# CO2-based Demand Controlled Ventilation (DCV)

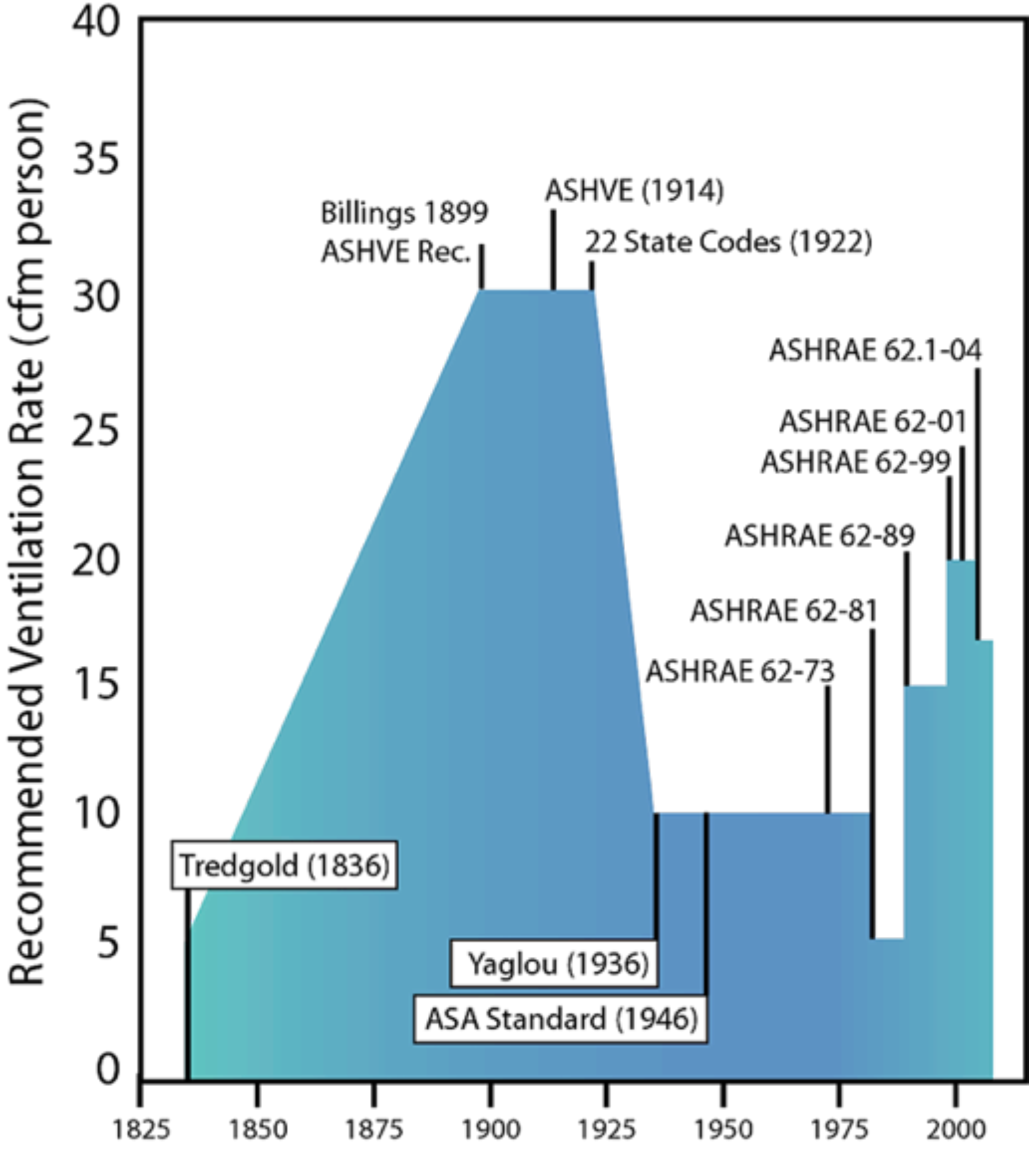
# Ventilation Control

How is ventilation provided in buildings today?

**The same way it was in 1930.**

**With Fixed Ventilation!**

# Minimum Ventilation Rates

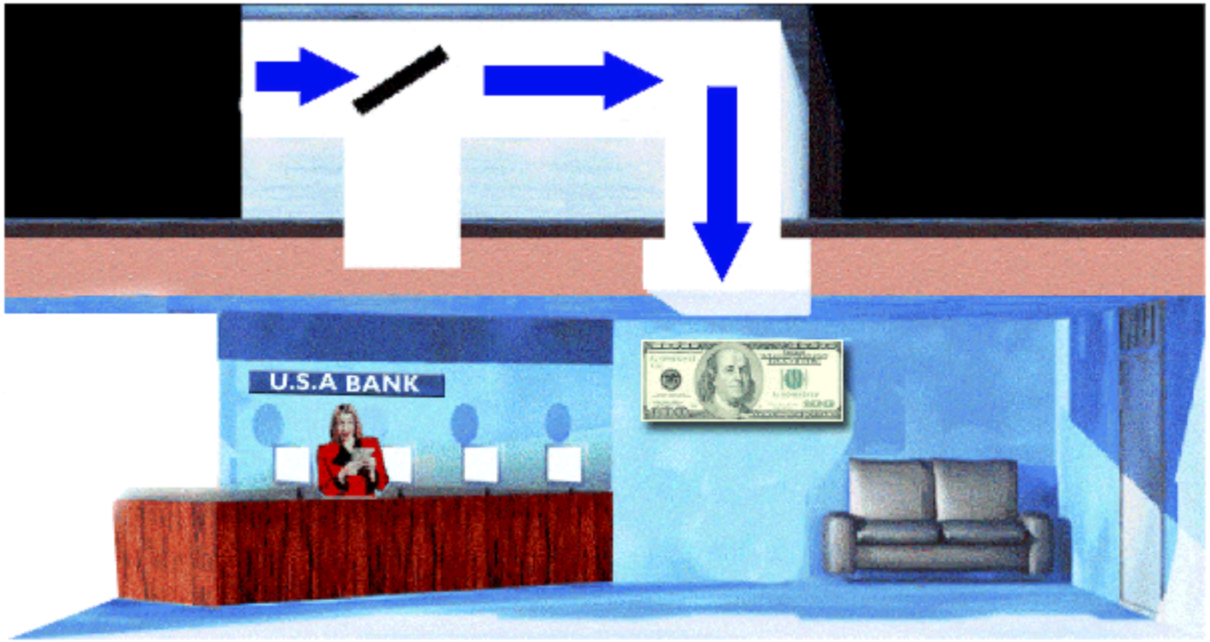


# Fixed Ventilation

Building codes require ventilation rates based on cfm/person: (typically 20 cfm/person)

***Max Occupancy: 25 people = 500 cfm***

***Actual Occupancy: 5 people = 500 cfm***



***Inefficient!***

# Controlling Ventilation

**There is a clearly defined relationship between indoor $CO_2$ levels & ventilation rates established by:**

ASHRAE 62.1 & 90.1

ASTM $CO_2$ &Ventilation Standard

**Indoor $CO_2$ levels are a measure of ventilation rates (cfm/person)**

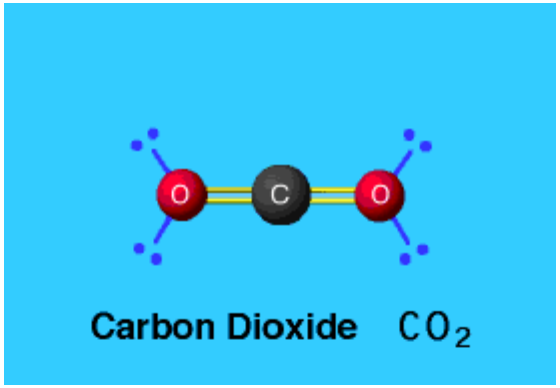
**$CO_2$ levels are not a measure of overall IAQ.**

**$CO_2$ is the control parameter for ventilation!**

# Indoor Air Quality

| | FIRST ALARM (TWA) | SECOND ALARM (STEL) | SENSOR LOCATION | RADIUS OF DETECTION |
|---|---|---|---|---|
| **Temperature & Humidity** | N/A | N/A | N/A | N/A |
| **Carbon Dioxide ($CO_2$)** | 800-1200 ppm | 5000 ppm | 5 ft. above floor | 20 ft. |
| **Oxygen ($O_2$)** | 19.5%<br>($O_2$ depletion) | 22%<br>($O_2$ saturation) | | |

# $CO_2$ Basics



- $CO_2$ is NOT a contaminant, it is a colorless, odorless gas found naturally in the atmosphere
  - Outdoor levels are fairly constant at 400 +/- 25 ppm
  - Typical indoor levels 400 to 2,500 ppm
  - Not harmful unless concentrations reach 30,000 ppm
- Carbon Monoxide (CO) and Carbon Dioxide are NOT the Same

# $CO_2$ Basics

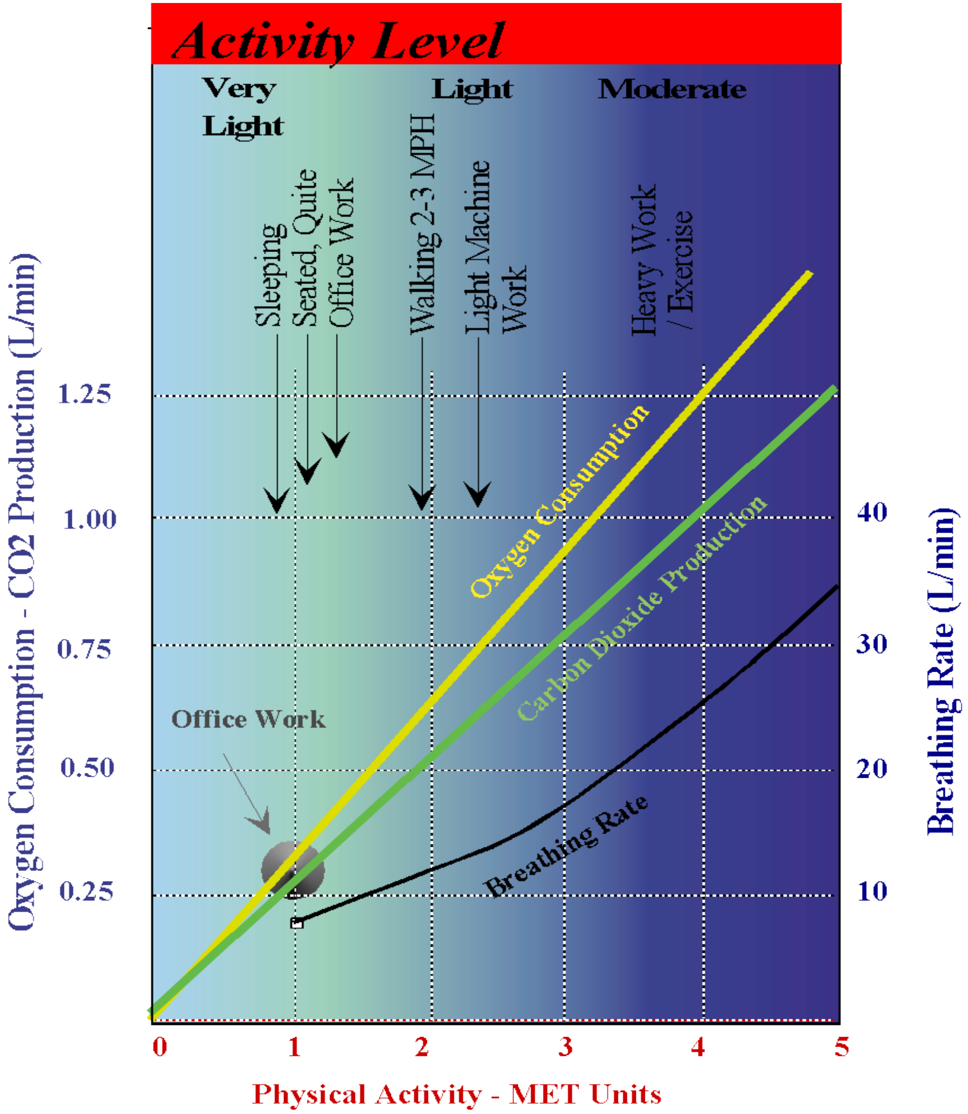
People exhale $CO_2$ at concentrations of 4% (40,000 ppm)

Normal room concentrations are in the range of 400 - 1200 ppm

As a gas, $CO_2$ diffuses and equalizes rapidly throughout a room (like humidity)

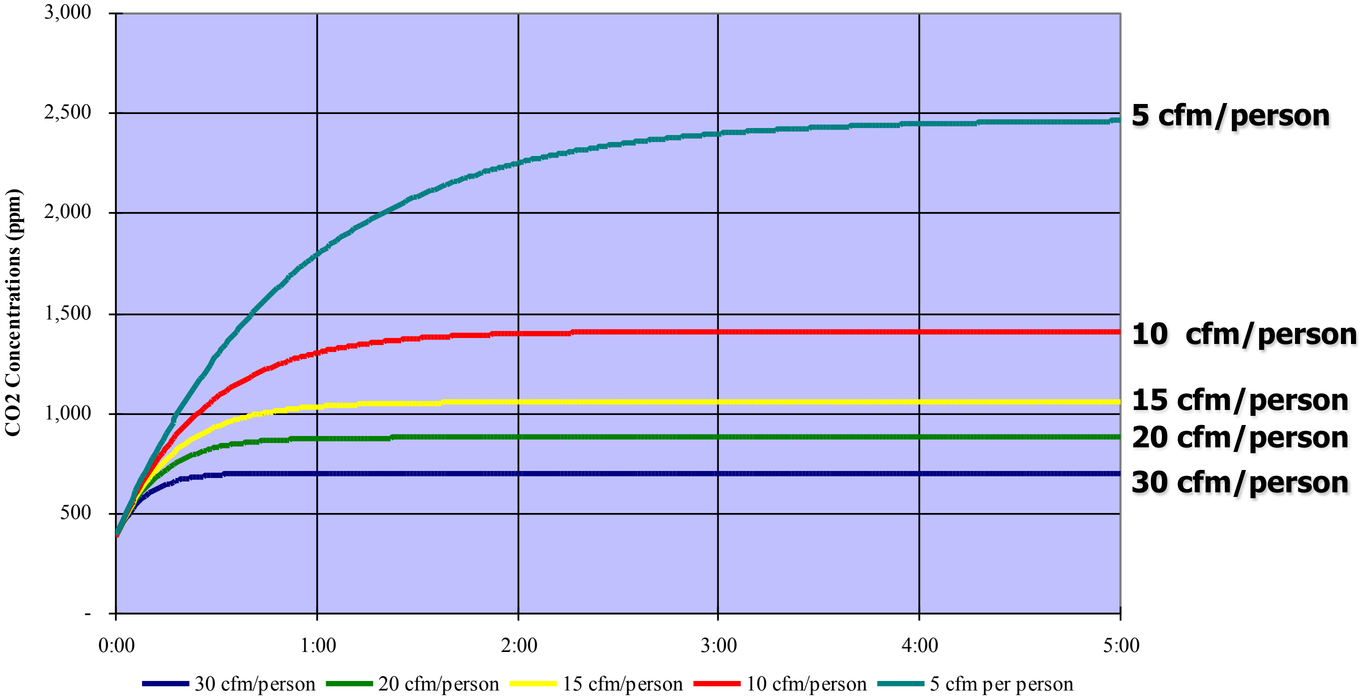
# $CO_2$ and Ventilation Rates

- $CO_2$ production by people is very predictable based on activity level
- Doubling the people in a room will double $CO_2$ production



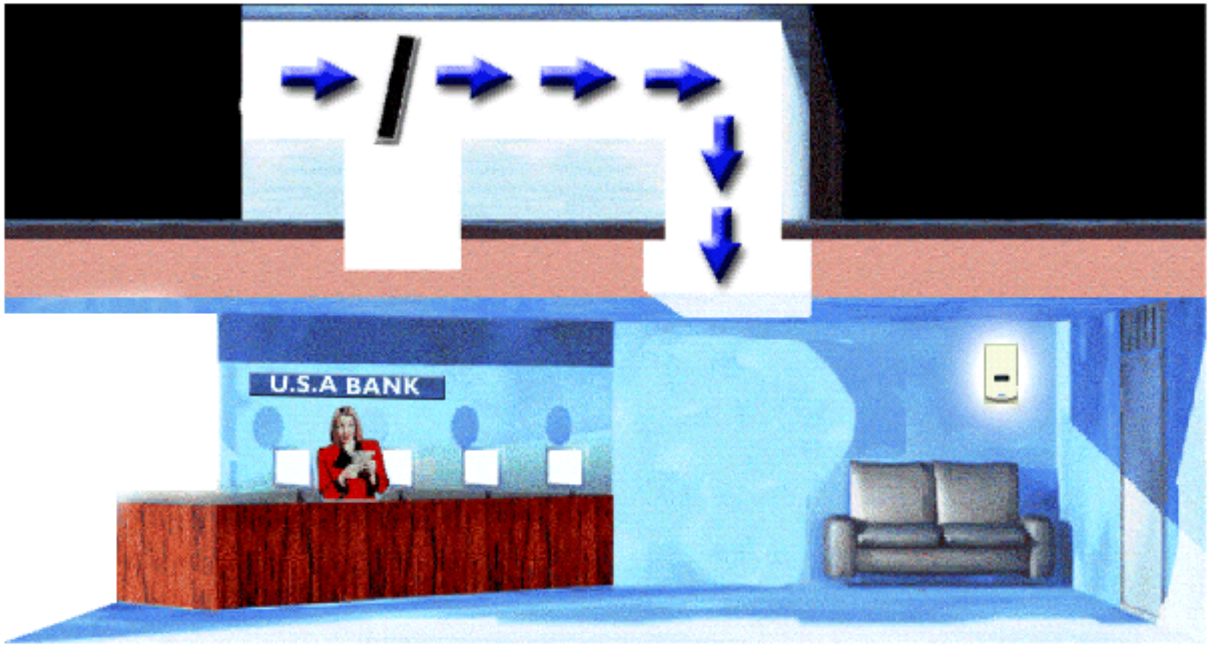
# $CO_2$ and Ventilation Rates

**CO2 levels will build until an equilibrium level is reached with outside air entering the space**



# Ventilation Control

***Actual Occupancy 15 people = 200 cfm***



**Ventilation based on actual occupancy!**

# Research & Studies

Numerous Studies Confirm that Correct Ventilation:

- Increases Productivity
- Improves Occupant/Customer Satisfaction
- Helps Prevent Sick Building Syndrome Health Affects

**DOE/Lawrence Berkeley Labs**
**Indoor Environment In Schools**

**Pupils' Health & Performance In Regard To $CO_2$ Concentrations**

**A significant correlation was found between decreased performance and high $CO_2$ levels (lower ventilation rates).**

# Research & Studies

Numerous Studies Confirm that Correct Ventilation:

- Increases Productivity
- Improves Occupant/Customer Satisfaction
- Helps Prevent Sick Building Syndrome Health Affects

**"Air Quality and Ventilation"**
**ranked very high (#2 of 25) on the list**
**of tenant retention issues**
**in a recent survey conducted by**
**Real Estate Information Systems.**

# Research & Studies

Numerous Studies Confirm that Correct Ventilation:

- Increases Productivity
- Improves Occupant/Customer Satisfaction
- Helps Prevent Sick Building Syndrome Health Affects

**DOE/Lawrence Berkeley Labs Evaluation of**
**Sick Leave Statistics vs. Ventilation Rates**
**(3720 employees / 40 buildings):**

