Titus
The Leader in Air Management

ret-ro-fit

# titus retrofit energy solutions

www.titus-hvac.com

U.S. Green Building Council Member

GreenSpec® LISTED
www.GreenSpec.com

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Table of Contents (continued)

# Energy Savings through Titus Retrofit Systems

General operating costs have increased steadily over the years; with rising energy costs and energy inefficiencies within HVAC systems contributing to that increasing cost. Many in the commercial building industry have achieved cost and energy savings without sacrificing comfort by retrofitting with energy responsible or green products.

Titus has been a leader in retrofitting buildings for energy savings for over 30 years. This educational guide will offer a detailed explanation of available retrofit options within the Titus product lines while demonstrating the cost and energy saving advantages.

GreenSpec listed solutions are also available for building projects looking to achieve LEED credits and certification through retrofitting.

The Terminal Units section includes examples of some of, but not limited to, the pre-existing system types and how they can be retrofitted for energy savings:

- ◇ Mechanical Constant Air Volume Systems
- ◇ Mechanical Variable Air Volume (VAV) Systems
- ◇ Bypass Systems
- ◇ Induction Systems
- ◇ System Powered VAV Systems
- ◇ Multi-Zone Systems
- ◇ Low Pressure Single Duct Re-Heat Systems

This section will also supply various alternative options for energy savings through the use of:

- ◇ ECM (Electronically Commutated Motor) assemblies
- ◇ VAV Diffusers
- ◇ Pneumatic, Analog, and Digital Control strategies

The Grille, Diffuser, and Accessory section discusses retrofit options based on efficient product selection for applications and an energy savings return. Options that will contribute to energy savings in retrofit applications:

- ◇ Low Pressure Diffusers
- ◇ Low Pressure Grilles
- ◇ GRD Accessories
- ◇ Displacement Ventilation
- ◇ Chilled Beam

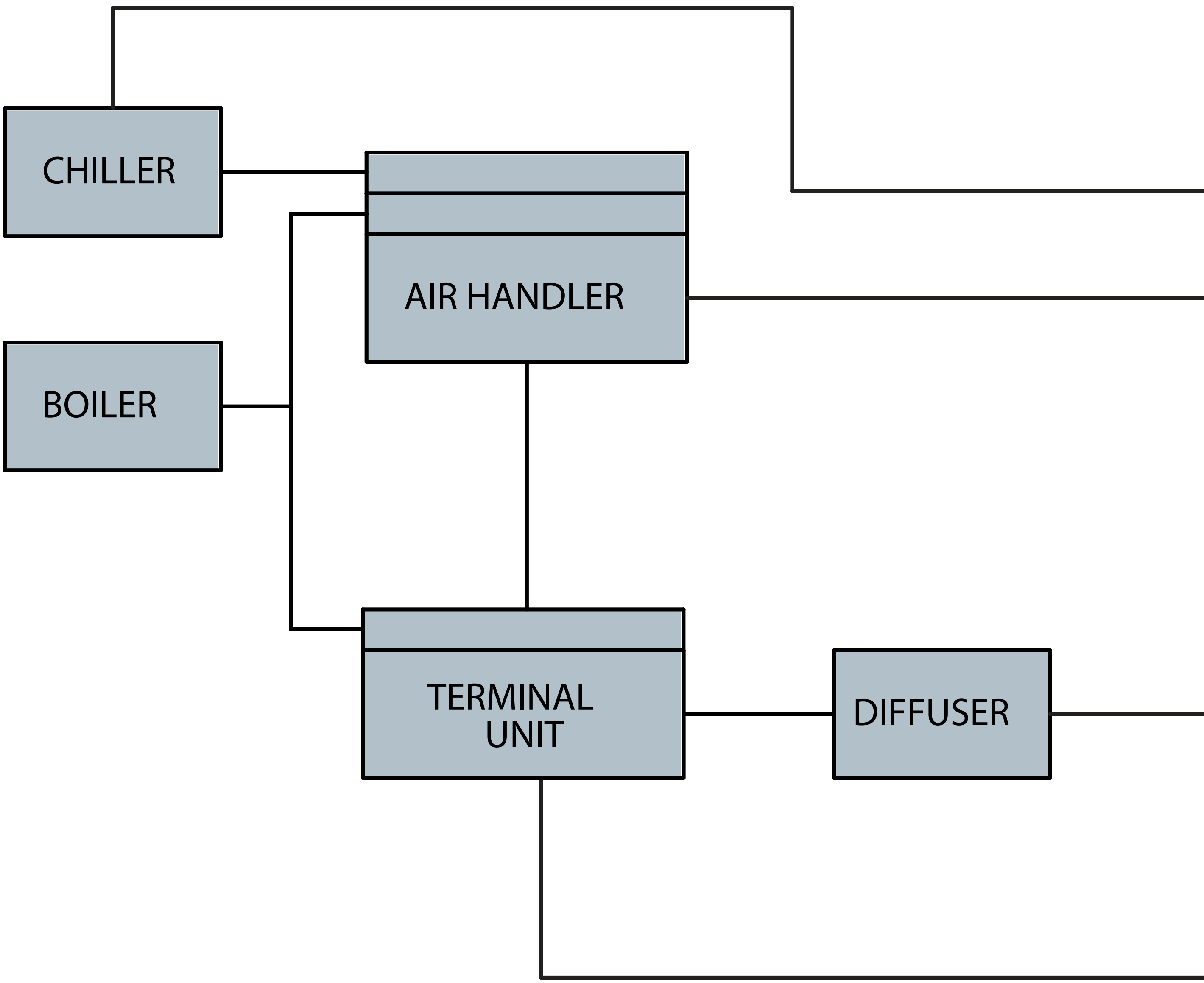
The Fan Coil section details achievable savings by upgrading individual components inside a unit to realize long term returns on investment and a reduced carbon footprint. The Fan Coil portion will expand on these points and show how they can be utilized to save on building operation expenses.

