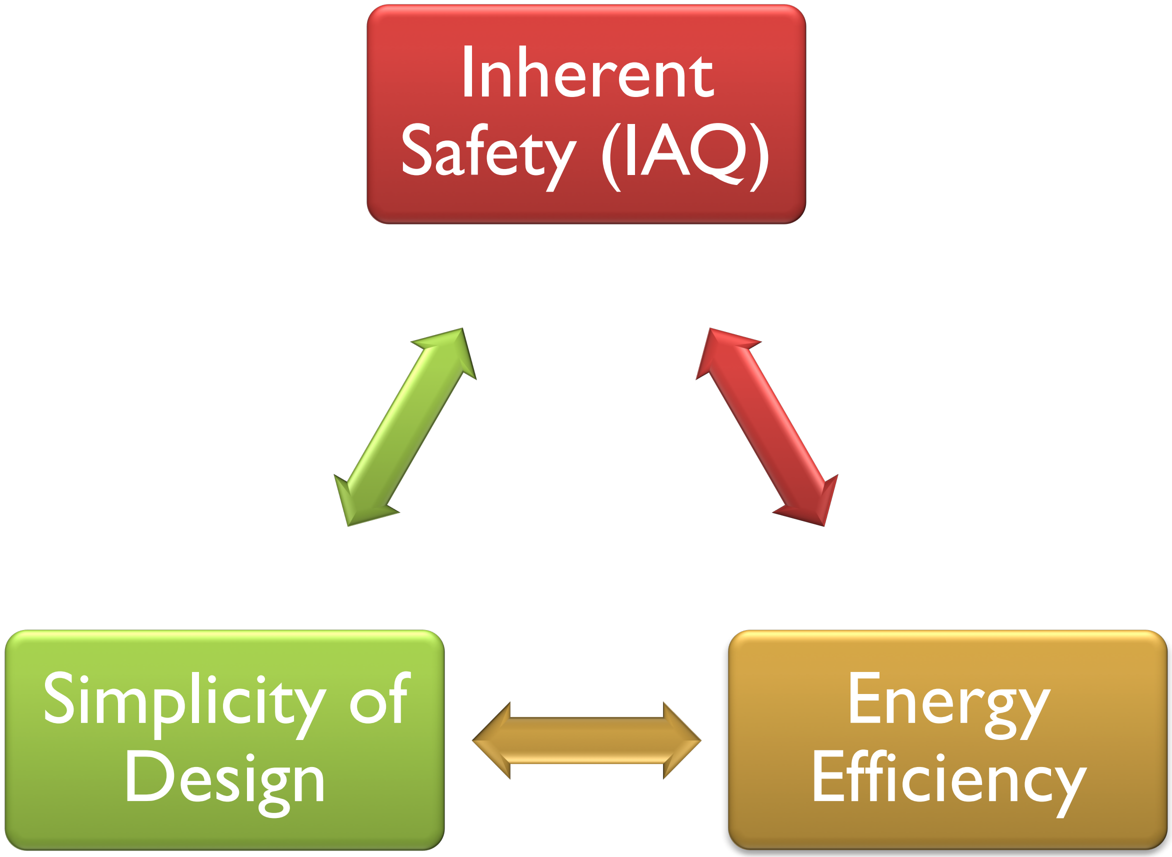
# *History of HTHV:*
## 100% OA Direct Fired Technologies

- CEI introduced "S" line in 1990's
- 160°F discharge temperature achieved
- Transformed heat only, non-ducted market (Warehouse/Distribution/Manufacturing)



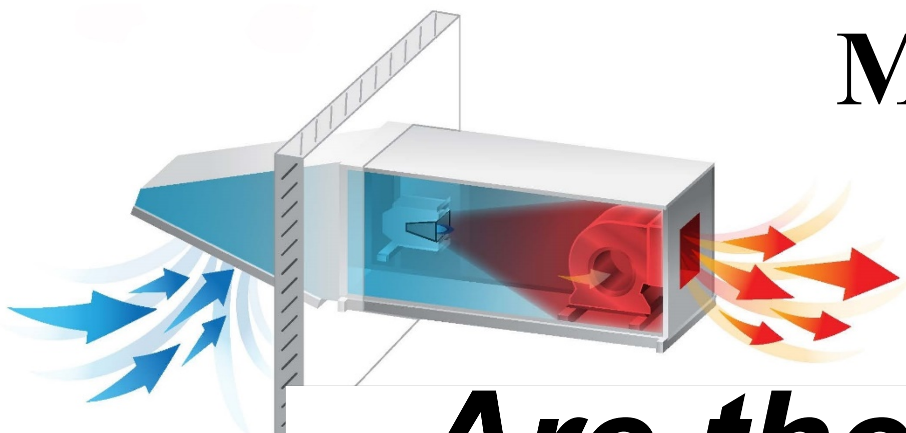

| Reason #1 | + | Reason #2 | + | Reason #3 |
|---|---|---|---|---|
| 40% Lower Install $ | | 40-70% Less Energy | | Free Ventilation (IEQ) |

# Key HTHV Education Statements



# 100% OA Direct Fired

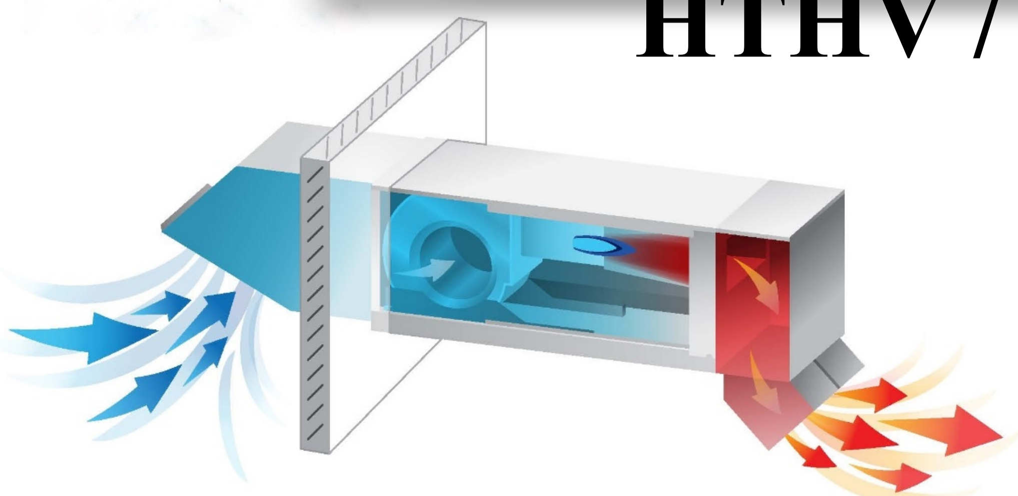
**No Heat Exchanger - No Flue Losses - 92% thermal /100% combustion Efficient**



## MAU / *(Draw Thru)*

- Blower in hot air stream
- 120°F max discharge

# ***Are these safe?***



## HTHV / *(Blow Thru®)*

- Blower in cold air stream
- 160°F max discharge

# *Inherently Safer Design (ISD)*
# *ANSI Z83.4*

- ANSI Z-83.4 – Unified Canadian/US Safety standard for 100% OA Direct Gas-Fired Air Heaters
  - Max CO less than 5ppm
- Allows ASHRAE 62.1 minimum ventilation for acceptable indoor air quality compliance
- 95+% of kitchen make-up air systems
- CSA Certified Clean Combustion
- Zero Clearance to Combustibles

# CDC Report on CO Poisoning

**"Unintentional CO exposure accounts for an estimated 15,000 emergency room visits and 500 unintentional deaths in the United States each year."**

- CAUSES
  - Automobile Exhaust 67%
  - Home Heating (Indirect Fired) 33%
  - Direct Fired 100% OA (ANZI Z83.4) 0, NADA

WHY?