**Optimal ventilation reduces sick time costs.**
**For every $1 spent on ventilation cost,**

**$2 are saved in sick time.**

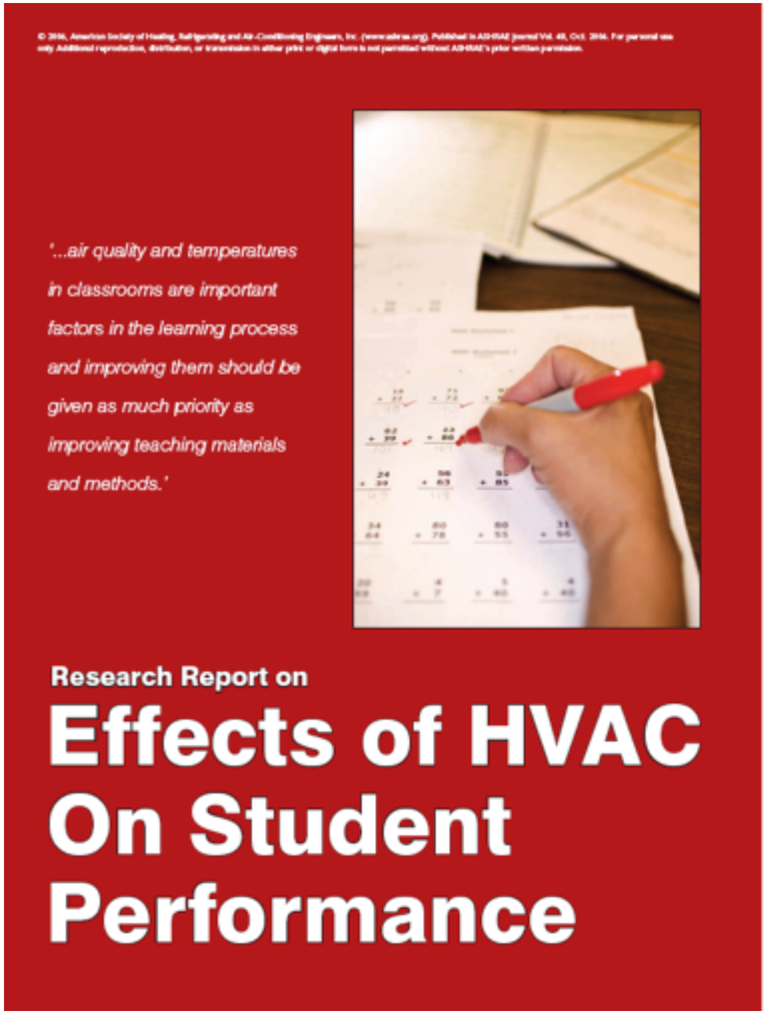
# Research & Studies

## *Status of American Schools*

- 60 million Americans go to school (staff & student)
- 14 million students in schools “considered below standard or dangerous”
- 15,000 Schools have indoor air quality that is “unfit to breathe”
- Students and faculty typically spend 85-90% of their time indoors (mostly at home and school)
- Concentration of pollutants indoors is typically higher than outdoors, sometimes by as much as 10 or even 100 times

Source: *A Report for the Massachusetts Technology Collaborative - November 2005*

# Research & Studies



*'...air quality and temperatures in classrooms are important factors in the learning process and improving them should be given as much priority as improving teaching materials and methods.'*

**Research Report on**

**Effects of HVAC On Student Performance**

**ASHRAE Journal, October 2006**

**School Study**

- Measured performance vs. temperature and outdoor air intake variations
- Temperature and ventilation were varied independently to gather data

**Outcome**

- Increasing OA intake and decreasing temperature both improved speed
- Increasing OA intake and decreasing temperature did not improve error rate

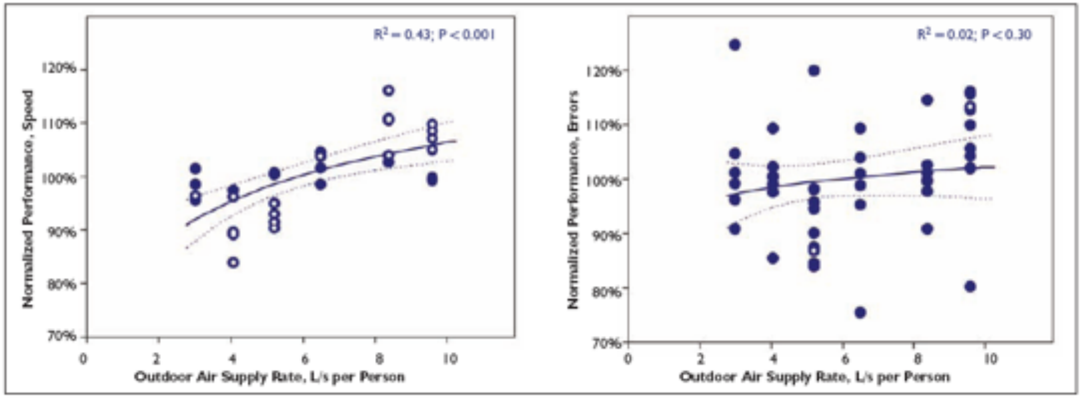


*Figure 3: Performance of schoolwork as a function of outdoor air supply rate. Performance is expressed in terms of the speed at which tasks were performed (left) and the percentage of errors committed (right). Dots show performance of individual tasks (open dots indicate those tasks in which performance differed significantly between conditions), while lines show the regression (solid line) with 95% confidence bands (dashed line).*

# Now Allowed by Most Mechanical Codes

Benefits of Ventilation Control

- ***Proof of Compliance***

ANSI/ASHRAE 62-1989

ASHRAE STANDARD

AN AMERICAN NATIONAL STANDARD

Ventilation
for Acceptable
Indoor Air Quality

AMERICAN SOCIETY OF HEATING,
REFRIGERATING AND
AIR-CONDITIONING ENGINEERS, INC.

**ASHRAE Standard 62.1**

↓

**International Mechanical Code (IMC)**

↓

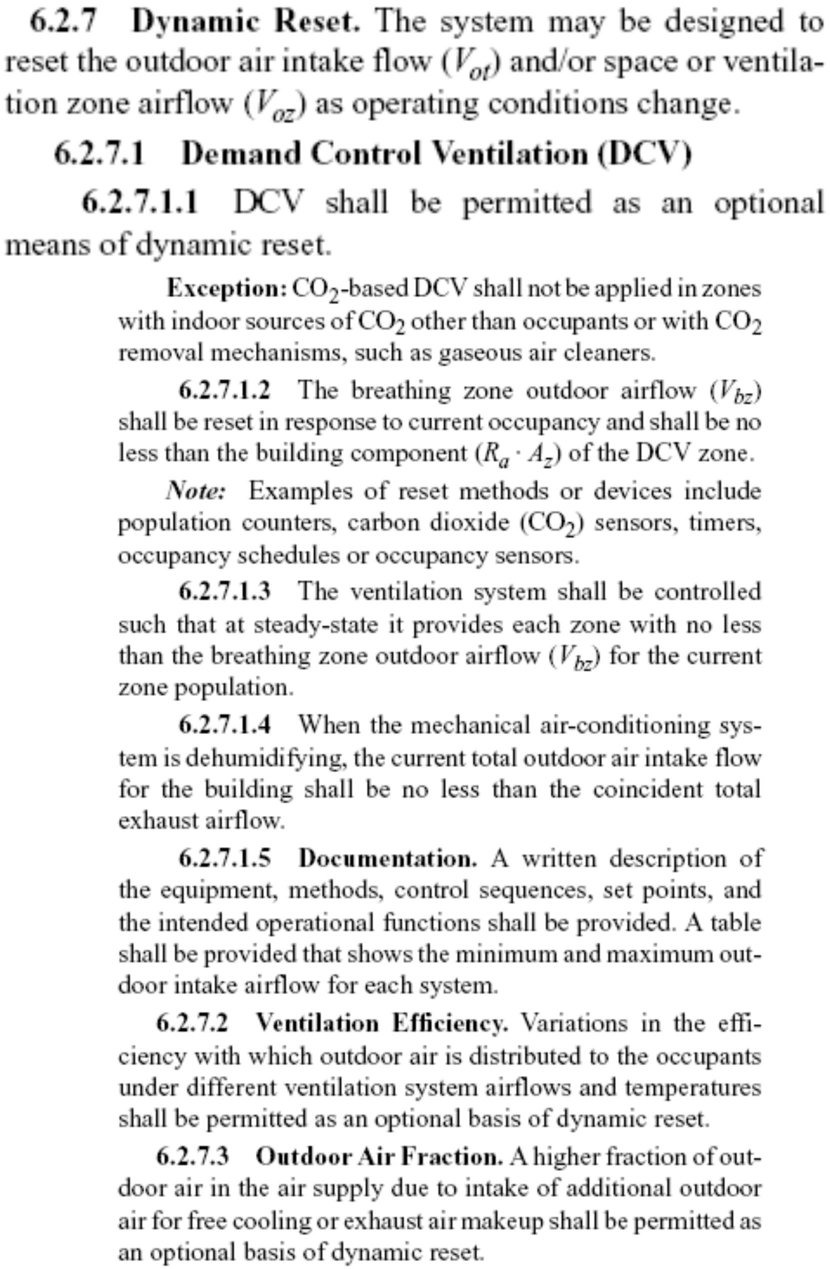
**Local Codes**

Using $CO_2$-based ventilation control ensures compliance to codes and standards

# Now Allowed by Most Mechanical Codes

ASHRAE
62.1-2010

Written into the actual standard since ASHRAE 62-2004



**6.2.7 Dynamic Reset.** The system may be designed to reset the outdoor air intake flow ($V_{ot}$) and/or space or ventilation zone airflow ($V_{oz}$) as operating conditions change.

**6.2.7.1 Demand Control Ventilation (DCV)**

**6.2.7.1.1** DCV shall be permitted as an optional means of dynamic reset.

**Exception:** $CO_2$-based DCV shall not be applied in zones with indoor sources of $CO_2$ other than occupants or with $CO_2$ removal mechanisms, such as gaseous air cleaners.

**6.2.7.1.2** The breathing zone outdoor airflow ($V_{bz}$) shall be reset in response to current occupancy and shall be no less than the building component ($R_a \cdot A_z$) of the DCV zone.

***Note:*** Examples of reset methods or devices include population counters, carbon dioxide ($CO_2$) sensors, timers, occupancy schedules or occupancy sensors.

**6.2.7.1.3** The ventilation system shall be controlled such that at steady-state it provides each zone with no less than the breathing zone outdoor airflow ($V_{bz}$) for the current zone population.

**6.2.7.1.4** When the mechanical air-conditioning system is dehumidifying, the current total outdoor air intake flow for the building shall be no less than the coincident total exhaust airflow.

**6.2.7.1.5 Documentation.** A written description of the equipment, methods, control sequences, set points, and the intended operational functions shall be provided. A table shall be provided that shows the minimum and maximum outdoor intake airflow for each system.

**6.2.7.2 Ventilation Efficiency.** Variations in the efficiency with which outdoor air is distributed to the occupants under different ventilation system airflows and temperatures shall be permitted as an optional basis of dynamic reset.

**6.2.7.3 Outdoor Air Fraction.** A higher fraction of outdoor air in the air supply due to intake of additional outdoor air for free cooling or exhaust air makeup shall be permitted as an optional basis of dynamic reset.

# Now Allowed by Most Mechanical Codes

## Commentary To The International Mechanical Code (IMC) Section 403.3.1

“*The intent of this section is to allow the rate of ventilation to modulate in proportion to the number of occupants. This can result in significant energy savings. Current technology can permit the design of ventilation systems that are capable of detecting the occupant load of the space and automatically adjusting the ventilation rate accordingly.*

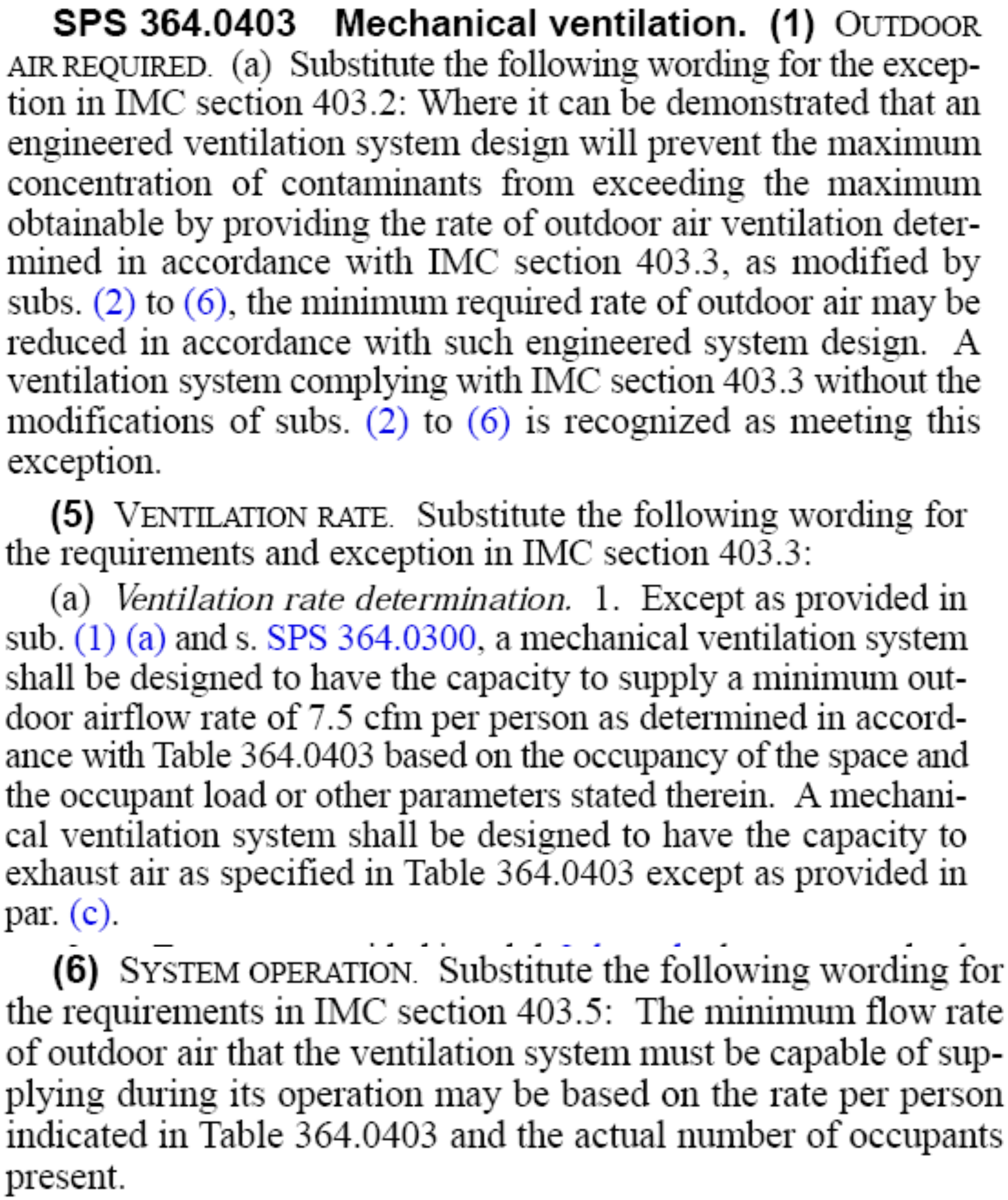
*For example, carbon dioxide ($CO_2$) detectors can be used to sense the level of $CO_2$ concentrations which are indicative of the number of occupants. People emit predictable quantities of $CO_2$ for any given activity, and this knowledge can be used to estimate the occupant load in a space.*”

Was written into the actual code for IMC 2006

# Wisconsin Ventilation Code 2011

Based on
IMC 2009

With about 10 pages of amendments



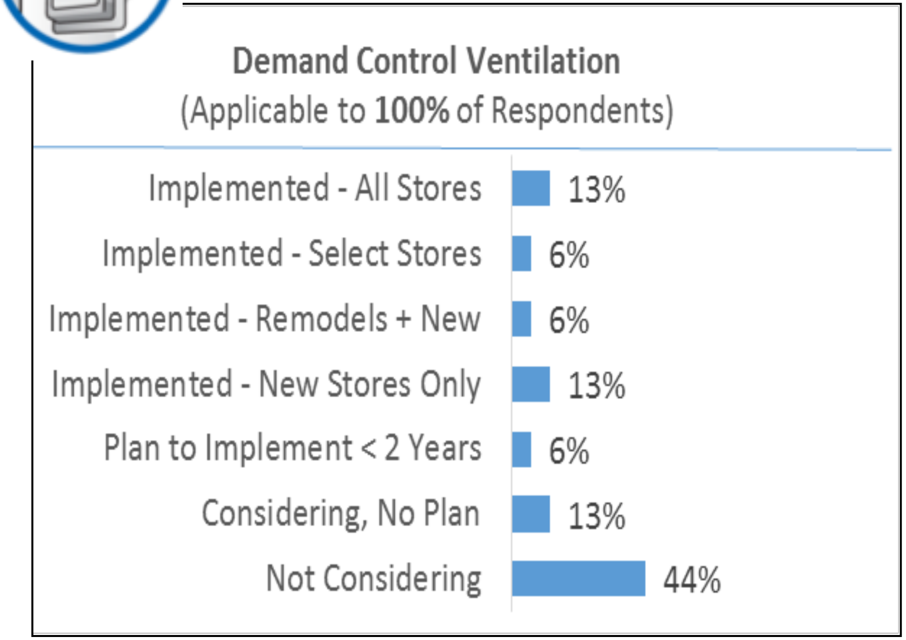
**SPS 364.0403 Mechanical ventilation. (1)** OUTDOOR AIR REQUIRED. (a) Substitute the following wording for the exception in IMC section 403.2: Where it can be demonstrated that an engineered ventilation system design will prevent the maximum concentration of contaminants from exceeding the maximum obtainable by providing the rate of outdoor air ventilation determined in accordance with IMC section 403.3, as modified by subs. (2) to (6), the minimum required rate of outdoor air may be reduced in accordance with such engineered system design. A ventilation system complying with IMC section 403.3 without the modifications of subs. (2) to (6) is recognized as meeting this exception.

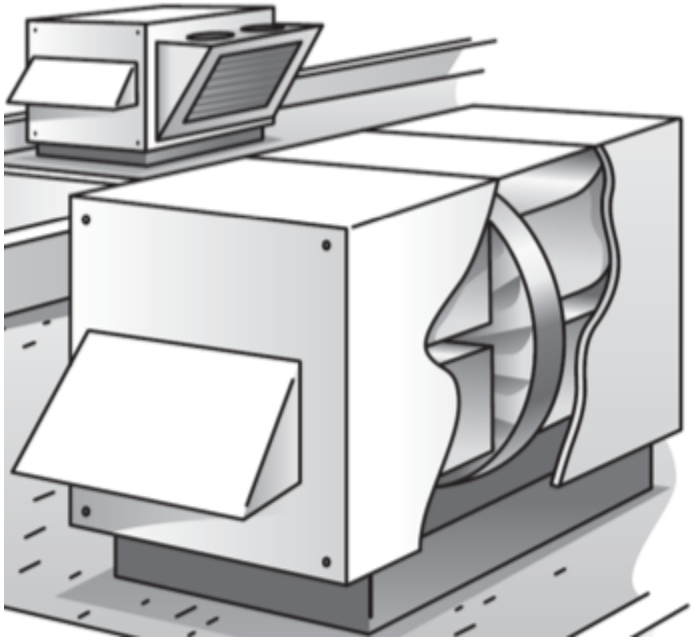
**(5)** VENTILATION RATE. Substitute the following wording for the requirements and exception in IMC section 403.3:

(a) *Ventilation rate determination.* 1. Except as provided in sub. (1) (a) and s. SPS 364.0300, a mechanical ventilation system shall be designed to have the capacity to supply a minimum outdoor airflow rate of 7.5 cfm per person as determined in accordance with Table 364.0403 based on the occupancy of the space and the occupant load or other parameters stated therein. A mechanical ventilation system shall be designed to have the capacity to exhaust air as specified in Table 364.0403 except as provided in par. (c).

**(6)** SYSTEM OPERATION. Substitute the following wording for the requirements in IMC section 403.5: The minimum flow rate of outdoor air that the ventilation system must be capable of supplying during its operation may be based on the rate per person indicated in Table 364.0403 and the actual number of occupants present.