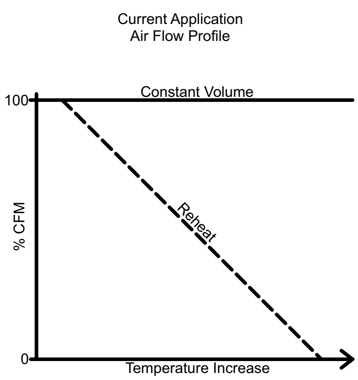
- ◇ Modulated Control Valves
- ◇ Electronically Commutated Speed Fan Motors
- ◇ Low Static Pressure Filters / Monitoring System
- ◇ PID Controls with Supported Accessories

Case studies illustrating Titus' decades of retrofit experience are included throughout this guide to highlight projects while documenting actual energy savings, equipment modifications, and provide additional insight into the depth of experience Titus has with these energy saving systems.

Please reference the Titus website at www.titus-hvac.com for full documentation and literature for any of the products listed or more solutions.

# MECHANICAL CONSTANT VOLUME SINGLE DUCT



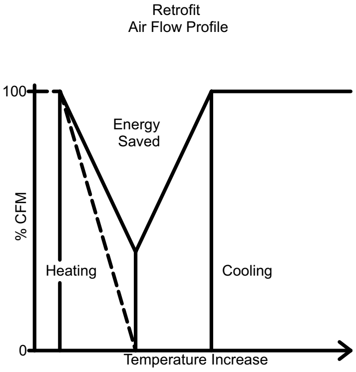
## RETROFIT SOLUTION

Absorption chillers efficiency – cop 8+
Water cooled centrifugal chiller with inverter controls – cop 7+
Water cooled screw chillers with inverter controls – cop 5+