# CDC Report on CO Poisoning

**"Unintentional CO exposure accounts for an estimated 15,000 emergency room visits and 500 unintentional deaths in the United States each year."**

- What is the single root cause for each of the 500 deaths

**Lack of adequate ventilation**

- ANSI Z-83.4 – Engineered technology to provide adequate ventilation to protect against these types of exposures.

# *What Insures Adequate Ventilation?*

- Redundant Engineering Controls
  - Air Flow Pressure Switch
  - High Limit Switch
  - Temperature Control System
- FMEA (Failure Mode Effects Analysis)
  - Removed all three controls
  - Block Airflow
  - Result – Highest CO Level Measured at 10 ppm

**Combustion air and Ventilation air are delivered by same blower attached to 100% OA – Cannot Separate**

# How Can It Be Efficient To Use Outside Air To Heat?



# Outside Air Compliance

1. Every building requires outside air for human occupancy - ASHRAE 62.1/62.2
2. Every building must get this air from either mechanical ventilation or natural infiltration.
3. Air load is significant portion of heat load (30-70% with balance being conduction losses)

# How Do You Heat This Air Load?

**Indirect Fired**

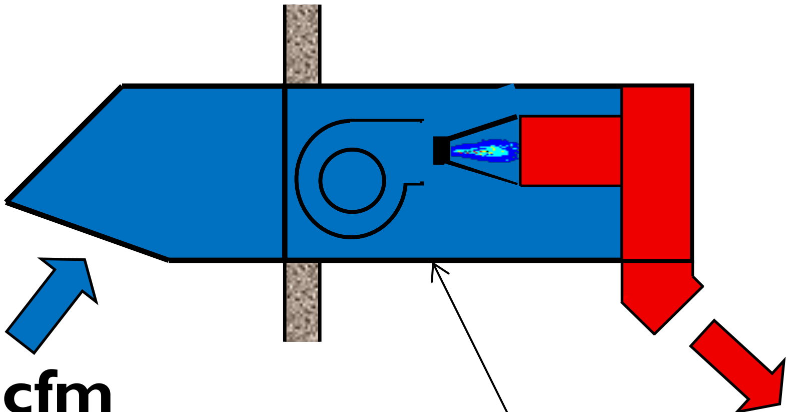
- 60%-83% AFUE
- Flue Losses

**Direct Fired**

- 92%-100% AFUE
- No Flue Losses
- 100% OA Make Up Air

**Who knows the most energy efficient way to heat the air load?**

# Ventilation Only System



10,000 cfm

0° Inlet Air

869 MBH Output

70°F Discharge (LT)

Low Velocity (LV)

No Heat Exchanger

No Flue Losses

92%/100% Efficient

Energy Efficient for Air Load and Most Competitive 1st Cost

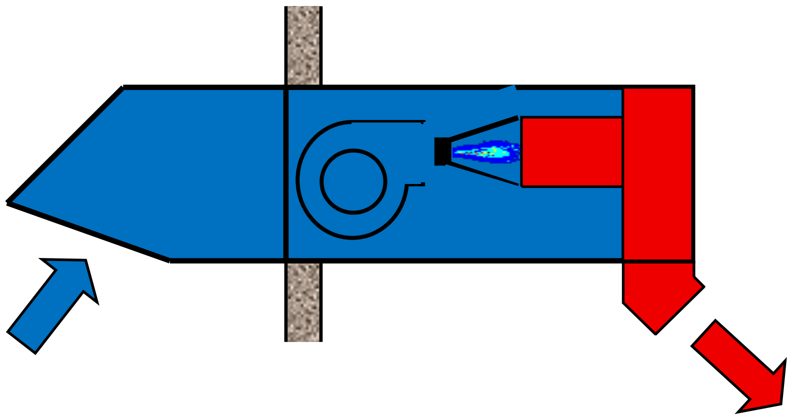
# How Do You Heat The Conduction Load?

- Add Indirect Fired System
  - 60%-83% AFUE
  - Flue Losses
- Turn Up Discharge of 100% OA Direct Fired System
  - 92%-100% AFUE
  - No Flue Losses
  - Every Degree Above Space Temperature is Usable for Conduction Losses

**Which of these is more energy efficient?**

**Which of these have lowest 1st cost?**

# Ventilation Only



**869 MBH Output**

**70°F Discharge (LT)**

**Low Velocity (LV)**

**10,000 cfm**

**0° Inlet Air**

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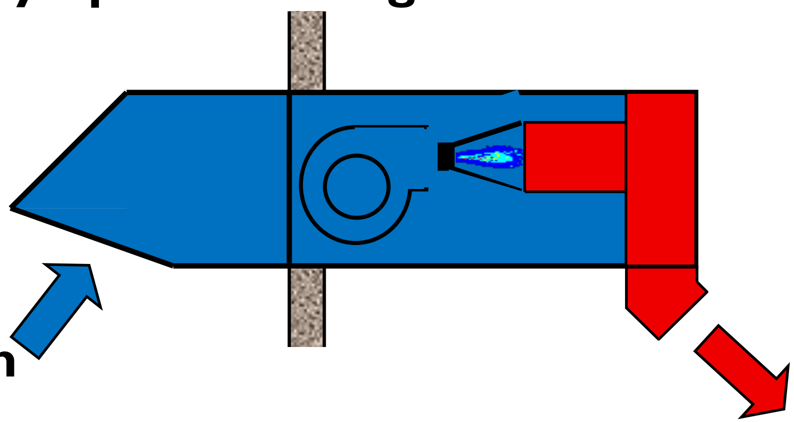
**High Efficiency Space Heating**



**1987 MBH Output**

**160°F Discharge (HT)**

**High Velocity (HV)**

**10,000 cfm**

**0° Inlet Air**

**Additional 90°F provides 1118 MBH of Usable Btu's (Available for Conduction) = 1987 MBH – 869 MBH**

# The Importance of High Discharge Temperature (HT)

Equipment $$/ Installation $$

- Example Design Load
  - 1118 MBH Conduction Load

Wasted Energy $$

| Unit Type | Discharge Temp | Design Temp | Usable BTU's/10,000 CFM | CFM Required to Cover Conduction Load |
|---|---|---|---|---|
| Push Thru | 160 | 70 | 1118 MBH | 10,000 |
| Draw Thru | 120 | 70 | 492 MBH | 24,000 |
| Draw Thru | 100 | 70 | 306 MBH | 39,000 |
| Draw Thru | 70 | 70 | 0 | ∞ |