# Wisconsin Implementation Trends – Demand Control Ventilation (DCV)


Demand Control Ventilation
(Applicable to **100%** of Respondents)



# Chicago Ventilation Code since 2003

**18-28-403.1.2 Demand ventilation.** The amount of outside air delivered by a mechanical supply system may be reduced during operation below the quantities listed in able 18-28-403.3 if the system is capable of measuring and maintaining CO2 levels in occupied spaces no greater than 1000 ppm. The system capacity shall be greater than or equal to the ordinance requirements.

# Now Required by Most Energy Codes

Benefits of Ventilation Control

- ***Proof of Compliance***

ANSI/ASHRAE 62-1989

**ASHRAE STANDARD**

AN AMERICAN NATIONAL STANDARD

**Ventilation for Acceptable Indoor Air Quality**

**AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.**

**ASHRAE Standard 90.1**

↓

**International Energy Conservation Code (IECC)**

↓

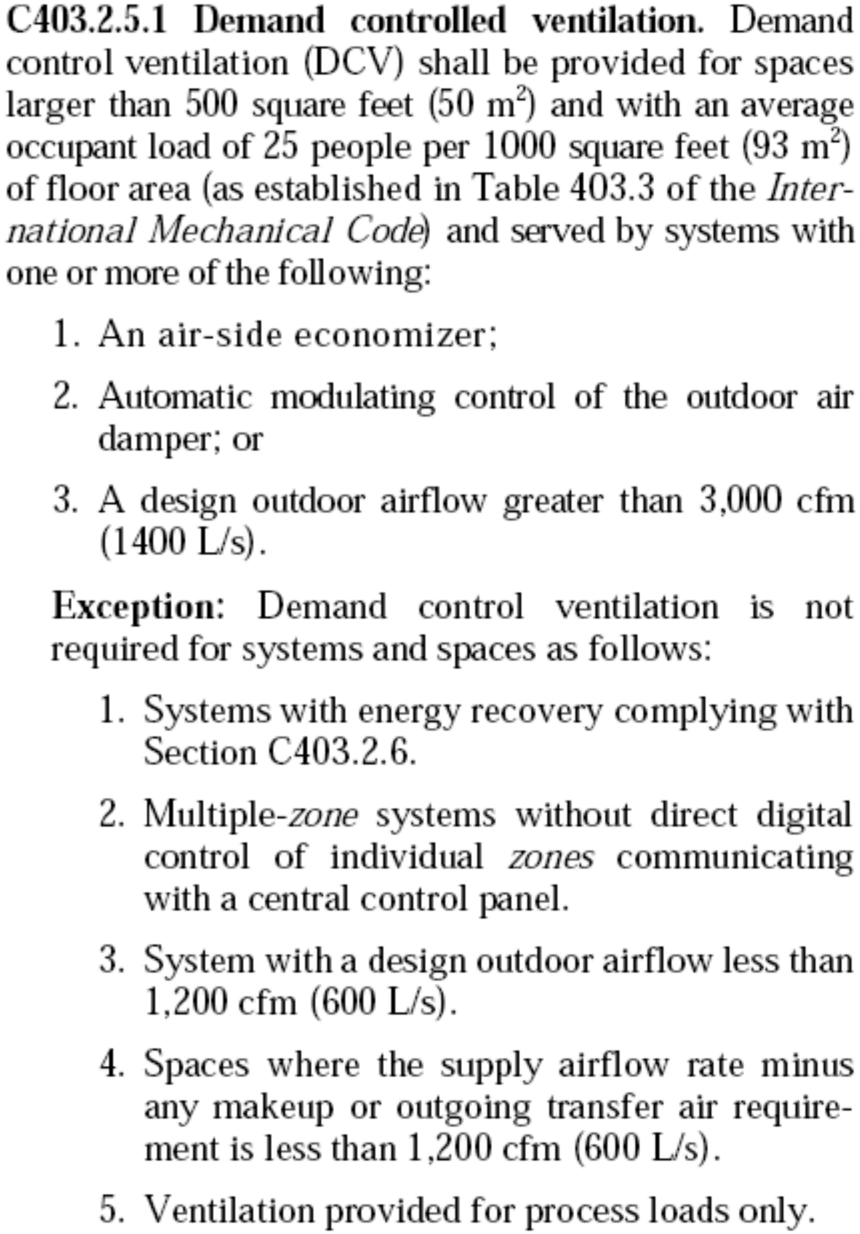
**Local Codes**

Also required in green codes such as ASHRAE 189.1, IgCC, and LEED

# DCV Now <u>Required</u> by Most Codes

IECC 2012 (code in 13 states) requires DCV at population densities of 25 people per 1000 ft2

IECC 2009 (WI and 28 other states) requires DCV at 40 people per 1000 ft2



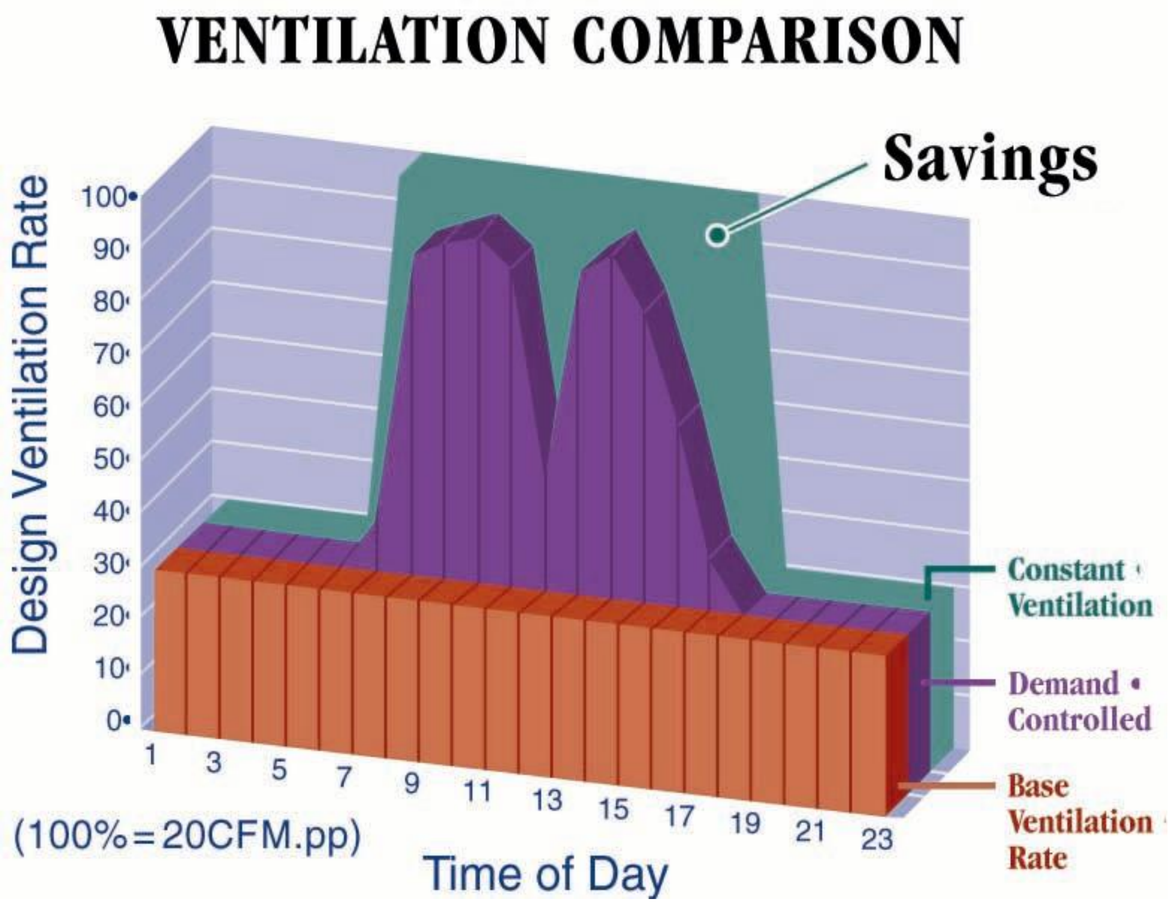
**C403.2.5.1 Demand controlled ventilation.** Demand control ventilation (DCV) shall be provided for spaces larger than 500 square feet (50 $m^2$) and with an average occupant load of 25 people per 1000 square feet (93 $m^2$) of floor area (as established in Table 403.3 of the *International Mechanical Code*) and served by systems with one or more of the following:

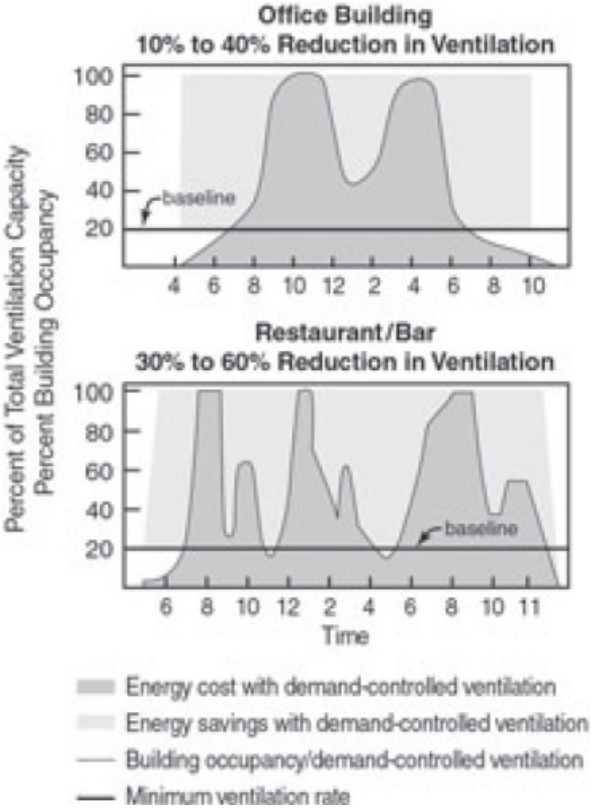
1. An air-side economizer;
2. Automatic modulating control of the outdoor air damper; or
3. A design outdoor airflow greater than 3,000 cfm (1400 L/s).

**Exception:** Demand control ventilation is not required for systems and spaces as follows:

1. Systems with energy recovery complying with Section C403.2.6.
2. Multiple-*zone* systems without direct digital control of individual *zones* communicating with a central control panel.
3. System with a design outdoor airflow less than 1,200 cfm (600 L/s).
4. Spaces where the supply airflow rate minus any makeup or outgoing transfer air requirement is less than 1,200 cfm (600 L/s).
5. Ventilation provided for process loads only.

# DCV Savings

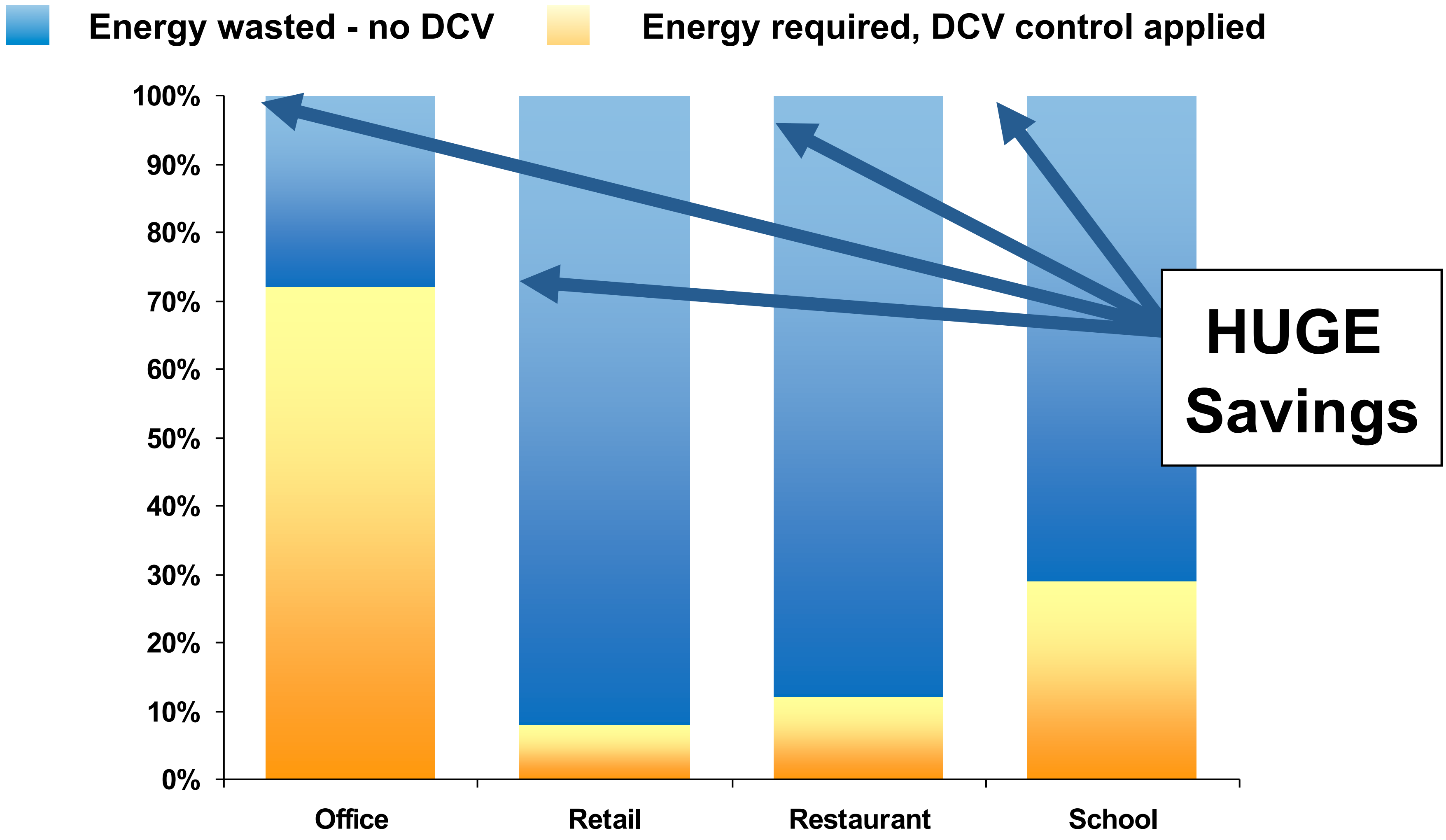




Federal Energy Management Program Study

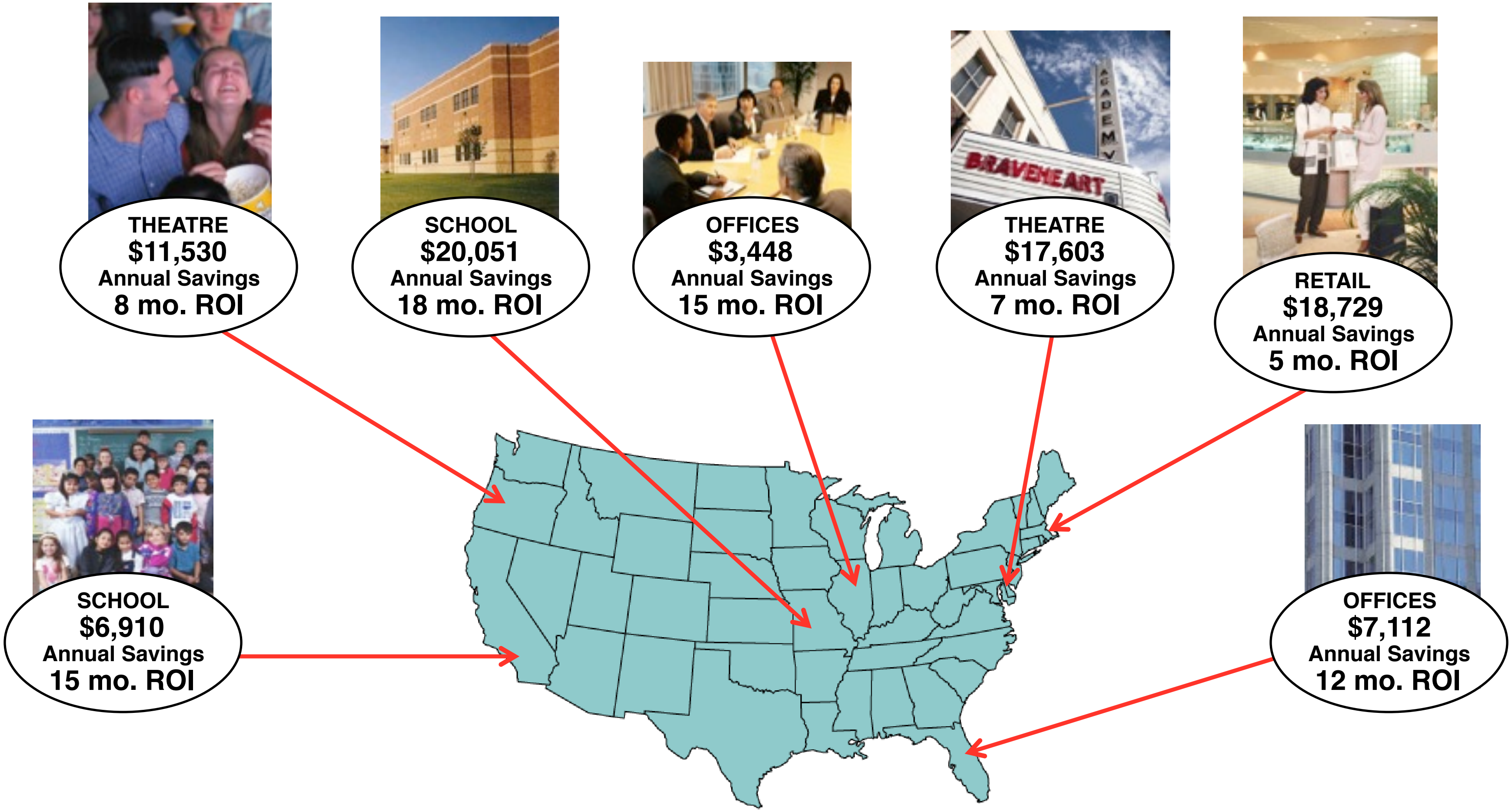
- Chart compares ventilation usage throughout typical day using purple to represent “demand controlled” and green to represent “constant”
- Difference between equates to significant savings

# Research Findings
# Demand Control Ventilation



**HUGE Savings**

# Examples of
# Potential Energy Savings and ROI



THEATRE
$11,530
Annual Savings
8 mo. ROI

SCHOOL
$20,051
Annual Savings
18 mo. ROI

OFFICES
$3,448
Annual Savings
15 mo. ROI

THEATRE
$17,603
Annual Savings
7 mo. ROI

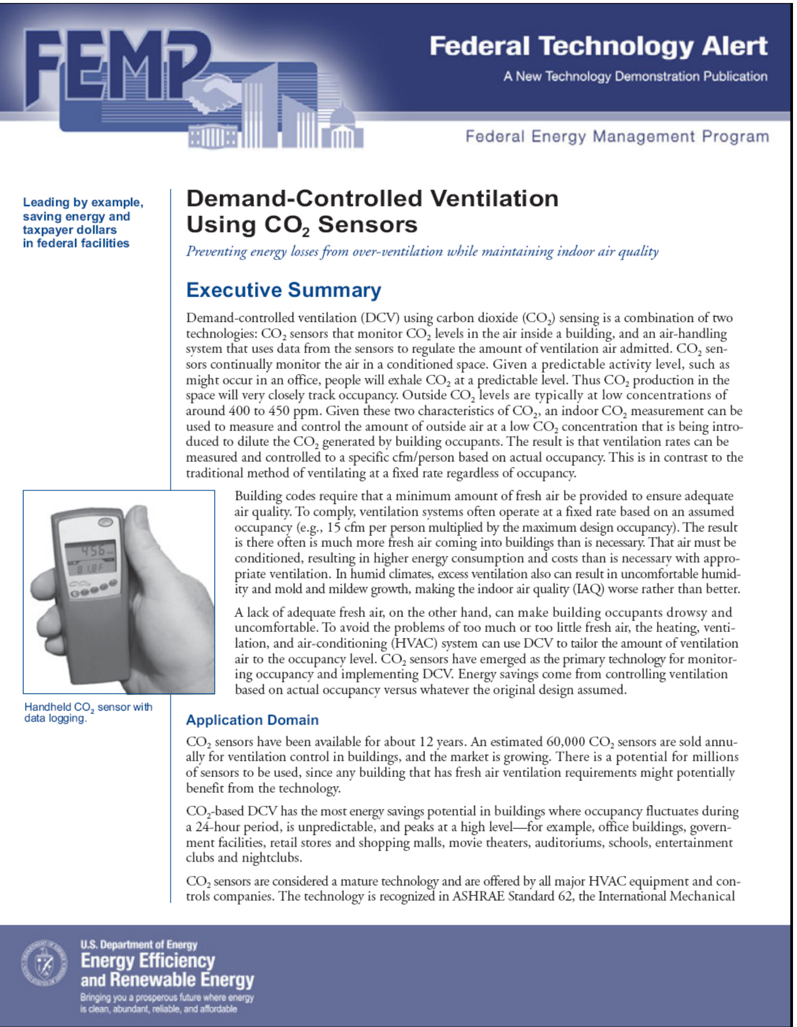
RETAIL
$18,729
Annual Savings
5 mo. ROI

SCHOOL
$6,910
Annual Savings
15 mo. ROI

OFFICES
$7,112
Annual Savings
12 mo. ROI

# 2004 FEMP Study

- 4 CO2 sensors per floor
  - Energy Model
    - $81,293 annually
    - $3,000 per floor
    - $0.22/ft$^2$
  - Actual saving for 6 months was $133,805



**Federal Technology Alert**

A New Technology Demonstration Publication

Federal Energy Management Program

**Leading by example, saving energy and taxpayer dollars in federal facilities**

## Demand-Controlled Ventilation Using $CO_2$ Sensors

*Preventing energy losses from over-ventilation while maintaining indoor air quality*

### Executive Summary

Demand-controlled ventilation (DCV) using carbon dioxide ($CO_2$) sensing is a combination of two technologies: $CO_2$ sensors that monitor $CO_2$ levels in the air inside a building, and an air-handling system that uses data from the sensors to regulate the amount of ventilation air admitted. $CO_2$ sensors continually monitor the air in a conditioned space. Given a predictable activity level, such as might occur in an office, people will exhale $CO_2$ at a predictable level. Thus $CO_2$ production in the space will very closely track occupancy. Outside $CO_2$ levels are typically at low concentrations of around 400 to 450 ppm. Given these two characteristics of $CO_2$, an indoor $CO_2$ measurement can be used to measure and control the amount of outside air at a low $CO_2$ concentration that is being introduced to dilute the $CO_2$ generated by building occupants. The result is that ventilation rates can be measured and controlled to a specific cfm/person based on actual occupancy. This is in contrast to the traditional method of ventilating at a fixed rate regardless of occupancy.