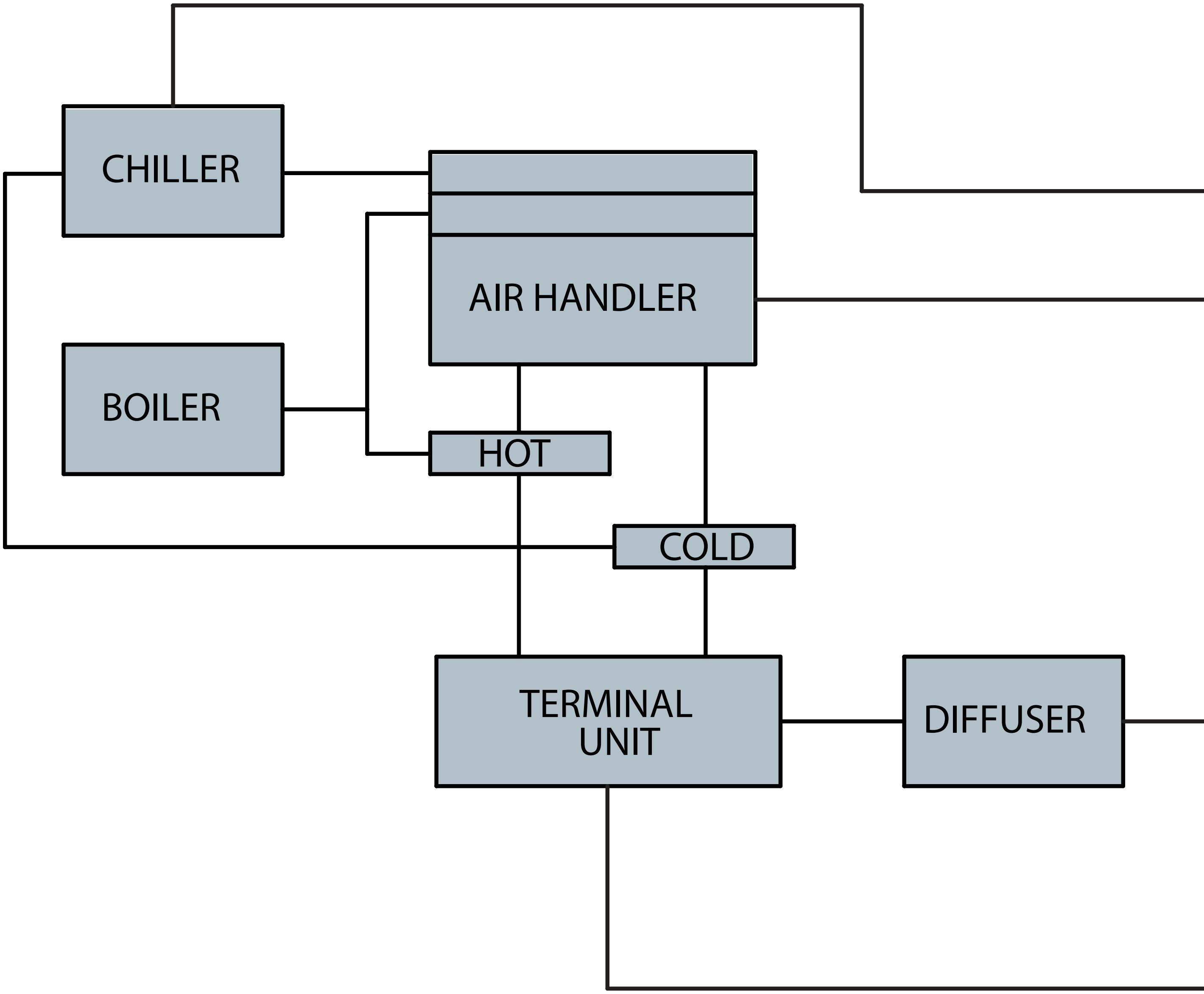
Change to variable speed drive
Change to variable pitch

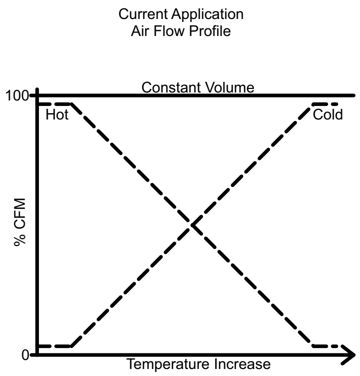
Refer to the diffuser section of this guide on pages 59-74 to select the unit best suited for your project

Change to variable air volume
Update controls to analog or digital
Retrofit using Titus ECT
Refer to the terminal unit section of this guide on pages 46, 47, 48, and 52 to select the unit best suited for your project