**Is this efficient?**

**92%/100% Efficient**

**100% Outside Air**

**Direct Fired**

# Hot Air Rises

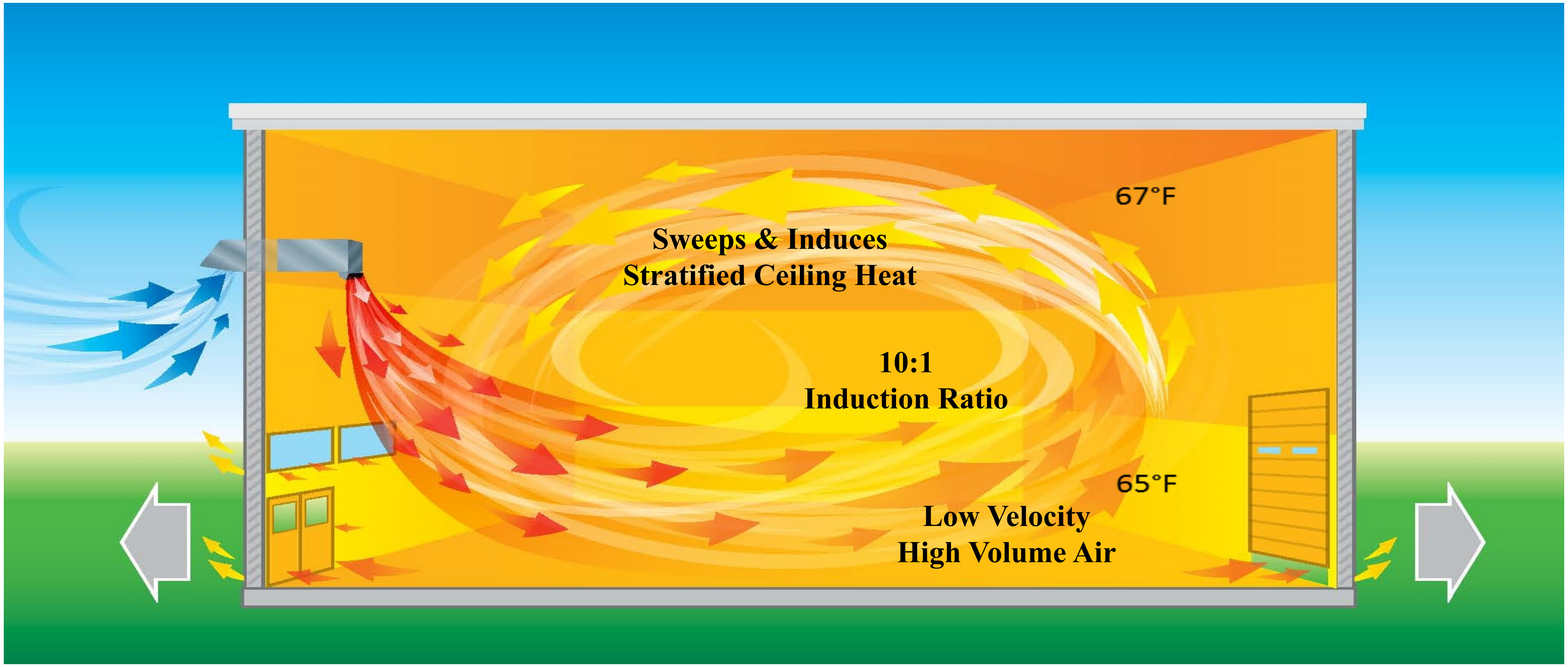
How do we address?

# De-stratification Technologies

- HVLS Fan/Pear Fans/Zoo Fans

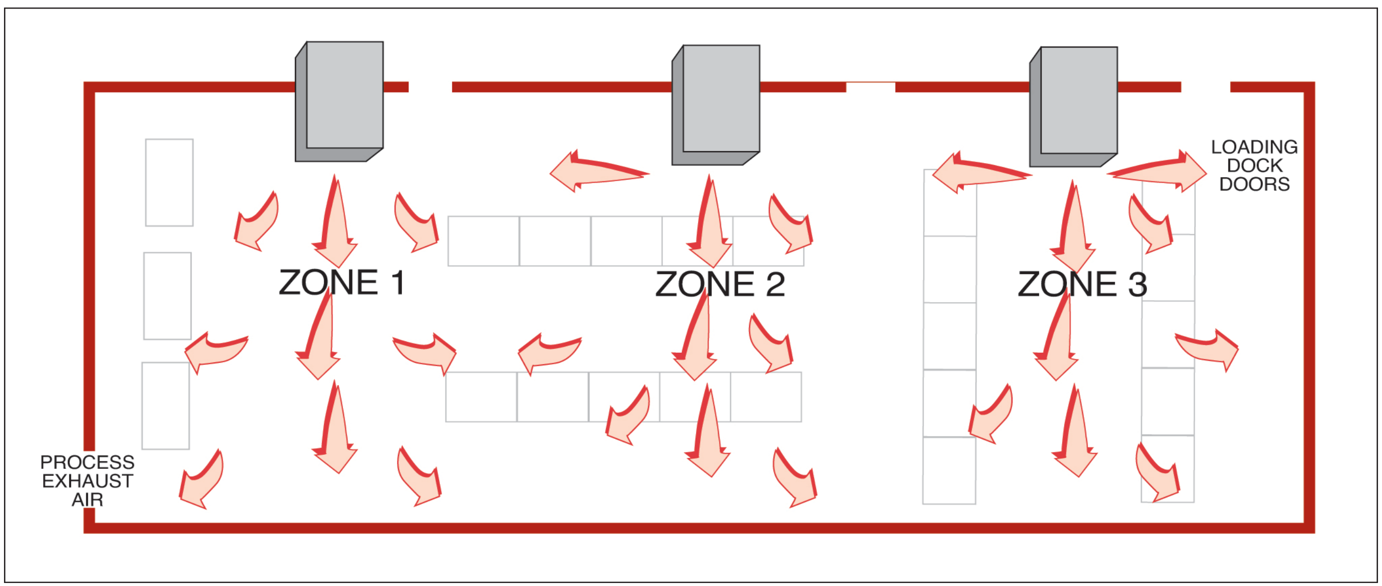
Or

- HTHV with Higher Velocity Discharge - 1500 FPM



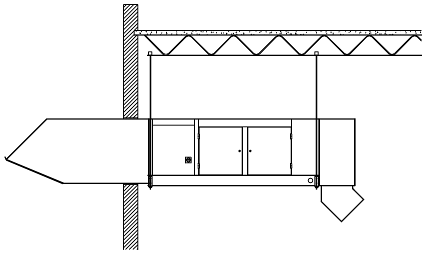
# Design Considerations - Distribution

- Zone Design
- Heaters positioned near greatest air load
- Cambridge - Technical Advisor Team