Building codes require that a minimum amount of fresh air be provided to ensure adequate air quality. To comply, ventilation systems often operate at a fixed rate based on an assumed occupancy (e.g., 15 cfm per person multiplied by the maximum design occupancy). The result is there often is much more fresh air coming into buildings than is necessary. That air must be conditioned, resulting in higher energy consumption and costs than is necessary with appropriate ventilation. In humid climates, excess ventilation also can result in uncomfortable humidity and mold and mildew growth, making the indoor air quality (IAQ) worse rather than better.

A lack of adequate fresh air, on the other hand, can make building occupants drowsy and uncomfortable. To avoid the problems of too much or too little fresh air, the heating, ventilation, and air-conditioning (HVAC) system can use DCV to tailor the amount of ventilation air to the occupancy level. $CO_2$ sensors have emerged as the primary technology for monitoring occupancy and implementing DCV. Energy savings come from controlling ventilation based on actual occupancy versus whatever the original design assumed.

Handheld $CO_2$ sensor with data logging.

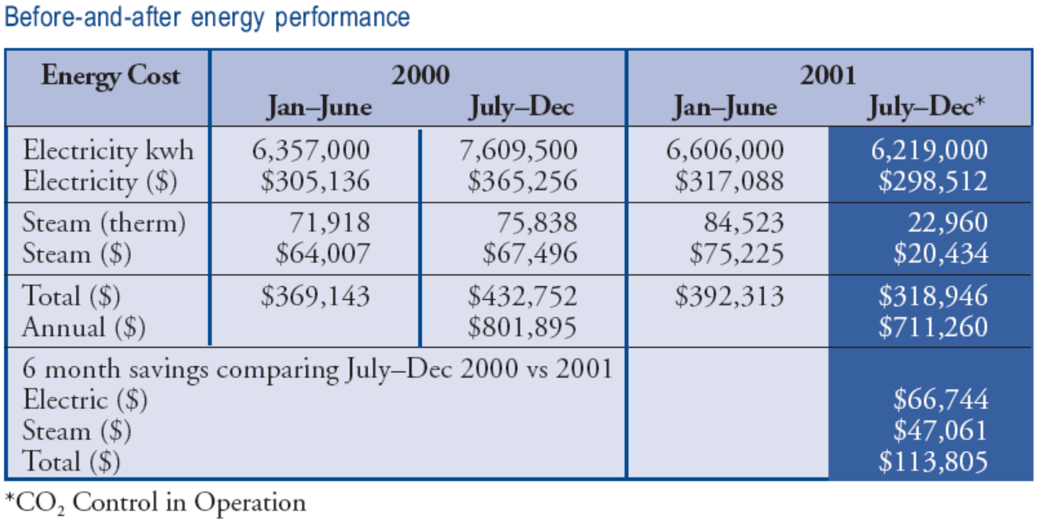
### Application Domain

$CO_2$ sensors have been available for about 12 years. An estimated 60,000 $CO_2$ sensors are sold annually for ventilation control in buildings, and the market is growing. There is a potential for millions of sensors to be used, since any building that has fresh air ventilation requirements might potentially benefit from the technology.

$CO_2$-based DCV has the most energy savings potential in buildings where occupancy fluctuates during a 24-hour period, is unpredictable, and peaks at a high level—for example, office buildings, government facilities, retail stores and shopping malls, movie theaters, auditoriums, schools, entertainment clubs and nightclubs.

$CO_2$ sensors are considered a mature technology and are offered by all major HVAC equipment and controls companies. The technology is recognized in ASHRAE Standard 62, the International Mechanical

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

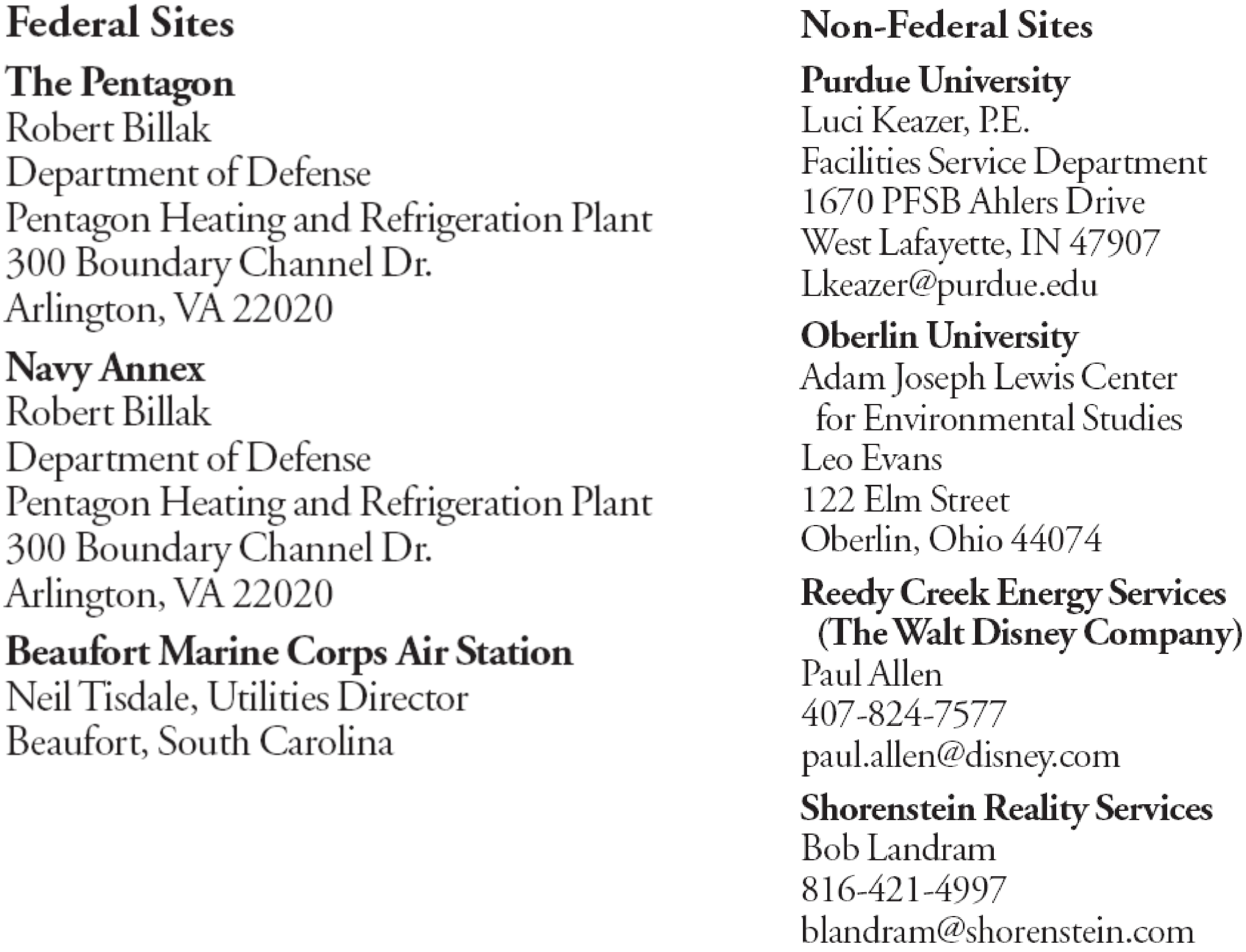


Before-and-after energy performance

| Energy Cost | 2000 | | 2001 | |
|---|---|---|---|---|
| | Jan–June | July–Dec | Jan–June | July–Dec* |
| Electricity kwh<br>Electricity ($) | 6,357,000<br>$305,136 | 7,609,500<br>$365,256 | 6,606,000<br>$317,088 | 6,219,000<br>$298,512 |
| Steam (therm)<br>Steam ($) | 71,918<br>$64,007 | 75,838<br>$67,496 | 84,523<br>$75,225 | 22,960<br>$20,434 |
| Total ($)<br>Annual ($) | $369,143 | $432,752<br>$801,895 | $392,313 | $318,946<br>$711,260 |
| 6 month savings comparing July–Dec 2000 vs 2001<br>Electric ($)<br>Steam ($)<br>Total ($) | | | | $66,744<br>$47,061<br>$113,805 |

*$CO_2$ Control in Operation

# FEMP Study – Who Is Using DCV?



**Federal Sites**

**The Pentagon**
Robert Billak
Department of Defense
Pentagon Heating and Refrigeration Plant
300 Boundary Channel Dr.
Arlington, VA 22020

**Navy Annex**
Robert Billak
Department of Defense
Pentagon Heating and Refrigeration Plant
300 Boundary Channel Dr.
Arlington, VA 22020

**Beaufort Marine Corps Air Station**
Neil Tisdale, Utilities Director
Beaufort, South Carolina

**Non-Federal Sites**

**Purdue University**
Luci Keazer, P.E.
Facilities Service Department
1670 PFSB Ahlers Drive
West Lafayette, IN 47907
Lkeazer@purdue.edu

**Oberlin University**
Adam Joseph Lewis Center
for Environmental Studies
Leo Evans
122 Elm Street
Oberlin, Ohio 44074

**Reedy Creek Energy Services (The Walt Disney Company)**
Paul Allen
407-824-7577
paul.allen@disney.com

**Shorenstein Reality Services**
Bob Landram
816-421-4997
blandram@shorenstein.com

# Early Adopters (1990s) - Midwest

Manufacturer, WI

University, IN

Office, MN

School, MN

# Red Wing School District, MN

***Drivers***

- Comfort/Productivity
- Need For Quick Response To Complaints

***Results***

- Problem areas identified and corrected quickly (over and under ventilation).
- Teacher concerns resolved quickly.

# LaSalle Plaza, MN

***Drivers***

- Energy Savings
- Tenant Comfort/Satisfaction

***Results***

- Significant reduction in heating and cooling costs ($200k 1st year)
- 3 month ROI

# Purdue University, IN

***Drivers***

- Energy Savings
- Productivity/Learning
- Low Maintenance Solution

***Results***

- “The installation provided a 1 to 2 year payback” (Luci Keazer, Controls Engineer)

# Harley Davidson, WI

***Drivers***

- Productivity
- Comfort
- Total Quality Environment

***Results***

- An Important part of Harley’s Quality Program for a comfortable and productive work environment.

# 2014 Wisconsin Case Study

Feasibility study to determine savings potential with DCV strategy:

- Monitored store for a week with CO2 monitors
- Compared against usage history
- 20-30% gas usage reduction was estimated
- Cost to implement $7,000 – floor space considered a ‘single zone’
- Payback around 8 months with incentives
- Other interesting findings

focus on energy™
Partnering with Wisconsin utilities

# Determine if CO$_2$ Control is Appropriate

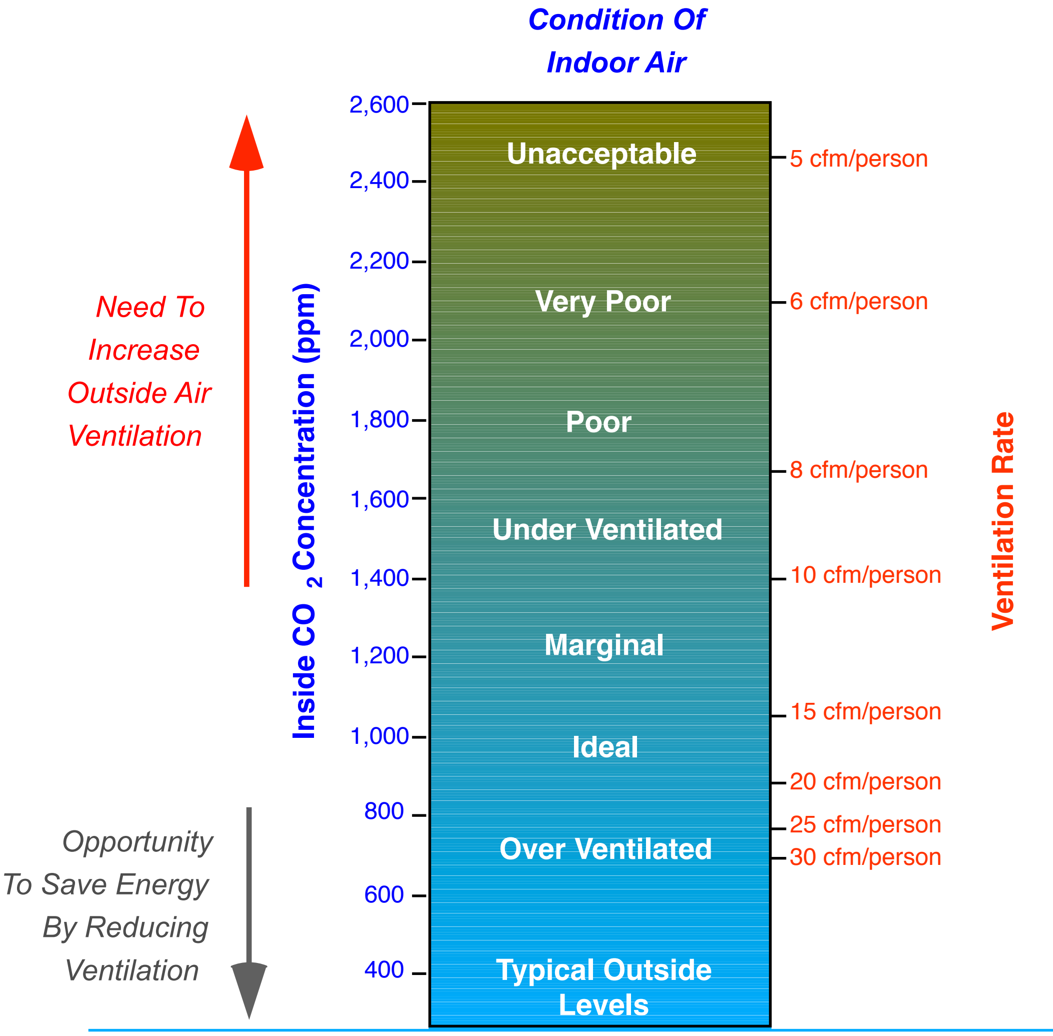
**Rating Legend:** **A** Recommended **B** Possible (Note 1) **C** Not Recommended

| Application | Rating |
|---|---|
| **Correctional facilities** | |
| Cells | A |
| Dining halls (Note 2) | B |
| Guard stations | C |
| **Dry cleaners and laundries** | |
| Commercial laundry | B |
| Commercial dry-cleaner | C |
| Storage and pickup | B |
| Coin-operated laundries | A |
| Coin-operated dry | C |
| **Education and schools** | |
| Classrooms | A |
| Laboratories (Note 4) | B |
| Training shops | B |
| Music rooms | A |
| Libraries | A |
| Locker rooms | C |
| Auditoriums | A |
| Smoking lounges (Note 3) | B |
| **Food and beverage service** | |
| Dining rooms (Note 2) | B |
| Cafeterias (Note 2) | B |
| Bars, cocktail lounges | B |
| Kitchens | C |
| **Garages, repair and service** | C |
| **Specialty shops** | |
| Barber and beauty | B |
| Reducing salons | B |
| Florists | B |
| Clothiers | B |
| Furniture | B |
| Hardware | B |
| Supermarkets | B |
| Pet shops | C |
| **Sports and amusement** | |
| Spectator areas | A |
| **Industrial facilities** | |
| Heavy manufacturing | C |
| Light manufacturing | B |
| Materials storage | C |
| Training facilities | C |
| Painting and finishing | C |
| Food and meat processing | C |
| **Office buildings** | A |
| **Retail stores** | |
| Sales floors | A |
| Dressing rooms | A |
| Malls and arcades | A |
| Shipping and receiving | C |
| Warehouses | C |
| **Hospitals and medical** | |
| Patient rooms | B |
| Medical procedure | C |
| Operating rooms | C |
| Recovery and ICU | B |
| Autopsy rooms | C |
| Physical therapy | A |
| Lobbies and waiting areas | A |
| **Hotels, resorts and** | |
| Bedrooms | B |
| Lobbies | A |
| Conference rooms | A |
| Meeting rooms | A |
| Ballrooms and assembly | A |
| Gambling casino | B |
| Game rooms | A |
| Ice arenas | A |
| Swimming pools | C |
| Gymnasiums | A |
| Ballrooms and discos | A |
| Bowling alleys | A |
| **Theaters** | A |
| **Transportation** | |
| Waiting rooms | A |
| Platforms | A |

# Control Setpoints

$CO_2$ Control Point Depends on:
- Outdoor $CO_2$ Level (typically 450 ppm)
- Required cfm/person ventilation rate

If OA $CO_2$ is 400 ppm:
20 cfm/person = 930 ppm $CO_2$
15 cfm/person = 1,100 ppm $CO_2$
10 cfm/person = 1,450 ppm $CO_2$