# MECHANICAL CONSTANT VOLUME DUAL DUCT



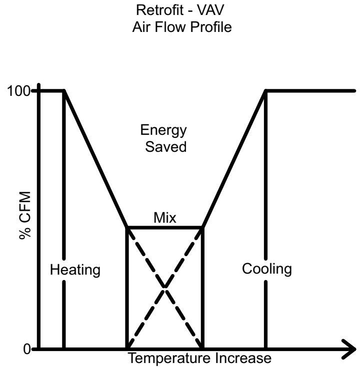
# RETROFIT SOLUTION

Absorption chillers efficiency – cop 8+
Water cooled centrifugal chiller with inverter controls – cop 7+
Water cooled screw chillers with inverter controls – cop 5+

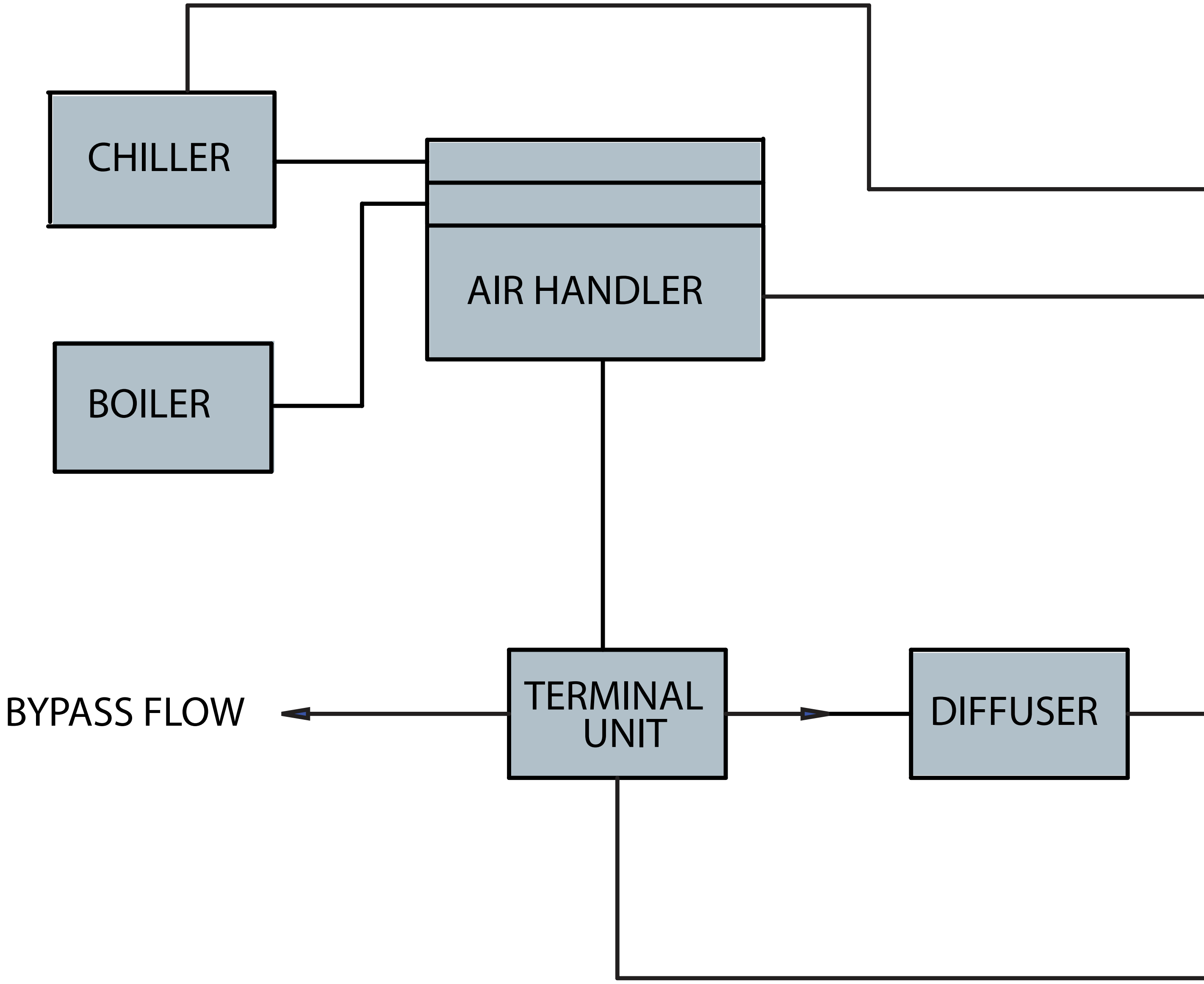
Change to variable speed drive
Change to variable pitch