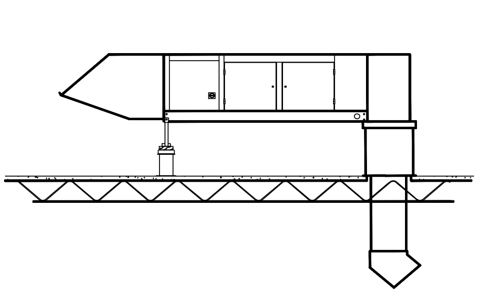


# HTHV

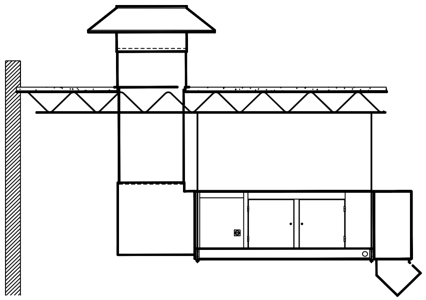
## Design Flexibility



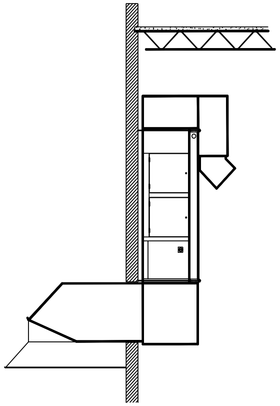
Thru Wall Installation



Roof Top Installation



Under Roof Installation

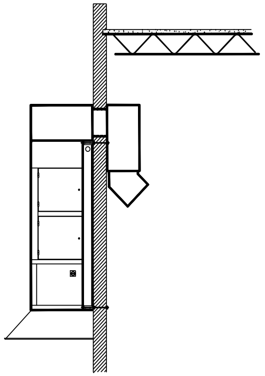


Indoor Vertical Installation

**10 Models**

**250- 3200 MBH**

**100 - 2000 lbs.**

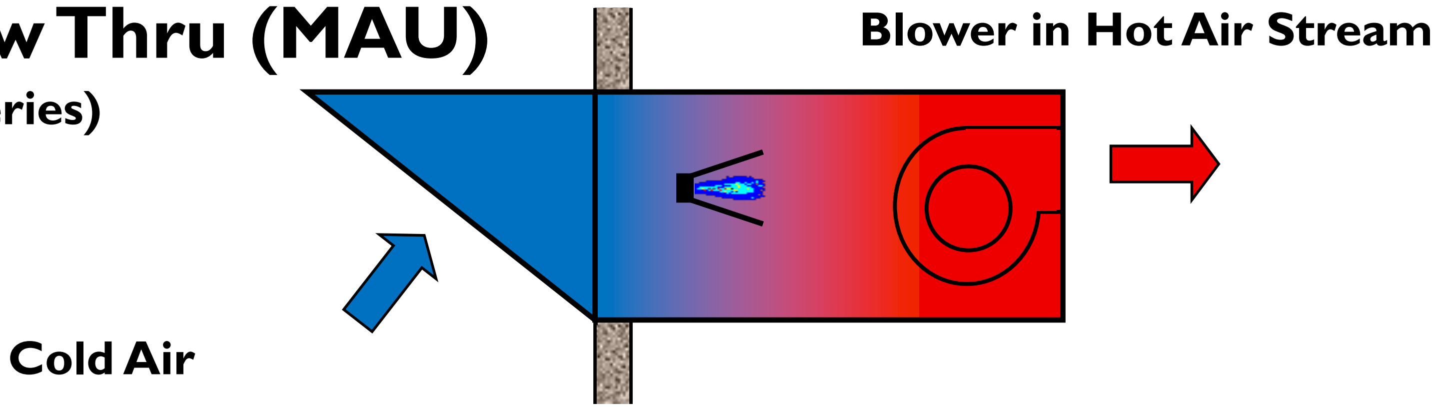


Outdoor Vertical Installation

# Efficiency & Design Impact

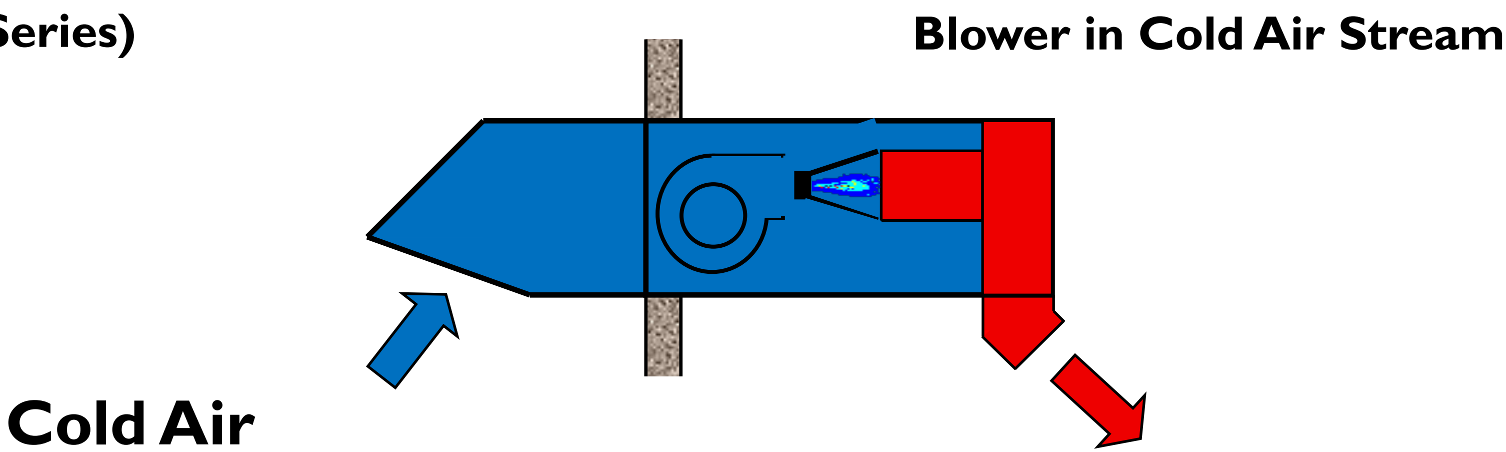
## Draw Thru (MAU)

(M-Series)




## Blow Thru® HTHV

(S-Series)



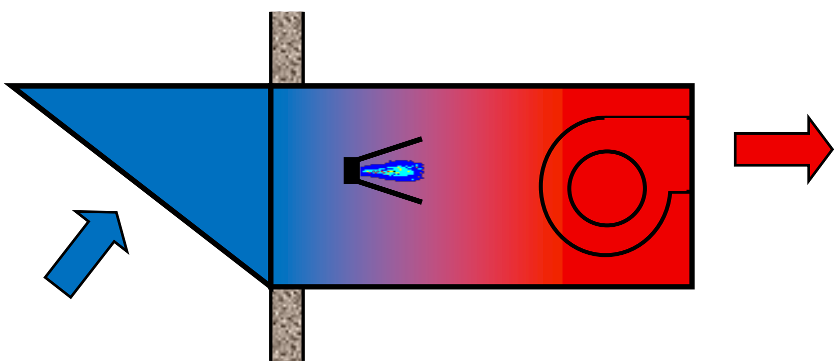
# What is the Difference?