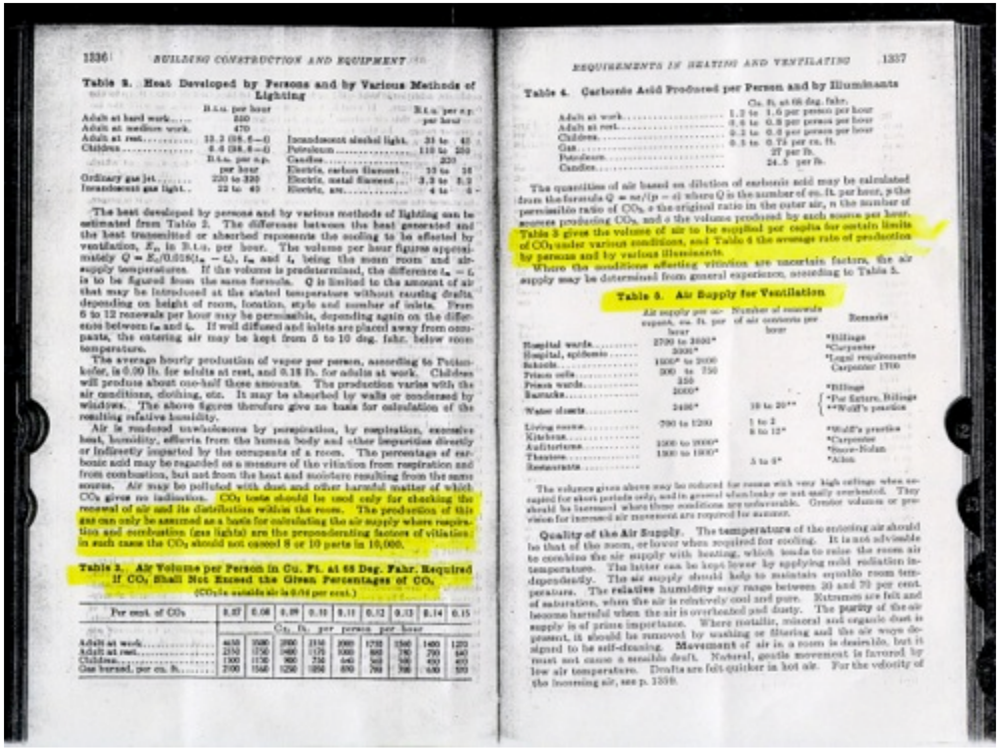


# Is Using $CO_2$ to Measure Ventilation a New Idea?

1916 Engineers Handbook

**“$CO_2$ tests should be used …for checking the renewal of air and its distribution within the room.**

**…the $CO_2$ should NOT exceed 8 or 10 parts in 10,000”**

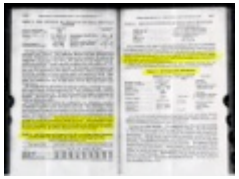


# DCV Timeline

**1916**

Mechanical Engineers Handbook

Explains relationship between $CO_2$ and ventilation



**1929**

NY Building code details $CO_2$ levels shall not be greater than one part in one thousand

VAV

**1973**

Energy crunch introduce VAV system for commercial buildings

**1989**

ASHRAE Standard 62-89 increases ventilation rates, foundation for DCV and 1000 PPM rate

$CO_2$

**1997**

Interpretation IC-62-1989-27 clarifies use of $CO_2$ as a method of controlling ventilation based on occupancy

**1999**

ASHRAE 62-99 eliminates 1000 PPM $CO_2$ threshold in/outside differential introduced

**2000**

Intro of low cost temp/$CO_2$ sensor enabling affordable zone level DCV

**2004**

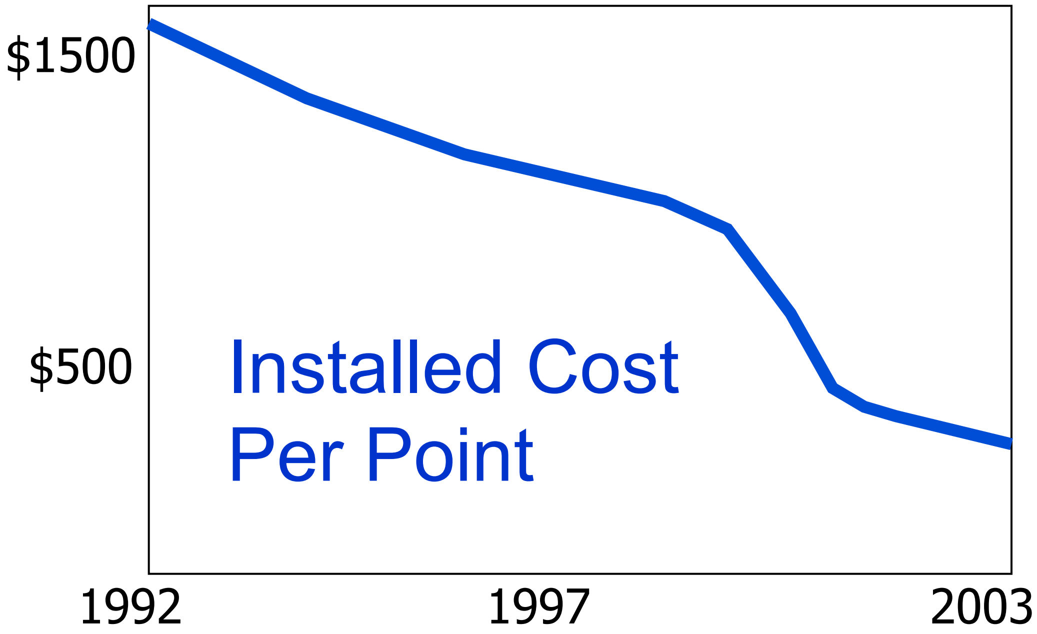
ASHRAE Standard 62 update adds DCV to body of standard

# Why Now?

- **Digital Control Systems**
  - **Integration of ventilation control**
- **Increased Ventilation Rates (ASHRAE/IMC)**
- **Increasing Energy Costs**
- **Required by Energy Codes**
- **<u>Decreasing Sensor Costs (First & Life Cycle) & Increased Sensor Reliability</u>**

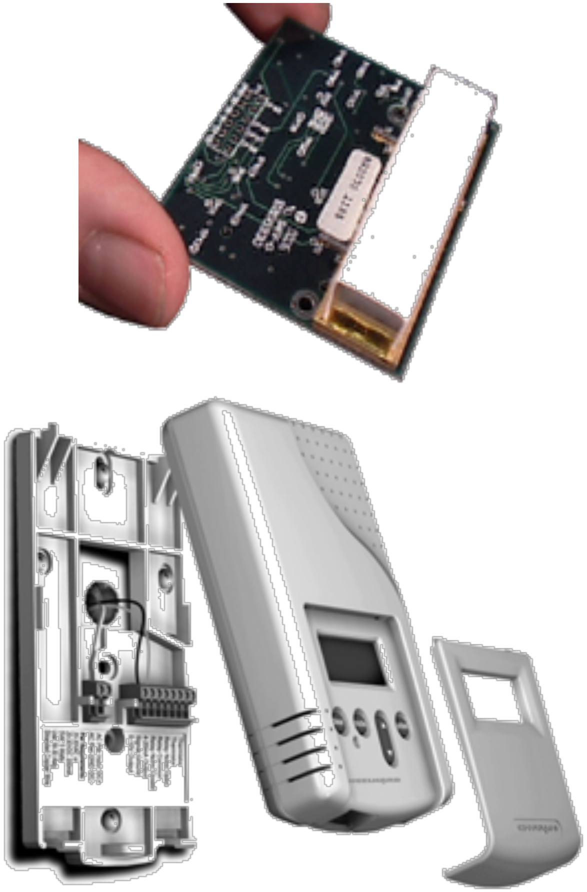
# Sensor Cost

- **Control system integration**
- **Sensor technology and integration ($CO_2$ + Temp)**
- **Volume increases**



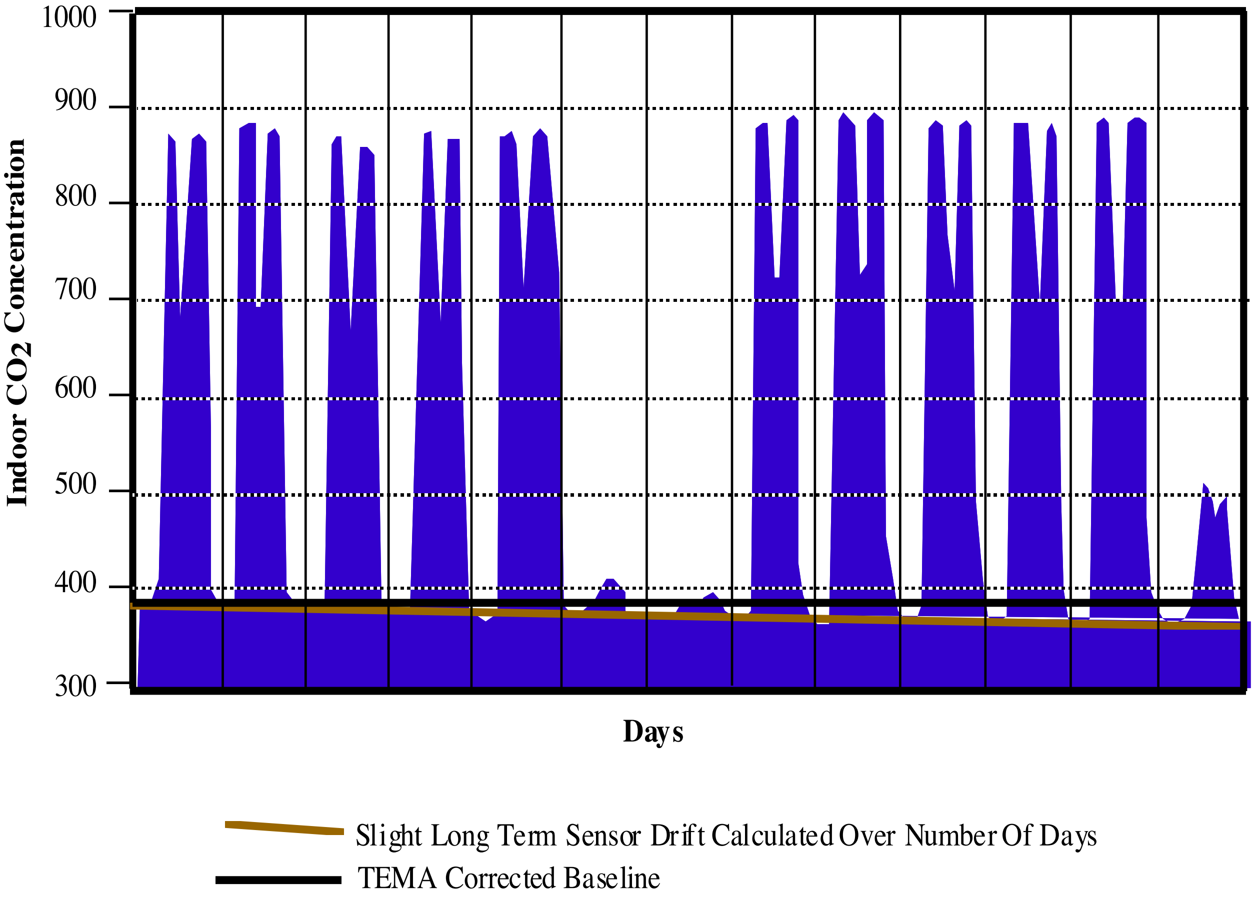
# Sensor Reliability

- **15 Year design life**
- **Non-interactive, selective to $CO_2$ only**
- **Stable - lifetime calibration**

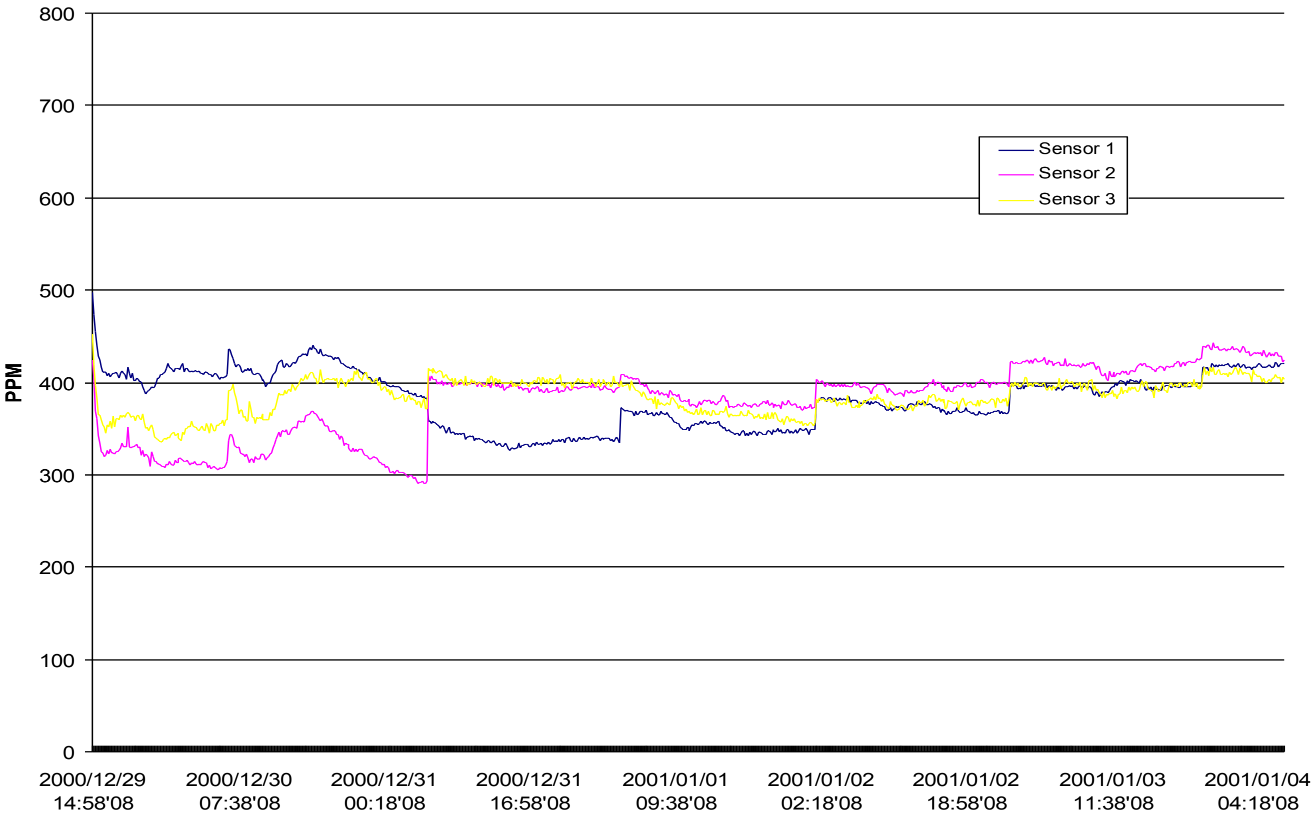


# Self Calibration of a $CO_2$ Detector

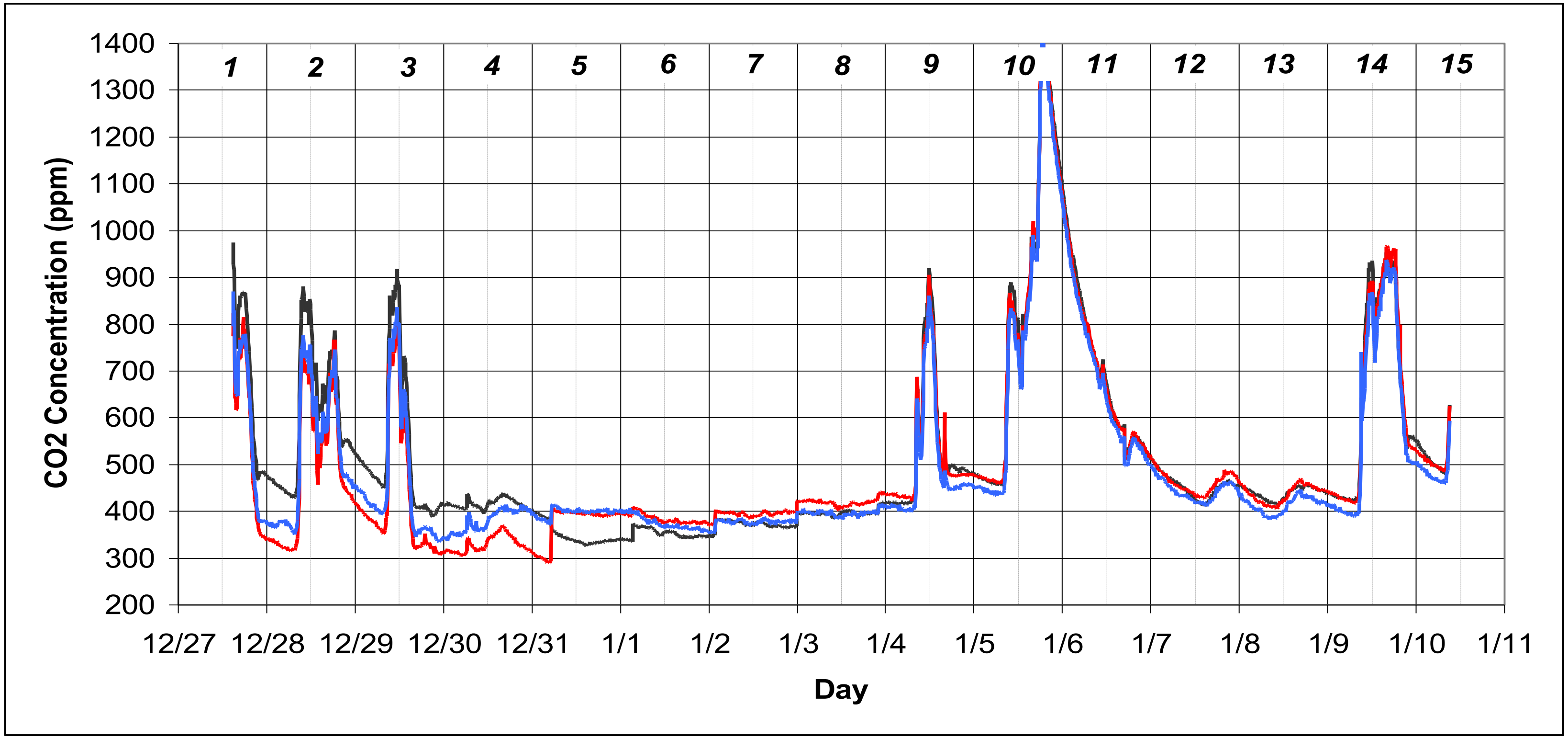
- **Automatic Baseline Calibration (ABC Logic)**
- **Self calibrating algorithm**
- **Considers lowest $CO_2$ level every 24 hrs**
- **Looks at long term changes in baseline**
- **Applies a correction factor for calibration**