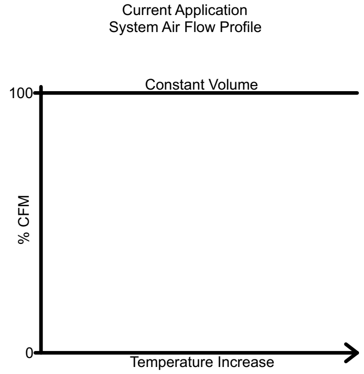
Refer to the diffuser section of this guide on pages 59-74 to select the unit best suited for your project

Change to variable air volume
Update controls to analog or digital
Retrofit using Titus ECT
Refer to the terminal unit section of this guide on pages 47-48 to select the unit best suited for your project



## BYPASS SYSTEM



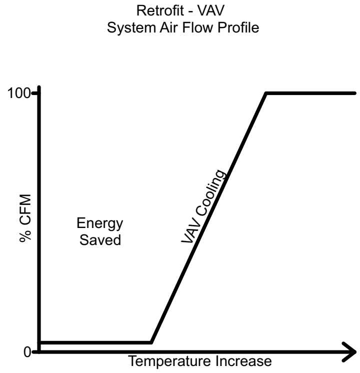
# RETROFIT SOLUTION

Absorption chillers efficiency – cop 8+
Water cooled centrifugal chiller with inverter controls – cop 7+
Water cooled screw chillers with inverter controls – cop 5+

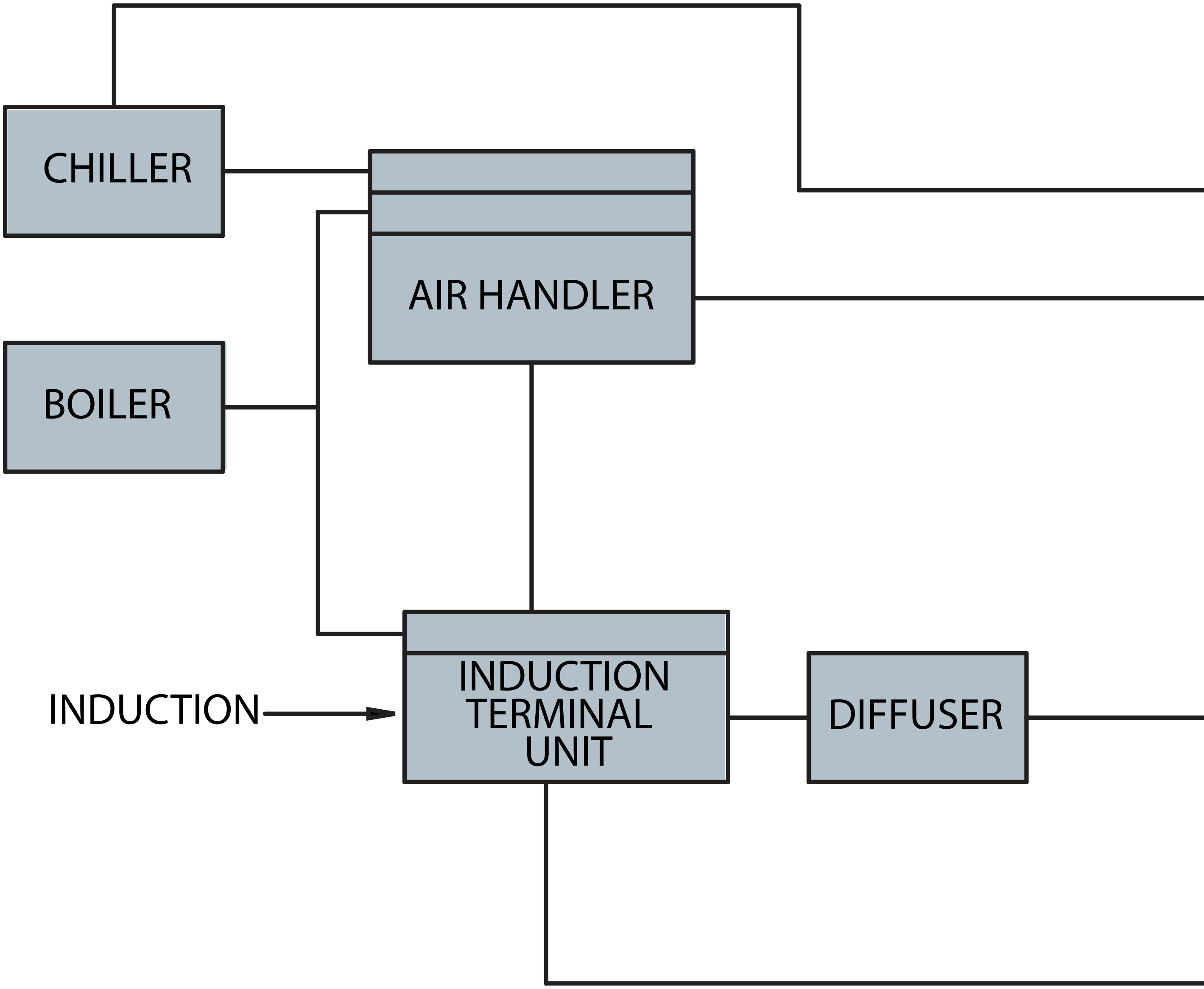
Change to variable speed drive
Change to variable pitch