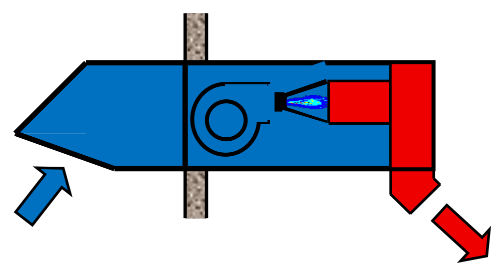
## Draw Thru (MAU)

- Constant Volume Fan
- Blower in Hot Air Stream (Less Dense)
- Lower Discharge Temperature (120°F)
- Lower mass flow rate

## Blow Thru® (HTHV)

- Constant Volume Fan
- Blower in Cold Air Stream (More Dense)
- Higher Discharge Temperature (160°F)
- Higher mass flow rate





# Convective Heat Transfer

100% direct fired outside air heating systems transfer sensible (dry-bulb) heat from the discharge air entering the building. The total input Btu/h can be expressed as

$$H_{tot} = q \times C_p \times \Delta T$$

$H_{tot}$ = *Total heat transferred (Btu/h)*

$q$ = *Mass flow of air (lb/h)*

$C_p$ = *Specific heat of air (.24 Btu/lb/°F)*

$\Delta T$ = *Discharge Temp - Outside Temp (°F - both at design)*

**Why can't we simply use** $H = CFM_{Fan} \times (1.08) \times (t_{dis} - t_{des})$

**1.08 is a Standard Correction Factor and is only valid at Standard Conditions (70F) or with Standard CFM not Fan CFM**

# Mass Flow Rate

$$H_{tot} = \boxed{q} \times C_p \times \Delta T$$

## Draw Thru (MAU)

- Constant Volume Fan
- Processing 120°F Air
- Density at Fan = .068 lbs/ft$^3$

## Blow Thru® (HTHV)

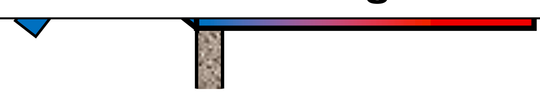
- Constant Volume Fan
- Processing 0°F Air
- Density at Fan = .086 lbs/ft$^3$

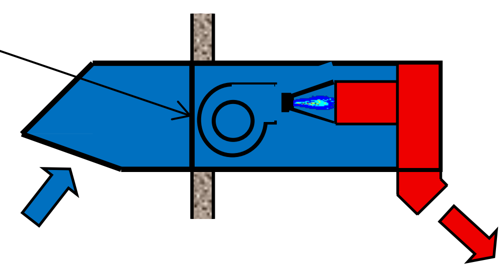
$$\frac{.086}{.068} = 126\%$$

- 26% More mass per fan CFM

**26% More btu/h transferred for every CFM processed by the constant volume fan simply due to density**

*** Based on 70°F Design at 0°F at Sea Level**





# Discharge Temp

$$H_{tot} = q \times C_p \times \boxed{\Delta T}$$

## Pull/Draw Thru

- Constant Volume Fan
- Lower Discharge Temperature (120°F)

$$\Delta T = 120 - 0 = 120$$

**33% More btu/h transferred for every CFM processed by the constant volume fan simply due to discharge temperature**

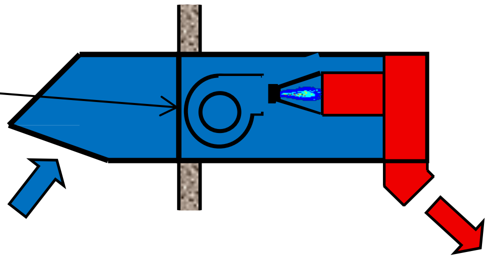
*** 70°F Space Temp/0F Design at Sea Level**

## Blow Thru®/Push Thru

- Constant Volume Fan
- Higher Discharge Temperature (160°F)

$$\Delta T = 160 - 0 = 160$$

$$\frac{160}{120} = 133\%$$



# Mass Flow + Discharge Temperature

$$H_{tot} = \boxed{q} \times C_p \times \boxed{\Delta T}$$

## Draw Thru (MAU)

- Constant Volume Fan
- Lower Mass Flow
- Lower Discharge Temperature (120°F)

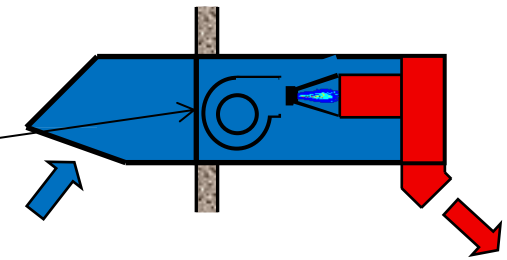
## Blow Thru® (HTHV)

- Constant Volume Fan
- Higher Mass Flow (26%)
- Higher Discharge Temperature (160°F - 33%)

$$H_{Blow\ Thru} = 1.26\ X\ 1.33 * H_{Draw\ Thru} = 1.68\ * H_{Draw\ Thru}$$

**68% More Btu/h Transferred for Every CFM Processed by the Constant Volume Fan**

*** 70°F Space Temp/0°F Design at Sea Level**



# Impact on Conduction Load

- Remember how we covered the conduction load?
- Turn up discharge of 100% OA direct fired system
  - 92%-100% AFUE
  - No flue losses
  - Every degree above space temperature is usable for conduction losses

**These are called net btus or usable btus**

# Discharge Temp

$$H_{tot} = q \times C_p \times \boxed{\Delta T}$$

## Draw Thru (MAU)

- Constant Volume Fan
- Lower Discharge Temperature (120°F)

$$\Delta T = 120 - 70 = 50$$

**80% more usable/net btu/h transferred for every CFM processed by the constant volume fan simply due to discharge temperature**

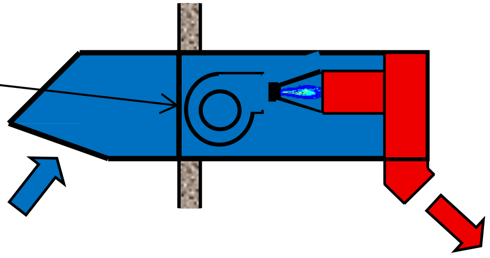
*** 70°F Space Temp/0°F Design at Sea Level**

## Blow Thru® (HTHV)

- Constant Volume Fan
- Higher Discharge Temperature (160°F)

$$\Delta T = 160 - 70 = 90$$

$$\frac{90}{50} = 180\%$$



# Usable BTU Impact Mass Flow + Discharge Temperature

$$H_{tot} = \boxed{q} \times C_p \times \boxed{\Delta T}$$

## Draw Thru (MAU)

- Constant Volume Fan
- Lower Mass Flow
- Lower Discharge Temperature (120°F)

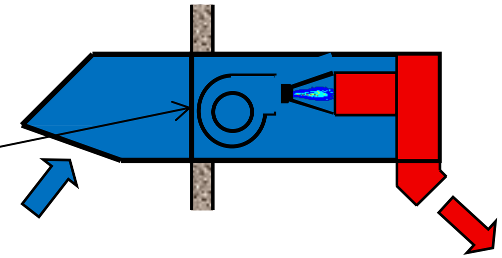
## Blow Thru® (HTHV)

- Constant Volume Fan
- Higher Mass Flow (26%)
- Higher Discharge Temperature (160°F - 80%)