# Self Calibration of a CO2 Detector

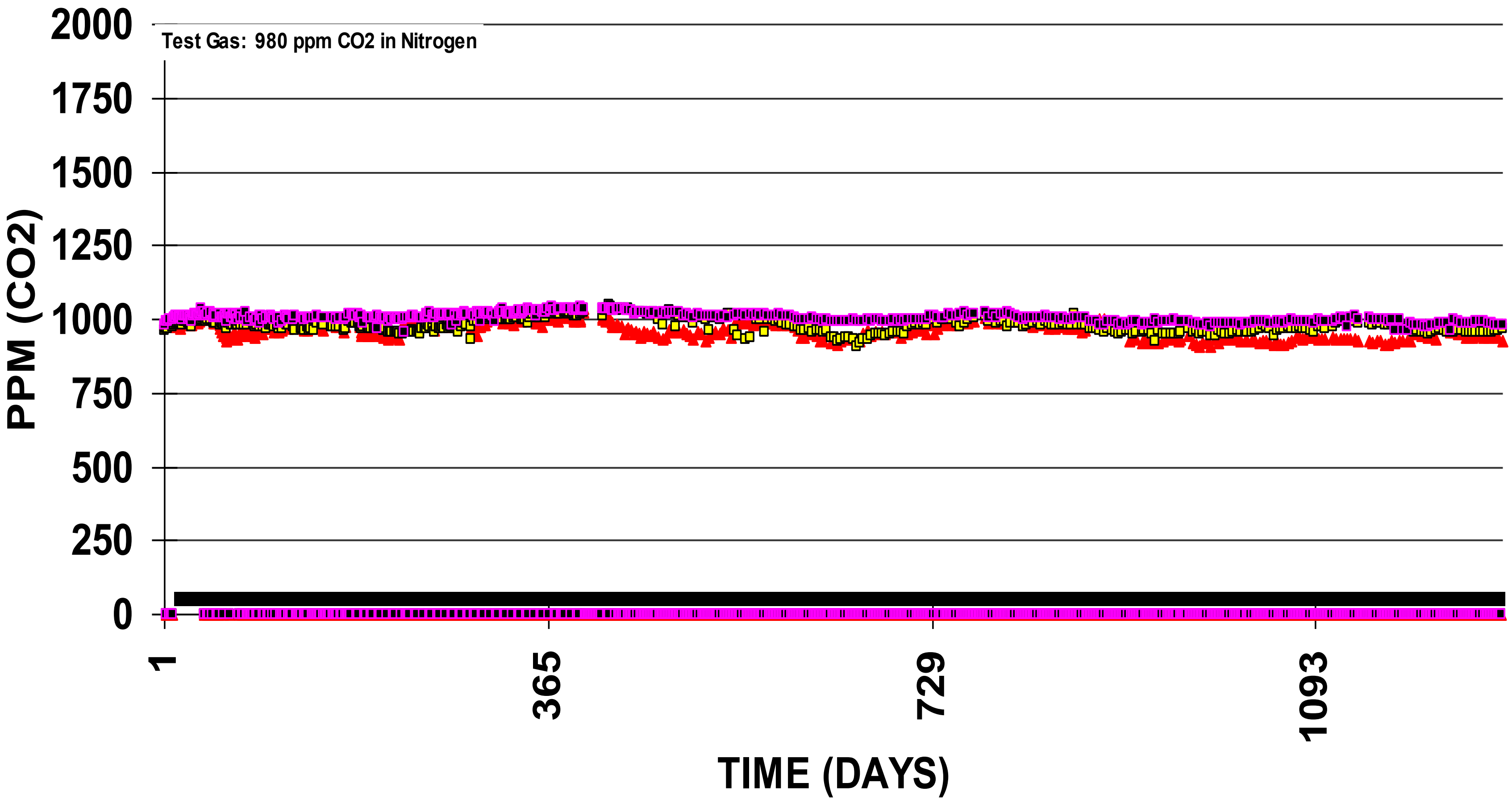


# Sensor Reliability



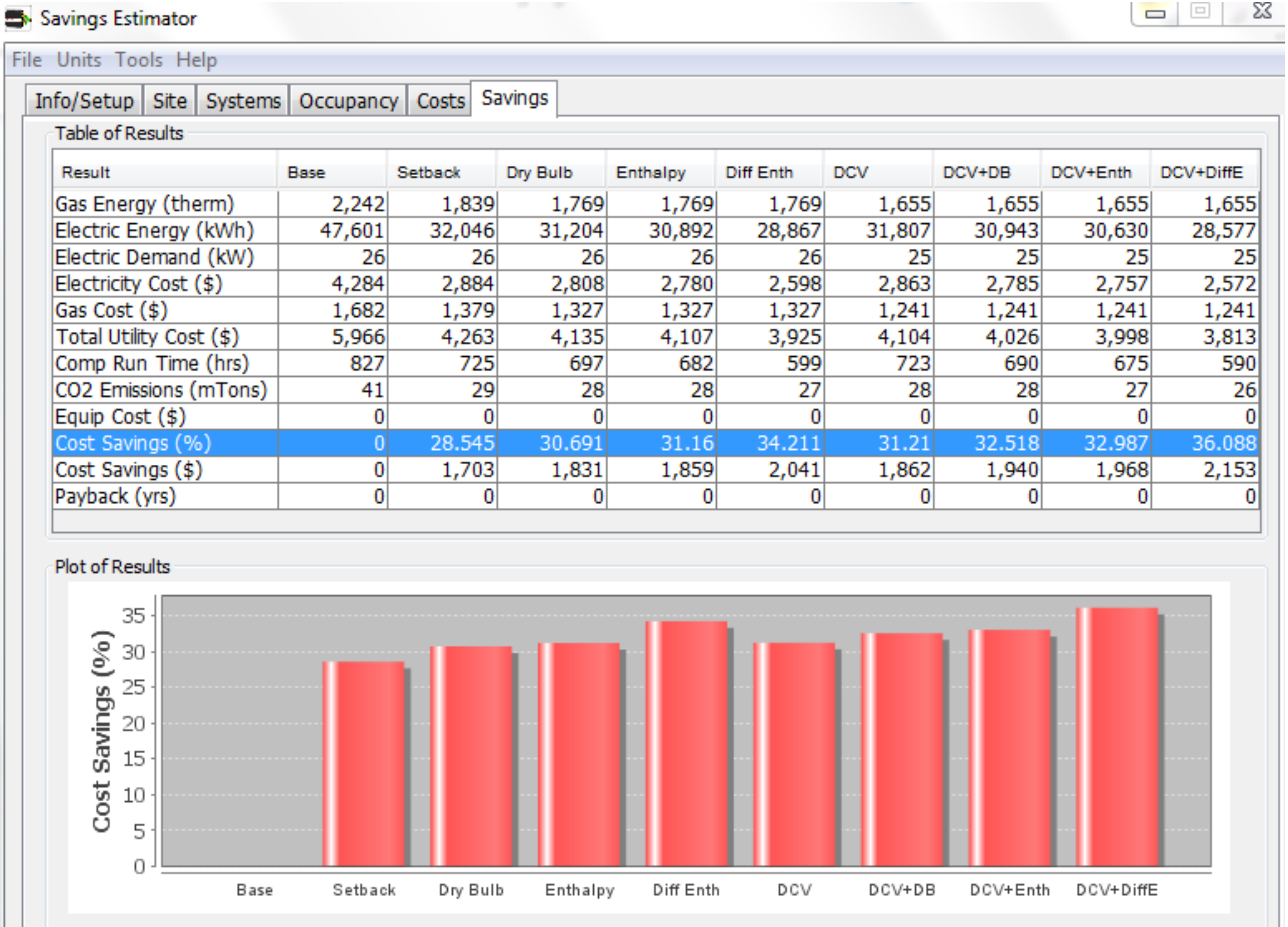
Self Calibration Over 14 Days

# Long Term Sensor Stability



# Stat, Econ, and DCV Energy Savings

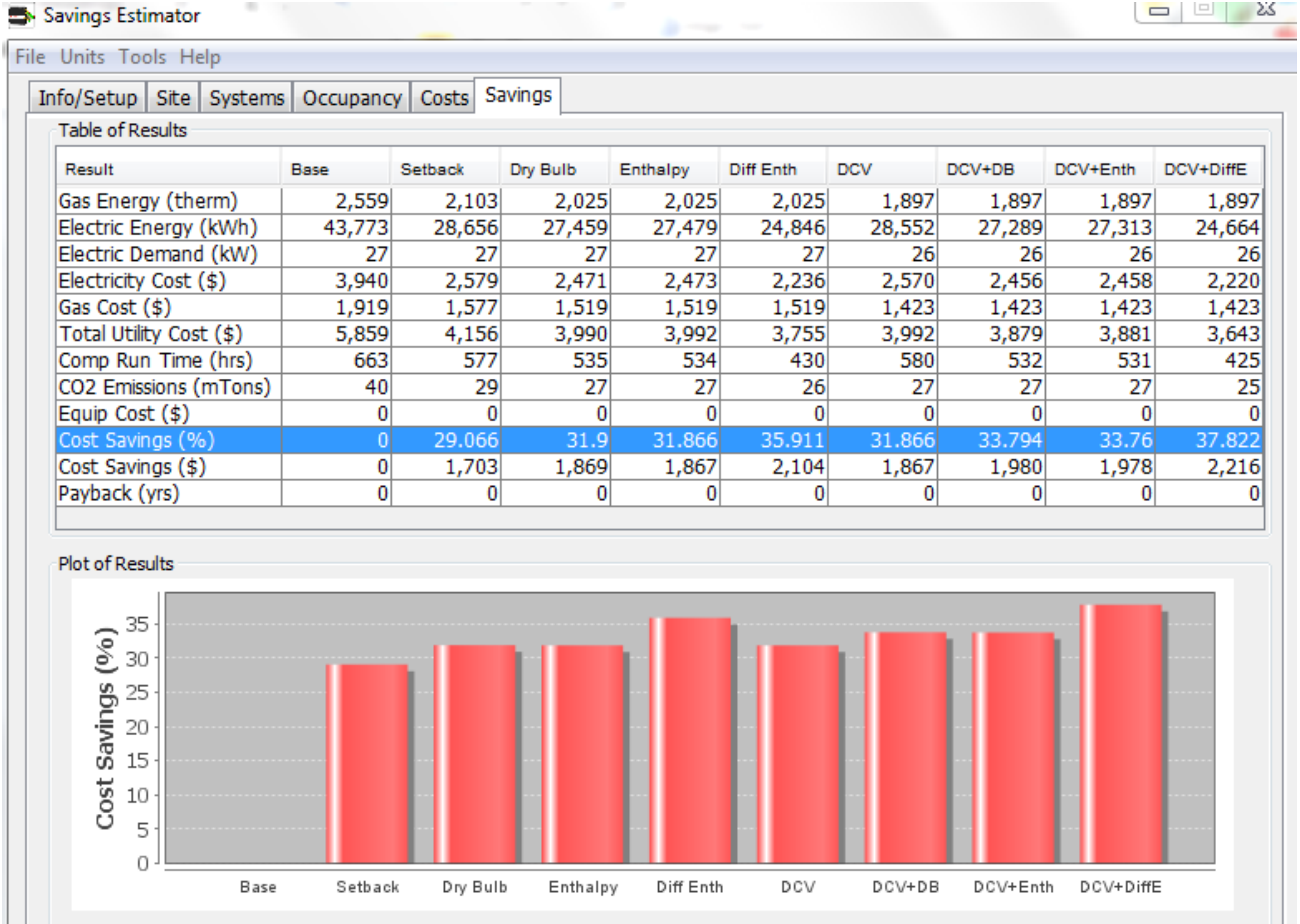
(Chicago retro-fit, RTU circa 2000)



| Result | Base | Setback | Dry Bulb | Enthalpy | Diff Enth | DCV | DCV+DB | DCV+Enth | DCV+DiffE |
|---|---|---|---|---|---|---|---|---|---|
| Gas Energy (therm) | 2,242 | 1,839 | 1,769 | 1,769 | 1,769 | 1,655 | 1,655 | 1,655 | 1,655 |
| Electric Energy (kWh) | 47,601 | 32,046 | 31,204 | 30,892 | 28,867 | 31,807 | 30,943 | 30,630 | 28,577 |
| Electric Demand (kW) | 26 | 26 | 26 | 26 | 26 | 25 | 25 | 25 | 25 |
| Electricity Cost ($) | 4,284 | 2,884 | 2,808 | 2,780 | 2,598 | 2,863 | 2,785 | 2,757 | 2,572 |
| Gas Cost ($) | 1,682 | 1,379 | 1,327 | 1,327 | 1,327 | 1,241 | 1,241 | 1,241 | 1,241 |
| Total Utility Cost ($) | 5,966 | 4,263 | 4,135 | 4,107 | 3,925 | 4,104 | 4,026 | 3,998 | 3,813 |
| Comp Run Time (hrs) | 827 | 725 | 697 | 682 | 599 | 723 | 690 | 675 | 590 |
| CO2 Emissions (mTons) | 41 | 29 | 28 | 28 | 27 | 28 | 28 | 27 | 26 |
| Equip Cost ($) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cost Savings (%) | 0 | 28.545 | 30.691 | 31.16 | 34.211 | 31.21 | 32.518 | 32.987 | 36.088 |
| Cost Savings ($) | 0 | 1,703 | 1,831 | 1,859 | 2,041 | 1,862 | 1,940 | 1,968 | 2,153 |
| Payback (yrs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Stat, Econ, and DCV Energy Savings

(Milwaukee retro-fit, RTU circa 2000)



| Result | Base | Setback | Dry Bulb | Enthalpy | Diff Enth | DCV | DCV+DB | DCV+Enth | DCV+DiffE |
|---|---|---|---|---|---|---|---|---|---|
| Gas Energy (therm) | 2,559 | 2,103 | 2,025 | 2,025 | 2,025 | 1,897 | 1,897 | 1,897 | 1,897 |
| Electric Energy (kWh) | 43,773 | 28,656 | 27,459 | 27,479 | 24,846 | 28,552 | 27,289 | 27,313 | 24,664 |
| Electric Demand (kW) | 27 | 27 | 27 | 27 | 27 | 26 | 26 | 26 | 26 |
| Electricity Cost ($) | 3,940 | 2,579 | 2,471 | 2,473 | 2,236 | 2,570 | 2,456 | 2,458 | 2,220 |
| Gas Cost ($) | 1,919 | 1,577 | 1,519 | 1,519 | 1,519 | 1,423 | 1,423 | 1,423 | 1,423 |
| Total Utility Cost ($) | 5,859 | 4,156 | 3,990 | 3,992 | 3,755 | 3,992 | 3,879 | 3,881 | 3,643 |
| Comp Run Time (hrs) | 663 | 577 | 535 | 534 | 430 | 580 | 532 | 531 | 425 |
| CO2 Emissions (mTons) | 40 | 29 | 27 | 27 | 26 | 27 | 27 | 27 | 25 |
| Equip Cost ($) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cost Savings (%) | 0 | 29.066 | 31.9 | 31.866 | 35.911 | 31.866 | 33.794 | 33.76 | 37.822 |
| Cost Savings ($) | 0 | 1,703 | 1,869 | 1,867 | 2,104 | 1,867 | 1,980 | 1,978 | 2,216 |
| Payback (yrs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Stat, Econ, and DCV Energy Savings

(Madison retro-fit, RTU circa 2000)