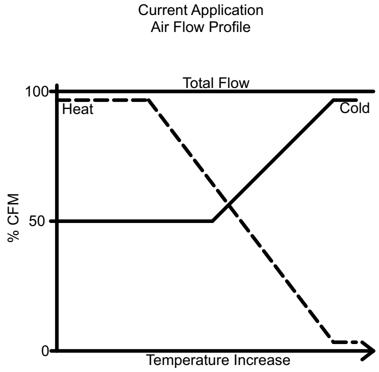
Refer to the diffuser section of this guide on pages 59-74 to select the unit best suited for your project

Blank off the induction opening
Update controls to analog & use Titus ECX
Update controls to digital & use Titus EXX
Refer to the terminal unit section of this guide on pages 48-49 to select the unit best suited for your project



# INDUCTION SYSTEM - CEILING



# RETROFIT SOLUTION

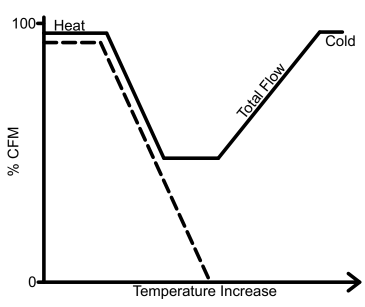
Absorption chillers efficiency – cop 8+
Water cooled centrifugal chiller with inverter controls – cop 7+
Water cooled screw chillers with inverter controls – cop 5+