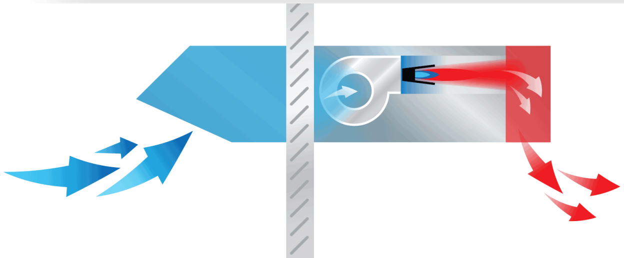
$$H_{(Net)\,Blow\,Thru} = 1.26\,X\,1.8 * H_{(Net)\,Draw\,Thru} = 2.27 * H_{(Net)\,Draw\,Thru}$$

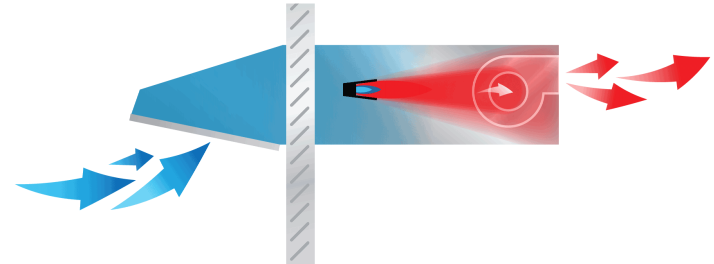
**127% More Net Btu/h Transferred for Every CFM Processed by the Constant Volume Fan**

*** 70°F Space Temp/0°F Design at Sea Level**



# TruBTU





| | | |
|---|---|---|
| BLOWER AIRFLOW | 10000 CFM | |
| INLET AIRFLOW | 10000 CFM @ 0 °F | |
| DISCHARGE AIRFLOW | 13478 CFM @ 160 °F | |
| NET AIRFLOW | 11522 CFM @ 70 °F | |
| | MAX | ACTUAL |
| DISCHARGE TEMP | 160 °F | 160 °F |
| TEMP RISE | 160 °F | 160 °F |
| INPUT CAPACITY | 2160 MBH | |
| X | 92% EFFICIENCY | |
| OUTPUT CAPACITY | 1987 MBH | |
| - | 869 MBH TO HEAT 10000 CFM TO 70 °F | |
| USABLE BTU** | 1118 MBH | |

| | | |
|---|---|---|
| BLOWER AIRFLOW | 10000 CFM | |
| | 7931 CFM @ 0 °F | |
| DISCHARGE AIRFLOW | 10000 CFM @ 120 °F | |
| NET AIRFLOW | 9138 CFM @ 70 °F | |
| | MAX | ACTUAL |
| DISCHARGE TEMP | 120 °F | 120 °F |
| TEMP RISE | 120 °F | 120 °F |
| INPUT CAPACITY | 1285 MBH | |
| X | 92% EFFICIENCY | |
| OUTPUT CAPACITY | 1182 MBH | |
| - | 689 MBH TO HEAT 10000 CFM TO 70 °F | |
| USABLE BTU** | 493 MBH | |

**Same Blower Airflow – 10,000 CFM**

**160°F vs. 120°F Discharge**

**68% More Output Btu**

**127% More Usable/Net Btu**

# Proven Performance

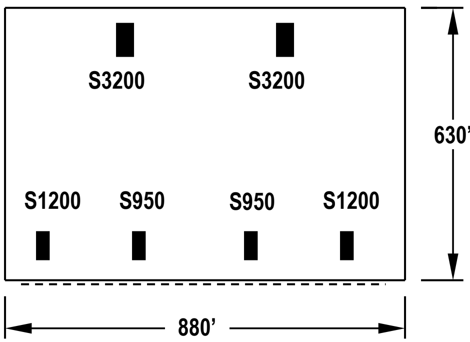
## 400+ Energy Building Studies (with Utility Bills)

| Other Industrial Heating Systems | Energy Savings with Blow Thru® Space Heaters* | Comparison Building Studies (click on links below) |
|---|---|---|
| **Indirect Gas Fired Systems** | | |
| Boilers | 40% to 70% | Cambridge vs. Boiler |
| Unit Heaters | 30% to 50% | Cambridge vs. Unit Heater |
| Air Turnover Systems | 25% to 70% | Cambridge vs. Air Turnover |
| Infrared (Radiant) | 15% to 40%** | Cambridge vs. Infrared |
| **Direct Gas-Fired Systems** | | |
| Make-Up Air (MUA) | 20% to 50% | Cambridge vs. Make-Up Air |
| Recirculation (pressurization) | 20% to 50% | Cambridge vs. Recirculation |

# Retrofit Case Study

HTHV Space Heaters vs.
Unit Heaters

## Food Distribution Warehouse


**Building Specifications**

- 540,700 $ft^2$
- Located in Cleveland, OH
- 61 Dock Doors

## *Before* – Unit Heaters

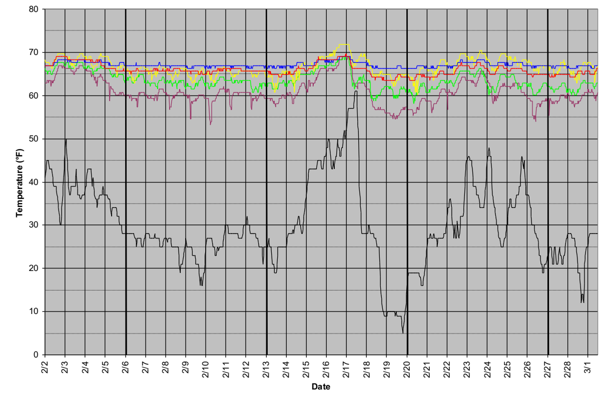
**Performance**

- Uneven temperatures
- Cold dock areas
- High gas costs
- Poor Indoor Air Quality

**Operating Costs**

Based on:
196,918 therms for 2006 -07 heating season
Normalized to 30 year averages

**$0.36/$ft^2$ Total cost**




## *After* – HTHV Space Heaters

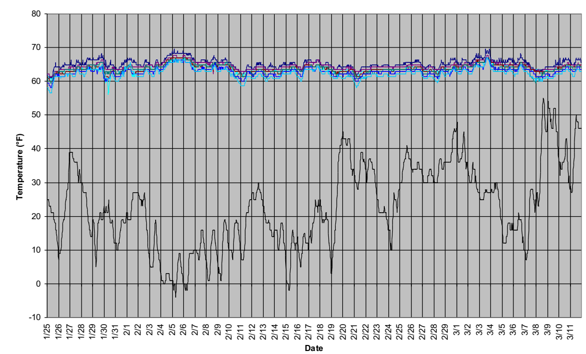
**Performance**

- More even temperatures
- Better Indoor Air Quality
- Lower Energy Cost

**Operating Costs**

Based on:
136,042 therms for 2007-08 heating season
Normalized to 30 year averages

**$0.25$ft^2$ Total cost**




### Summary

The HTHV system saved **31% in gas** while providing better overall temperatures in the building.