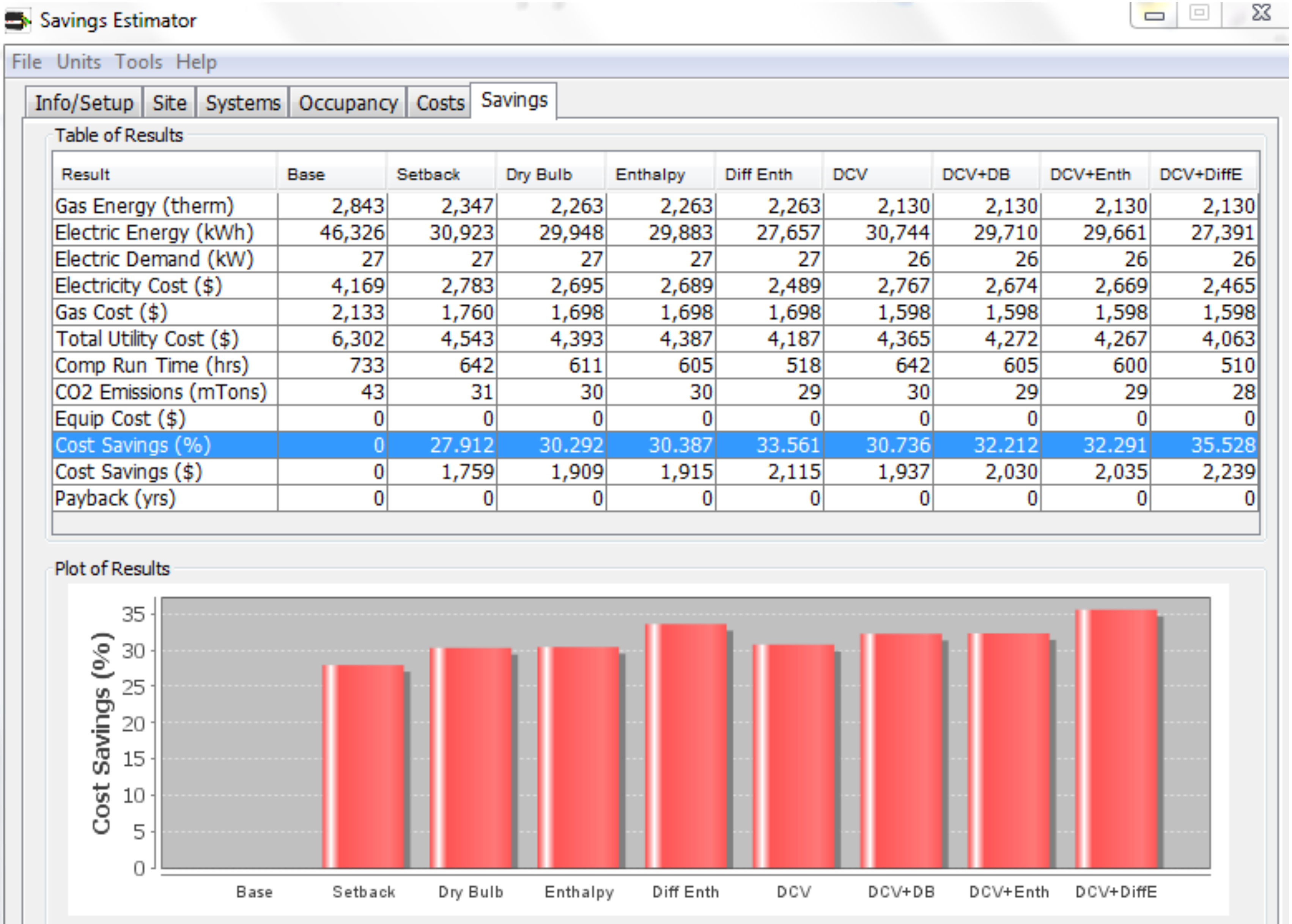


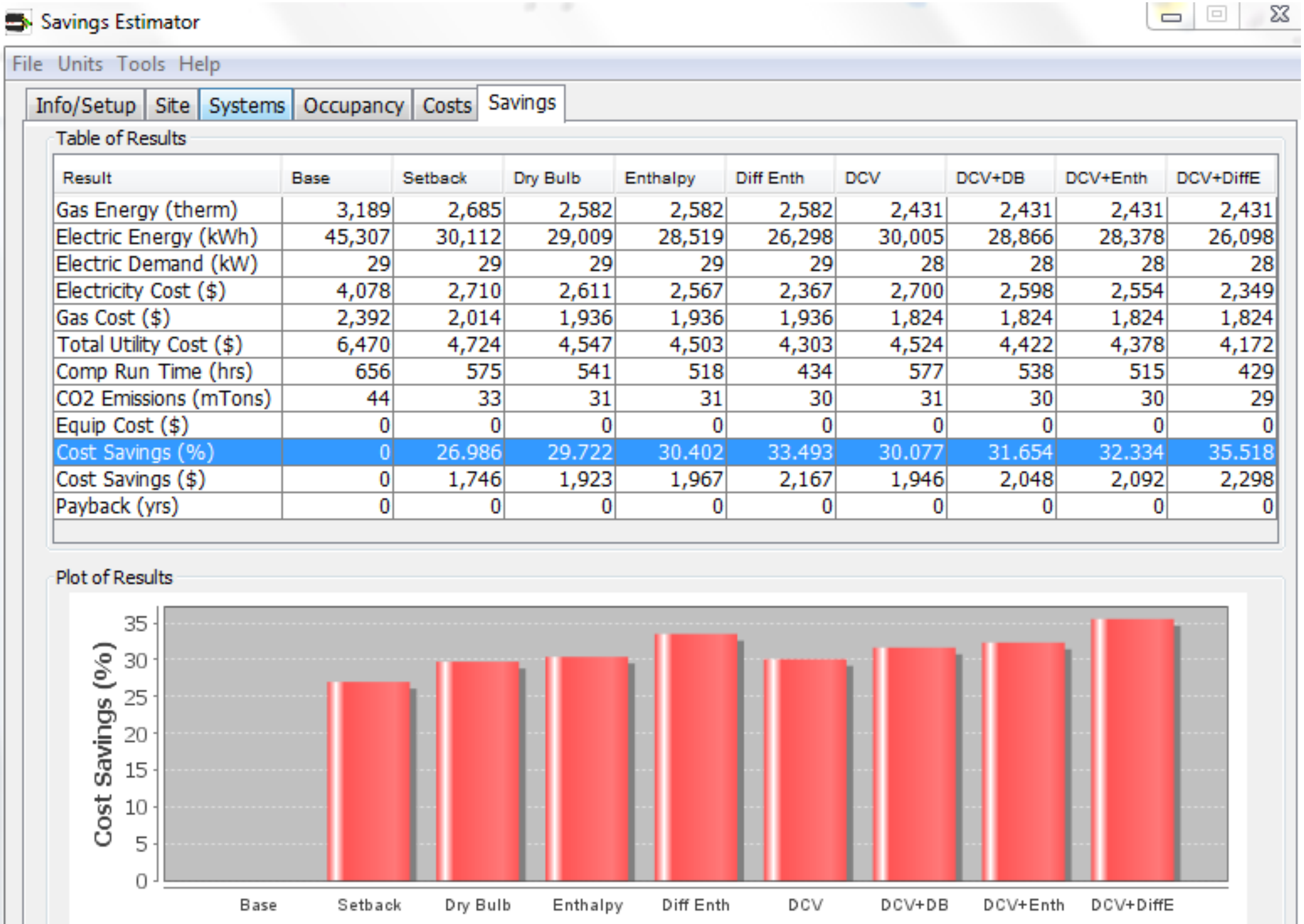
Table of Results

| Result | Base | Setback | Dry Bulb | Enthalpy | Diff Enth | DCV | DCV+DB | DCV+Enth | DCV+DiffE |
|---|---|---|---|---|---|---|---|---|---|
| Gas Energy (therm) | 2,843 | 2,347 | 2,263 | 2,263 | 2,263 | 2,130 | 2,130 | 2,130 | 2,130 |
| Electric Energy (kWh) | 46,326 | 30,923 | 29,948 | 29,883 | 27,657 | 30,744 | 29,710 | 29,661 | 27,391 |
| Electric Demand (kW) | 27 | 27 | 27 | 27 | 27 | 26 | 26 | 26 | 26 |
| Electricity Cost ($) | 4,169 | 2,783 | 2,695 | 2,689 | 2,489 | 2,767 | 2,674 | 2,669 | 2,465 |
| Gas Cost ($) | 2,133 | 1,760 | 1,698 | 1,698 | 1,698 | 1,598 | 1,598 | 1,598 | 1,598 |
| Total Utility Cost ($) | 6,302 | 4,543 | 4,393 | 4,387 | 4,187 | 4,365 | 4,272 | 4,267 | 4,063 |
| Comp Run Time (hrs) | 733 | 642 | 611 | 605 | 518 | 642 | 605 | 600 | 510 |
| CO2 Emissions (mTons) | 43 | 31 | 30 | 30 | 29 | 30 | 29 | 29 | 28 |
| Equip Cost ($) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cost Savings (%) | 0 | 27.912 | 30.292 | 30.387 | 33.561 | 30.736 | 32.212 | 32.291 | 35.528 |
| Cost Savings ($) | 0 | 1,759 | 1,909 | 1,915 | 2,115 | 1,937 | 2,030 | 2,035 | 2,239 |
| Payback (yrs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Plot of Results

# Stat, Econ, and DCV Energy Savings

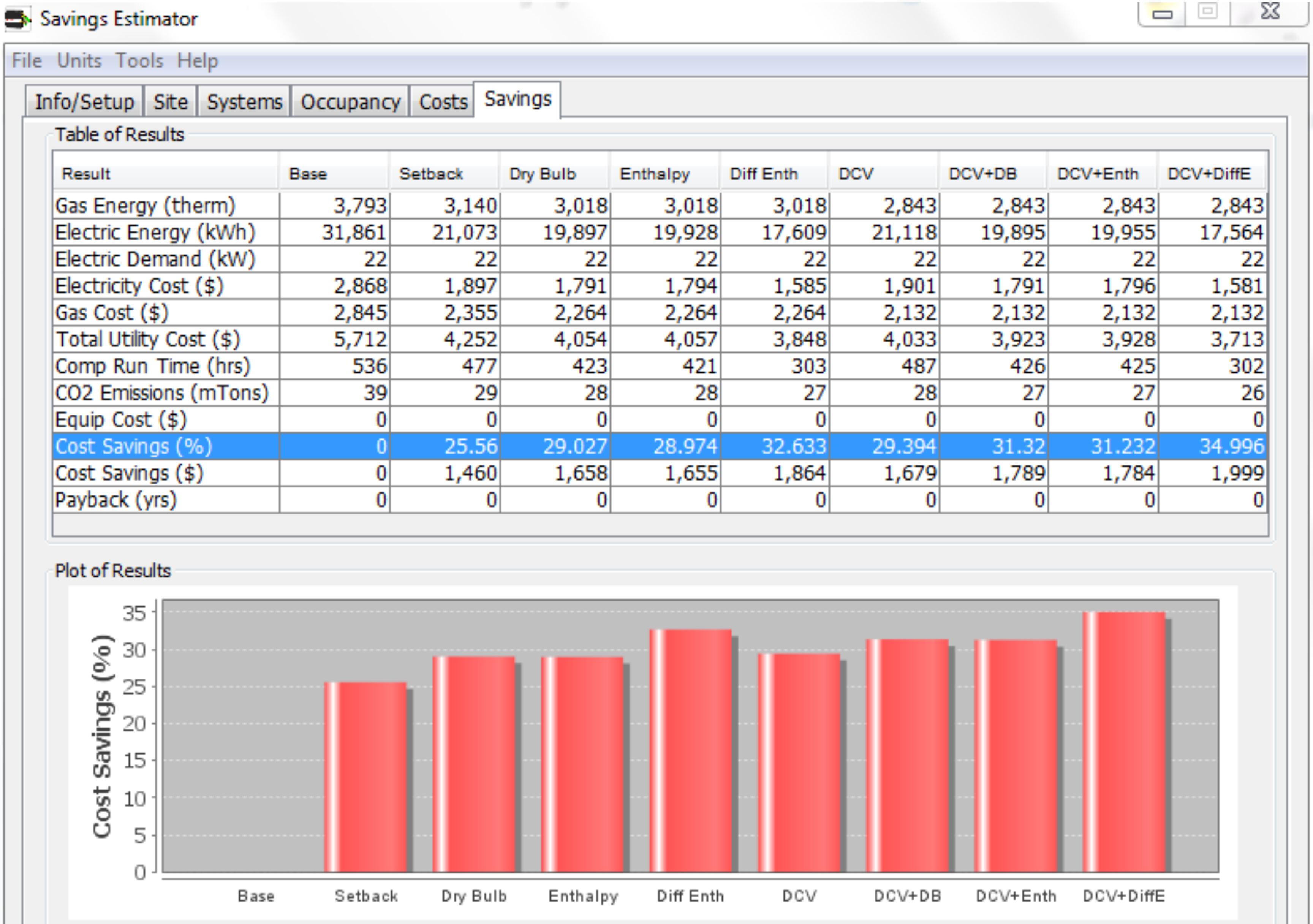
(Eau Claire retro-fit, RTU circa 2000)



| Result | Base | Setback | Dry Bulb | Enthalpy | Diff Enth | DCV | DCV+DB | DCV+Enth | DCV+DiffE |
|---|---|---|---|---|---|---|---|---|---|
| Gas Energy (therm) | 3,189 | 2,685 | 2,582 | 2,582 | 2,582 | 2,431 | 2,431 | 2,431 | 2,431 |
| Electric Energy (kWh) | 45,307 | 30,112 | 29,009 | 28,519 | 26,298 | 30,005 | 28,866 | 28,378 | 26,098 |
| Electric Demand (kW) | 29 | 29 | 29 | 29 | 29 | 28 | 28 | 28 | 28 |
| Electricity Cost ($) | 4,078 | 2,710 | 2,611 | 2,567 | 2,367 | 2,700 | 2,598 | 2,554 | 2,349 |
| Gas Cost ($) | 2,392 | 2,014 | 1,936 | 1,936 | 1,936 | 1,824 | 1,824 | 1,824 | 1,824 |
| Total Utility Cost ($) | 6,470 | 4,724 | 4,547 | 4,503 | 4,303 | 4,524 | 4,422 | 4,378 | 4,172 |
| Comp Run Time (hrs) | 656 | 575 | 541 | 518 | 434 | 577 | 538 | 515 | 429 |
| CO2 Emissions (mTons) | 44 | 33 | 31 | 31 | 30 | 31 | 30 | 30 | 29 |
| Equip Cost ($) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cost Savings (%) | 0 | 26.986 | 29.722 | 30.402 | 33.493 | 30.077 | 31.654 | 32.334 | 35.518 |
| Cost Savings ($) | 0 | 1,746 | 1,923 | 1,967 | 2,167 | 1,946 | 2,048 | 2,092 | 2,298 |
| Payback (yrs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Stat, Econ, and DCV Energy Savings

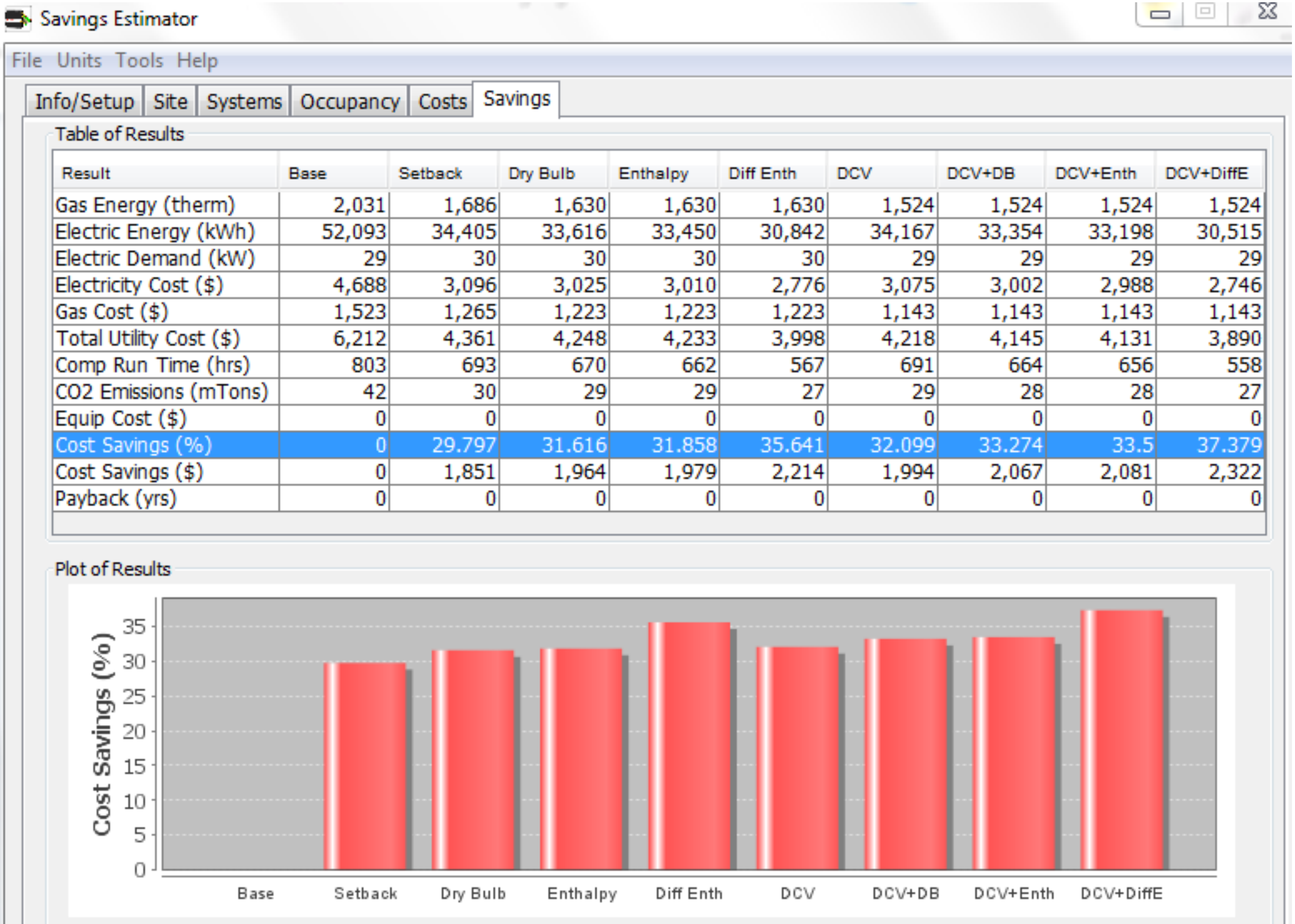
(Duluth retro-fit, RTU circa 2000)



| Result | Base | Setback | Dry Bulb | Enthalpy | Diff Enth | DCV | DCV+DB | DCV+Enth | DCV+DiffE |
|---|---|---|---|---|---|---|---|---|---|
| Gas Energy (therm) | 3,793 | 3,140 | 3,018 | 3,018 | 3,018 | 2,843 | 2,843 | 2,843 | 2,843 |
| Electric Energy (kWh) | 31,861 | 21,073 | 19,897 | 19,928 | 17,609 | 21,118 | 19,895 | 19,955 | 17,564 |
| Electric Demand (kW) | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 |
| Electricity Cost ($) | 2,868 | 1,897 | 1,791 | 1,794 | 1,585 | 1,901 | 1,791 | 1,796 | 1,581 |
| Gas Cost ($) | 2,845 | 2,355 | 2,264 | 2,264 | 2,264 | 2,132 | 2,132 | 2,132 | 2,132 |
| Total Utility Cost ($) | 5,712 | 4,252 | 4,054 | 4,057 | 3,848 | 4,033 | 3,923 | 3,928 | 3,713 |
| Comp Run Time (hrs) | 536 | 477 | 423 | 421 | 303 | 487 | 426 | 425 | 302 |
| CO2 Emissions (mTons) | 39 | 29 | 28 | 28 | 27 | 28 | 27 | 27 | 26 |
| Equip Cost ($) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cost Savings (%) | 0 | 25.56 | 29.027 | 28.974 | 32.633 | 29.394 | 31.32 | 31.232 | 34.996 |
| Cost Savings ($) | 0 | 1,460 | 1,658 | 1,655 | 1,864 | 1,679 | 1,789 | 1,784 | 1,999 |
| Payback (yrs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Stat, Econ, and DCV Energy Savings

## (South Bend retro-fit, RTU circa 2000)



| Result | Base | Setback | Dry Bulb | Enthalpy | Diff Enth | DCV | DCV+DB | DCV+Enth | DCV+DiffE |
|---|---|---|---|---|---|---|---|---|---|
| Gas Energy (therm) | 2,031 | 1,686 | 1,630 | 1,630 | 1,630 | 1,524 | 1,524 | 1,524 | 1,524 |
| Electric Energy (kWh) | 52,093 | 34,405 | 33,616 | 33,450 | 30,842 | 34,167 | 33,354 | 33,198 | 30,515 |
| Electric Demand (kW) | 29 | 30 | 30 | 30 | 30 | 29 | 29 | 29 | 29 |
| Electricity Cost ($) | 4,688 | 3,096 | 3,025 | 3,010 | 2,776 | 3,075 | 3,002 | 2,988 | 2,746 |
| Gas Cost ($) | 1,523 | 1,265 | 1,223 | 1,223 | 1,223 | 1,143 | 1,143 | 1,143 | 1,143 |
| Total Utility Cost ($) | 6,212 | 4,361 | 4,248 | 4,233 | 3,998 | 4,218 | 4,145 | 4,131 | 3,890 |
| Comp Run Time (hrs) | 803 | 693 | 670 | 662 | 567 | 691 | 664 | 656 | 558 |
| CO2 Emissions (mTons) | 42 | 30 | 29 | 29 | 27 | 29 | 28 | 28 | 27 |
| Equip Cost ($) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cost Savings (%) | 0 | 29.797 | 31.616 | 31.858 | 35.641 | 32.099 | 33.274 | 33.5 | 37.379 |
| Cost Savings ($) | 0 | 1,851 | 1,964 | 1,979 | 2,214 | 1,994 | 2,067 | 2,081 | 2,322 |
| Payback (yrs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Stat, Econ, and DCV Energy Savings

(Kansas City retro-fit, RTU circa 2000)

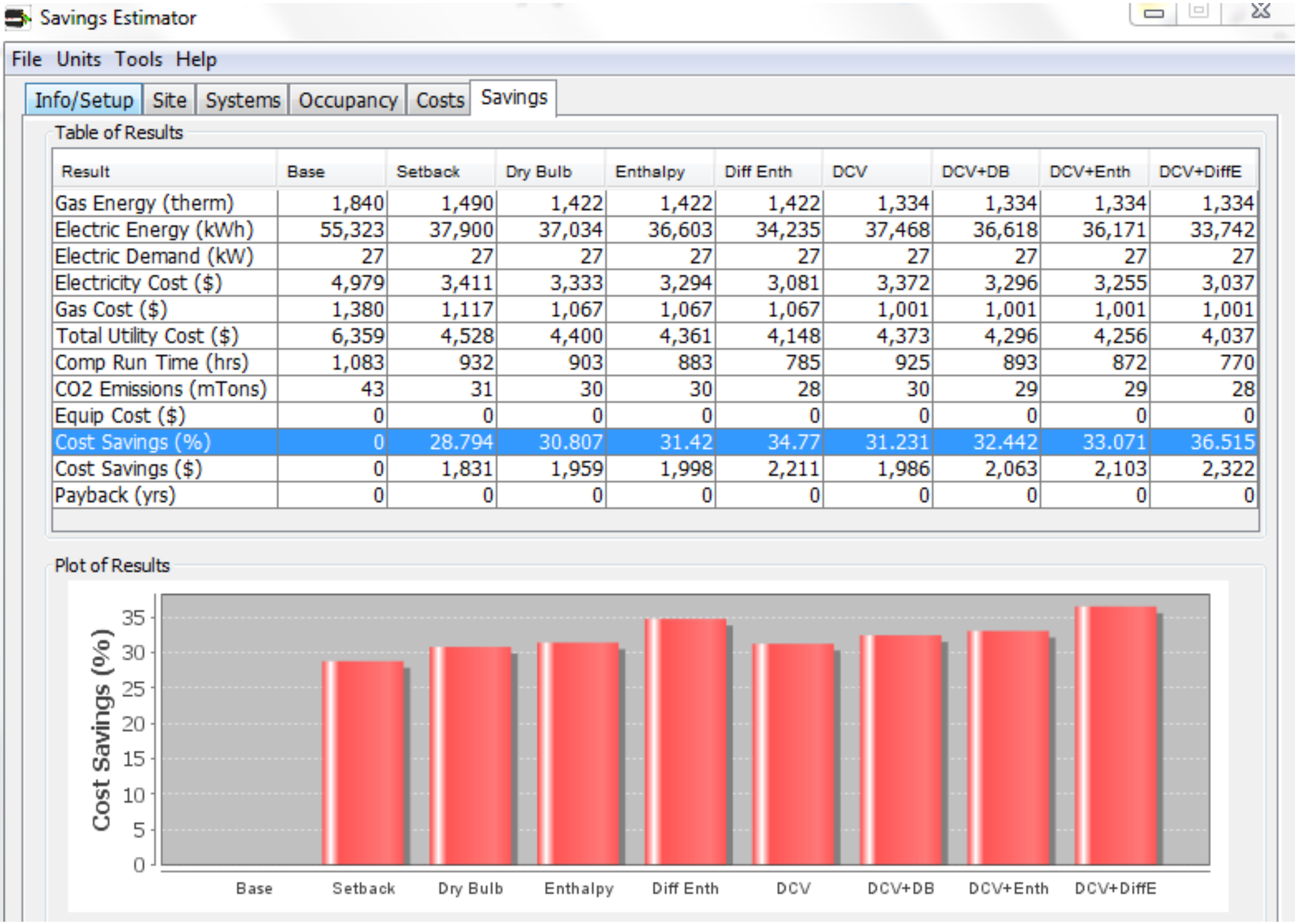


Table of Results

| Result | Base | Setback | Dry Bulb | Enthalpy | Diff Enth | DCV | DCV+DB | DCV+Enth | DCV+DiffE |
|---|---|---|---|---|---|---|---|---|---|
| Gas Energy (therm) | 1,840 | 1,490 | 1,422 | 1,422 | 1,422 | 1,334 | 1,334 | 1,334 | 1,334 |
| Electric Energy (kWh) | 55,323 | 37,900 | 37,034 | 36,603 | 34,235 | 37,468 | 36,618 | 36,171 | 33,742 |
| Electric Demand (kW) | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| Electricity Cost ($) | 4,979 | 3,411 | 3,333 | 3,294 | 3,081 | 3,372 | 3,296 | 3,255 | 3,037 |
| Gas Cost ($) | 1,380 | 1,117 | 1,067 | 1,067 | 1,067 | 1,001 | 1,001 | 1,001 | 1,001 |
| Total Utility Cost ($) | 6,359 | 4,528 | 4,400 | 4,361 | 4,148 | 4,373 | 4,296 | 4,256 | 4,037 |
| Comp Run Time (hrs) | 1,083 | 932 | 903 | 883 | 785 | 925 | 893 | 872 | 770 |
| CO2 Emissions (mTons) | 43 | 31 | 30 | 30 | 28 | 30 | 29 | 29 | 28 |
| Equip Cost ($) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cost Savings (%) | 0 | 28.794 | 30.807 | 31.42 | 34.77 | 31.231 | 32.442 | 33.071 | 36.515 |
| Cost Savings ($) | 0 | 1,831 | 1,959 | 1,998 | 2,211 | 1,986 | 2,063 | 2,103 | 2,322 |
| Payback (yrs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Plot of Results

# Example Rebates for CO2-based DCV

- Minnesota Power = $400
- Focus on Energy in Wisconsin
  - Single Zone RTU = $400
  - Multi-zone RTU = $0.20 per OA CFM
- Minnesota Xcel
  - $20/ton as part of the economizer rebate
- ComEd Electric in Illinois
  - $0.04 per ft2
  - Or as part of new Advanced RTU Control package
- NIPSCO Gas in Indiana
  - $0.15 per ft2
- Efficiency United in Michigan
  - $0.08 per ft2 (gas side)
  - $0.035 per ft2 (electric side)
- Many Midwestern gas utilities permit under custom

Please read all rules and qualifications for each incentive.

# Energy Recovery Ventilation (ERV)

# Potential HVAC Energy Conservation

- Analyzed 40 technologies
- Summary report shows top 15 technologies
- Power station provides about 1.1 quad per year
- 1 quad = $10^{15}$ BTU/H

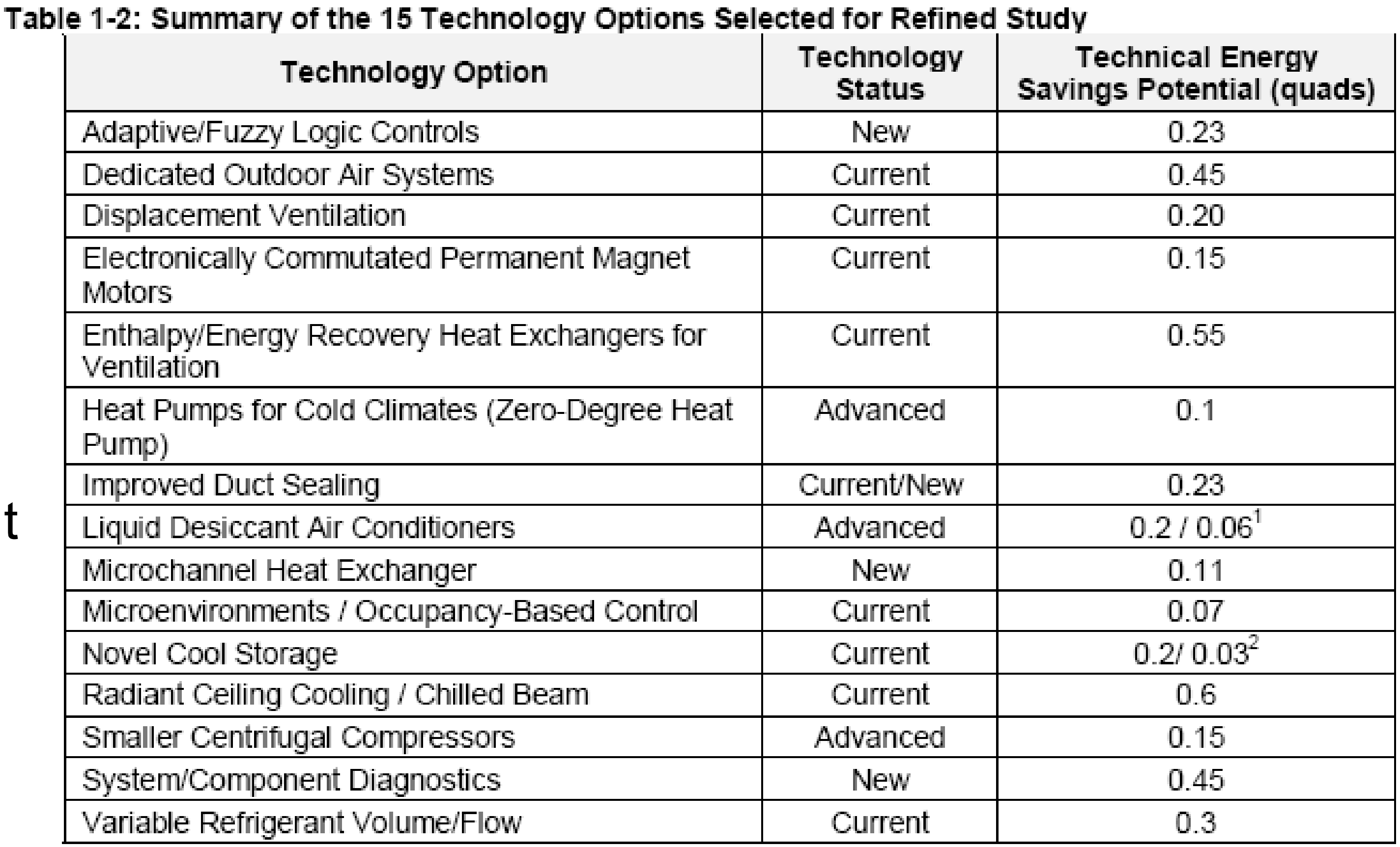


**Table 1-2: Summary of the 15 Technology Options Selected for Refined Study**

| Technology Option | Technology Status | Technical Energy Savings Potential (quads) |
|---|---|---|
| Adaptive/Fuzzy Logic Controls | New | 0.23 |
| Dedicated Outdoor Air Systems | Current | 0.45 |
| Displacement Ventilation | Current | 0.20 |
| Electronically Commutated Permanent Magnet Motors | Current | 0.15 |
| Enthalpy/Energy Recovery Heat Exchangers for Ventilation | Current | 0.55 |
| Heat Pumps for Cold Climates (Zero-Degree Heat Pump) | Advanced | 0.1 |
| Improved Duct Sealing | Current/New | 0.23 |
| Liquid Desiccant Air Conditioners | Advanced | 0.2 / 0.06[1] |
| Microchannel Heat Exchanger | New | 0.11 |
| Microenvironments / Occupancy-Based Control | Current | 0.07 |
| Novel Cool Storage | Current | 0.2/ 0.03[2] |
| Radiant Ceiling Cooling / Chilled Beam | Current | 0.6 |
| Smaller Centrifugal Compressors | Advanced | 0.15 |
| System/Component Diagnostics | New | 0.45 |
| Variable Refrigerant Volume/Flow | Current | 0.3 |

U.S. Department of Energy July 2002

# The ABCs of ERVs

- Ventilation with Energy Recovery

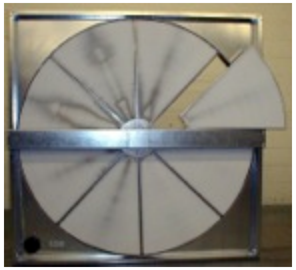
  **<u>E</u> – Energy**

  **<u>R</u> – Recovery**

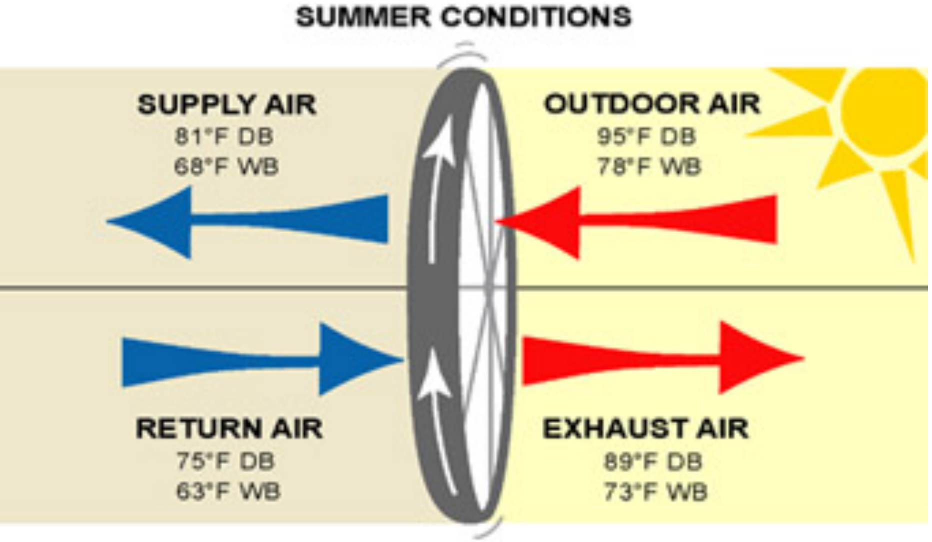
  **<u>V</u> – Ventilator**

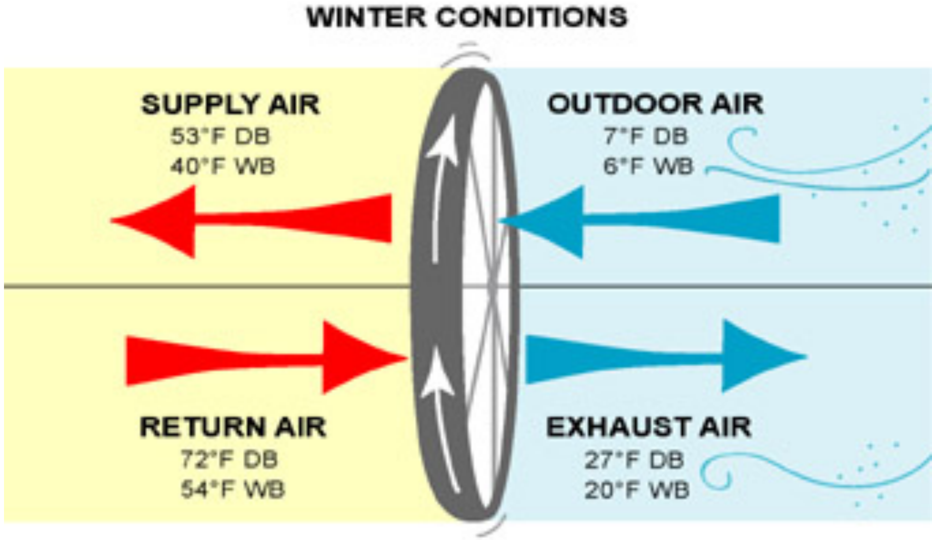
- KEY QUESTION – How much outside air is required?

# Energy Recovery Ventilators (ERV)



- Uses exhaust air to pre-heat or pre-cool ventilation air
- Can be adapted to existing systems
- HRV or ERV? Wheel or fixed plate?
- Improvements to IAQ
- Required by code in some cases
- Paybacks less than 24 months





| OUTSIDE AIR (CFM) | ERV MODEL | VENTILATION LOAD A/C REDUCTION (TONS) | VENTILATION LOAD HEAT REDUCTION (BTU/h) | NEW O/A CONDITIONS SUMMER (DB / WB) | NEW O/A CONDITIONS WINTER (DB / WB) | ECONOMIC ANALYSIS PAYBACK (YEARS) | ECONOMIC ANALYSIS ROI % | ECONOMIC ANALYSIS ANNUAL SAVINGS |
|---|---|---|---|---|---|---|---|---|
| 500 | EVAA bolt-on | 1.0 | 31,367 | 82.2 / 68.7 | 41.0 / 33.8 | | | $400 |
| 500 | EVCC | 1.4 | 43,961 | 78.4 / 65.7 | 56.1 / 44.6 | 4.6 | 22 | $550 |
| 1000 | EVCD | 2.6 | 80,611 | 79.7 / 66.4 | 50.4 / 41.2 | 3.1 | 32 | $940 |
| 1500 | D | 3.9 | 120,367 | 79.8 / 66.5 | 49.9 | 1.6 | | $1,400 |
| 2000 | EVED | 5.3 | 163,748 | 79.5 / 66.3 | 50.9 / 41.6 | 1.6 | 63 | $1,940 |
| 2500 | EVED | 6.2 | 194,161 | 80.3 / 66.8 | 47.6 / 39.3 | 1.1 | 91 | $2,100 |
| 3000 | EVHF | 7.9 | 245,774 | 79.4 / 66.4 | 51.5 / 41.7 | 1.1 | 91 | $3,270 |
| 4000 | EVHD | 10.8 | 331,501 | 79.4 / 66.2 | 51.7 / 42.1 | 0.6 | 157 | $4,160 |
| 5000 | EVKG | 13.3 | 409,900 | 79.5 / 66.3 | 51.1 / 41.7 | 0.6 | 167 | $5,550 |
| 6000 | EVLD | 16.5 | 505,827 | 79.1 / 66.0 | 53.0 / 42.9 | 0.9 | 111 | $6,570 |
| 7000 | EVKD | 18.0 | 554,912 | 80.0 / 66.6 | 49.0 / 40.3 | 0.4 | 250 | $6,570 |
| 8000 | EVLD | 20.6 | 635,832 | 79.9 / 66.6 | 49.1 / 40.4 | 0.3 | 333 | $7,580 |
| 9000 | EVND | 24.8 | 755,867 | 79.2 / 66.0 | 52.6 / 42.8 | 0.4 | 250 | $9,750 |
| 10000 | EVMD | 25.4 | 783,645 | 80.1 / 66.8 | 48.2 / 39.8 | 0.4 | 250 | $9,150 |
| 12,000 | | 31.0 | 943,255 | 80.2 / 66.6 | 48.0 / 40.0 | 0.1 | | $11,100 |
| 14,000 | EVRD | 36.9 | 1,121,163 | 79.9 / 66.4 | 49.3 / 40.8 | 0.5 | 200 | $13,600 |
| 16,000 | EVSD | 42.6 | 1,295,721 | 79.7 / 66.3 | 50.0 / 41.3 | 0.4 | 250 | $16,000 |
| 18,000 | EVSD | 46.5 | 1,414,388 | 80.2 / 66.6 | 48.0 / 40.0 | 0.3 | 333 | $16,700 |
| 20,000 | EVTD | 51.4 | 1,560,067 | 80.3 / 66.6 | 47.5 / 39.7 | 0.1 | 1000 | $18,300 |

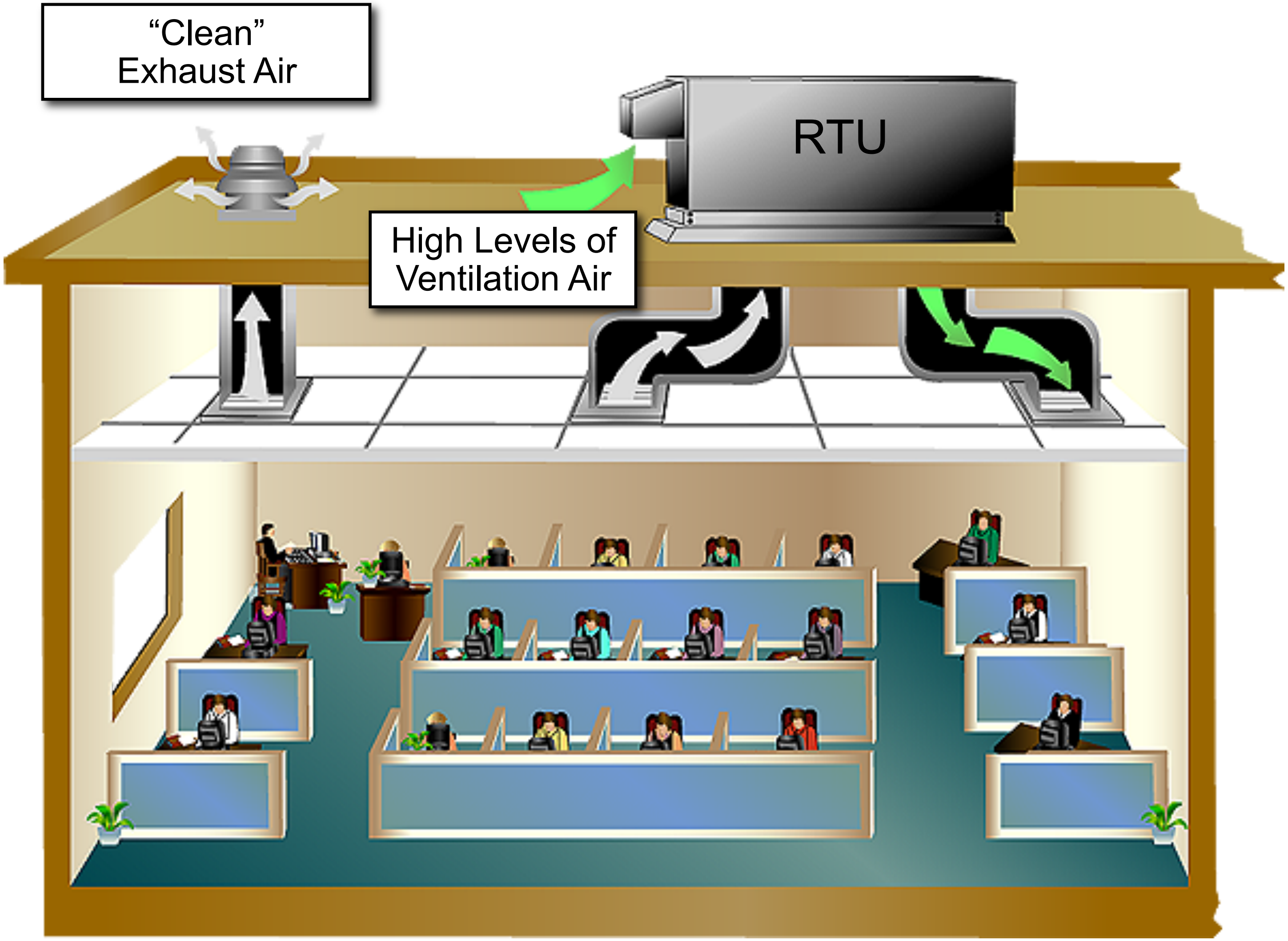
# Identifying Potential Recovery Applications

## When to Use ERV

- Anywhere constant air changes are required and humidity control (latent capacity) is an issue
- When large quantities of ventilation air are desired
- When long-term energy cost are more important then first cost
- When there is a need to expand beyond the typical RTU operational characteristics:

**More latent vs. sensible capability**
**Higher system efficiencies**
**Lower energy consumption**
**More stages of operation**

# Identifying Potential Applications



## Candidates for Recovery

- Retail
- Schools
- Offices
- Theaters
- Fitness Centers
- Gymnasiums
- Hospitals
- Restaurants
- Nursing Homes

# Plate Exchanger Crossflow

50 to 80 % <u>sensible</u> effectiveness – latent possible