The HTHV system saved approximately **$59,500/year** operating at $0.25/$ft^2$ vs. $0.36/$ft^2$.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# Retrofit Case Study

HTHV Space Heaters vs.
Hot Water Boiler

### Heavy Equipment Warehouse

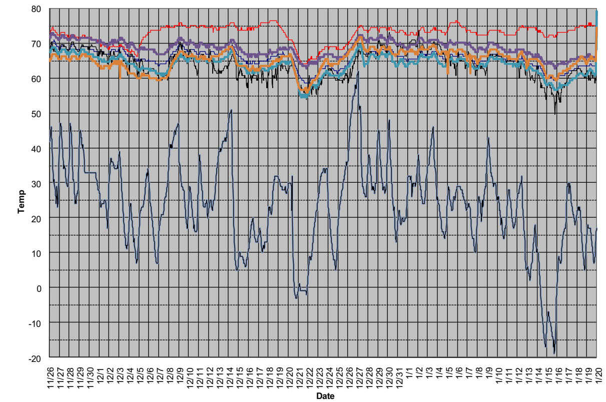
**Building Specifications**
- (8) 134,375 ft² buildings
- 1,075,000 ft² total
- 24' high
- Concrete walls
- Concrete roof w/ 1½" insulation
- Located in Delavan, IL

## *Before* – Hot Water Boiler/Unit Heaters

**Performance**
- Uneven  temperatures
- Cold draft areas
- High maintenance cost
- High gas and electric bills

**Operating Costs**
**Based on:**
589,793 therms/1,640,667 kWh for 2008
Normalized to 30 year averages

**$0.55/ft² Gas cost** @ $1.00/therm
**$0.14/ft² Electrical cost** @ $0.09/kWh

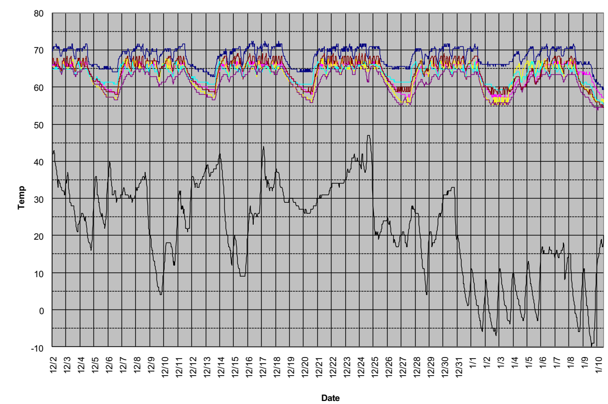



## *After* – HTHV Space Heaters

**Performance**
- More even temperatures
- Reduced maintenance costs
- Red uced gas and electric bills

**Operating Costs**
**Based on:**
406,256 therms/267,216 kWh for 2010
Normalized to 30 year averages

**$0.38/ft² Gas cost** @ $1.00/therm
**$0.02/ft² Electrical cost** @ $0.09/kWh




### Summary

The HTHV system used **42% less** total energy.

The HTHV system saved approximately **$312,000/year** operating at $0.40/ft² vs $0.69/ft².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# Comparative Case Study

HTHV Space Heaters vs.
Draw Thru Make-up Air

## HTHV Space Heaters

**Operating Costs**
Based on 5,215 Heating Degree Days @ 65°

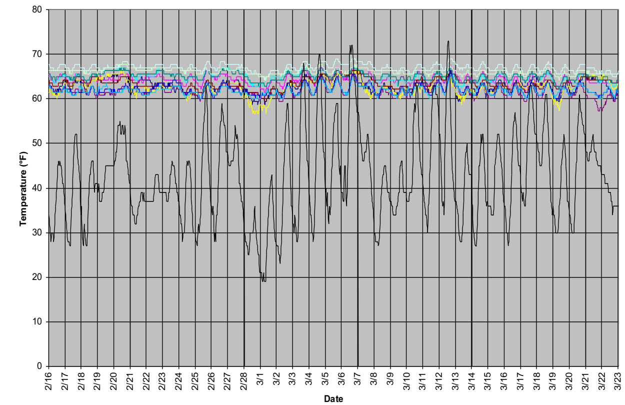
$0.14/ft² Gas cost @ $1.00/therm
$0.01/ft² Electric cost @ $0.08/kWh

**Building Specifications**
- 1,291,950 ft² x 36' high
- R-19 Roof / R-10 Walls
- Located in Topeka, KS

**Heating System**
- (15) HTHV Space Heaters
- Roof top mounting
- 27,806 MBH total
- 132,340 CFM total
- 95 HP total

**$0.15/ft² Total cost**

**Performance**




**11° indoor temperature variation**

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## Draw Thru Make-up Air Heaters

**Operating Costs**
Based on 5,545 Heating Degree Days @ 65°

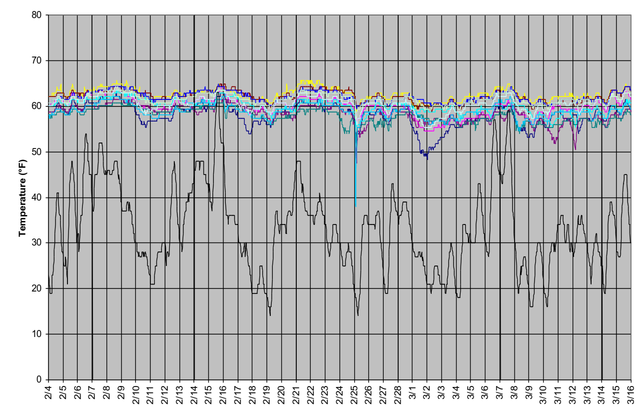
$0.27/ft² Gas cost @ $1.00/therm
$0.02/ft² Electric cost @ $0.08/kWh

**Building Specifications**
- 1,291,950 ft² x 36' high
- R-19 Roof / R-10 Walls
- Located in Columbus, OH

**Heating Systems**
- (15) Draw Thru Make-up Air Heaters
- Roof top mounting
- 30,315 MBH total
- 210,000 CFM total
- 150 HP total

**$0.29/ft² Total cost**

**Performance**




**28° indoor temperature variation**

## Summary

The HTHV system used **47% less** total energy.

If the Ohio facility had installed a HTHV system they could have saved approximately **$177,000/year** operating at $0.15/ft² vs. $0.29/ft².

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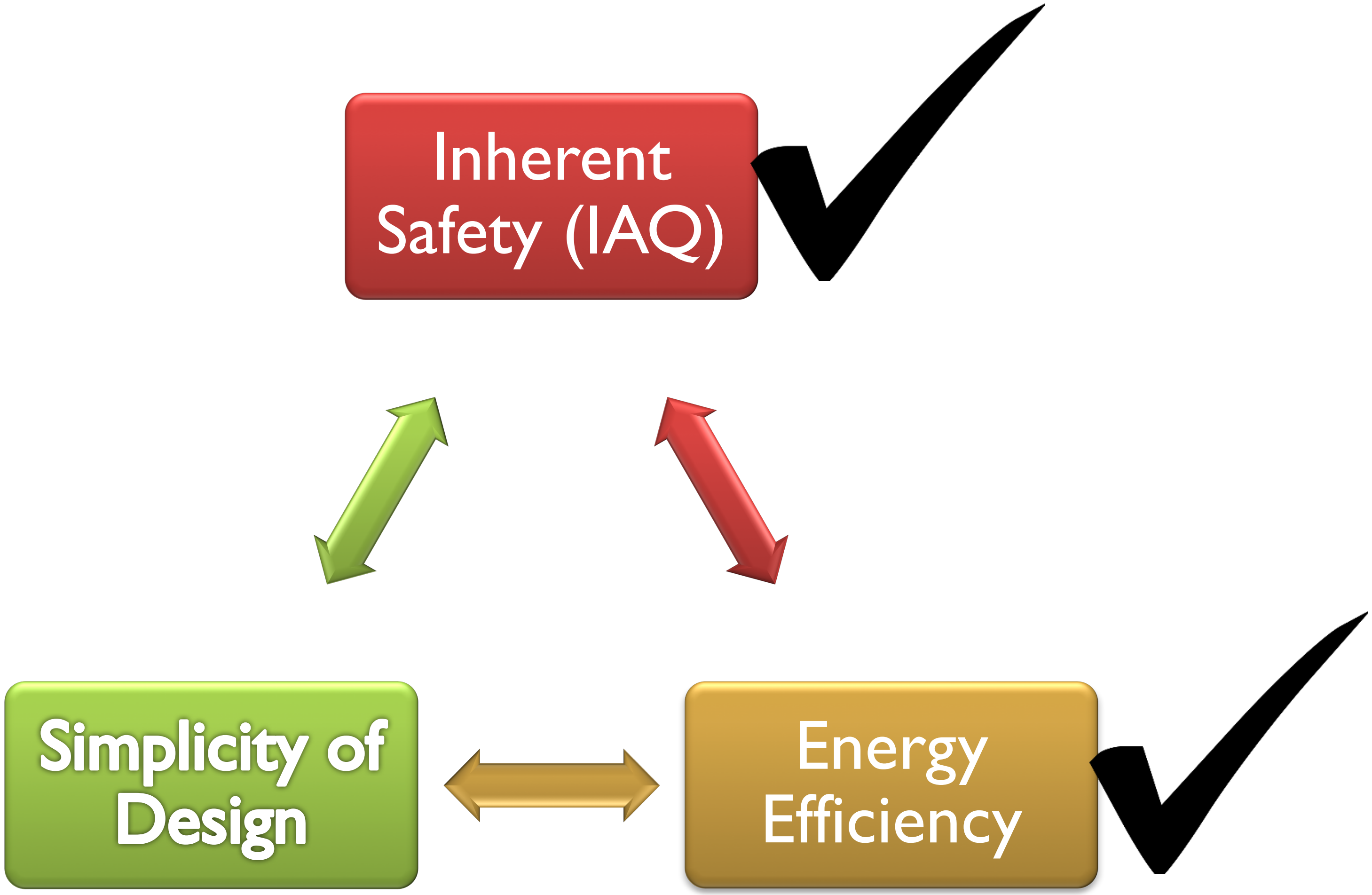
# 3rd Party Energy Modeling (EnergyPlus)

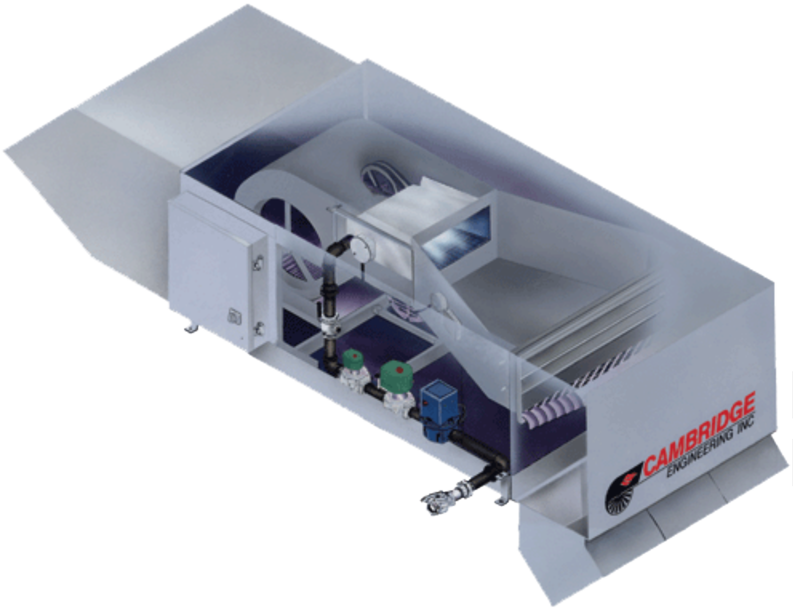
| Energy Consumption | Gas (therms) | Fan Electric (kWh) |
|---|---|---|
| ASHRAE 90.1 Baseline | 32,563 | 78,594 |
| Blow-Thru (HTHV) | 20,220 | 5,758 |
| Draw-Thru (LTLV) | 27,506 | 7,589 |
| Recirculation | 27,805 | 52,644 |
| Unit Heater | 32,833 | 16,875 |
| Air Turnover | 26,822 | 17,153 |
| Infrared | 32,156 | 11,164 |
| **% Savings vs. 90.1 Baseline** | | |
| Blow-Thru (HTHV) | 37.9% | 92.7% |
| Draw-Thru (LTLV) | 15.5% | 90.3% |
| Recirculation | 14.6% | 33.0% |
| Unit Heater | -0.8% | 78.5% |
| Air Turnover | 17.6% | 78.2% |
| Infrared | 1.2% | 85.8% |

**38% Gas Savings and 93% Electrical Savings over AHRAE 90.1 Energy Standard**

# Review:  Key HTHV Education Statements



# Massive Value for the Money




1 X 1600 MBH (HTHV)

=


6 x High Efficiency Unit Heaters

+

High Volume Low Speed (HVLS) Fans

+


Heated Dedicated Outdoor Air Systems (DOAS)

# Simplicity of Design

- HTHV
  - Single Piece of Equipment
  - Single Electrical Connection
  - Single Wall Penetration
  - Zero Roof Penetrations
- UH's + HVLS + DOAS
  - Multiple Pieces of Equipment
  - Multiple Electrical Connections
  - Multiple Flue Vents
  - One Roof Curb
  - Multiple Roof Penetrations

***IMPROVES THE INTEGRITY OF THE BUILDING ENVELOPE***

# Key Take-Aways

- Widespread use of 100% Outside Air, Direct Fired MAU
  - HTHV  Applications (Heating & Ventilating)
  - LTLV (Ventilating & Heating)
- Inherently Safe Design –
  - Ventilation is the Key
  - Ventilation air & combustion air delivered by the same device
  - Safety Codes
- Energy Efficiency Explained (Thermodynamics Lesson)
  - Cambridge Building Studies (40-70% Energy Savings)
  - Gard Analytics Report (Energy Modeling HTHV)
  - DOE Study – HTHV vs. Indirect Fired Unit Heaters
- Lowest Total Installed Cost
  - Simplicity of Design
  - More Systems/Less Equipment
  - Less Time & Materials
  - Readiness at Install

# Suggested Next Steps

1. Site Visit - Join your Cambridge Engineering, Inc. representative at a local installation
2. Collaborate on a <u>future project</u> for Cambridge design recommendations
3. Review a <u>past project</u> for Cambridge design comparison value
4. **Thrill** your customers

# Questions