Change to variable speed drive
Change to variable pitch

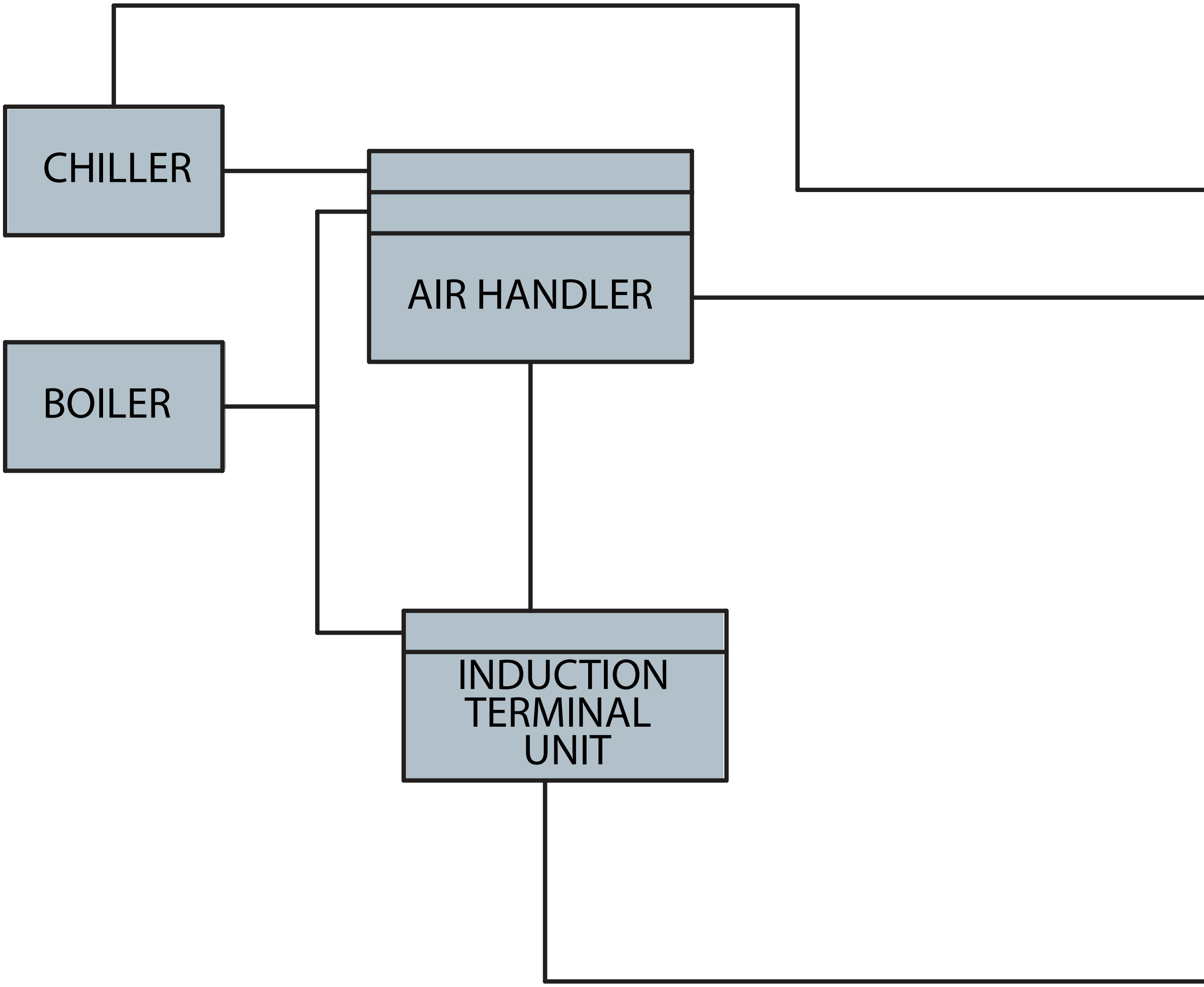
Refer to the diffuser section of this guide on pages 59-74 to select the unit best suited for your project

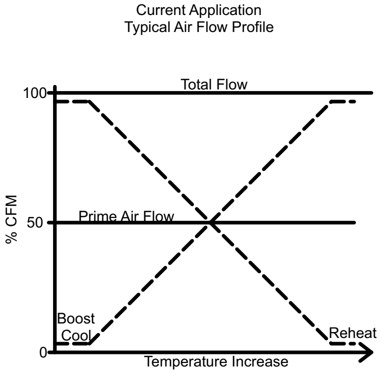
Blank off the induction opening
Update controls to digital & use Titus EXX
Refer to the terminal unit section of this guide on pages 45-58 to select the unit best suited for your project

Retrofit Application
Air Flow Profile



## INDUCTION SYSTEM - UNDER WINDOW



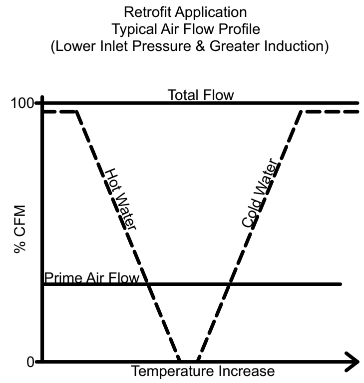



# RETROFIT SOLUTION

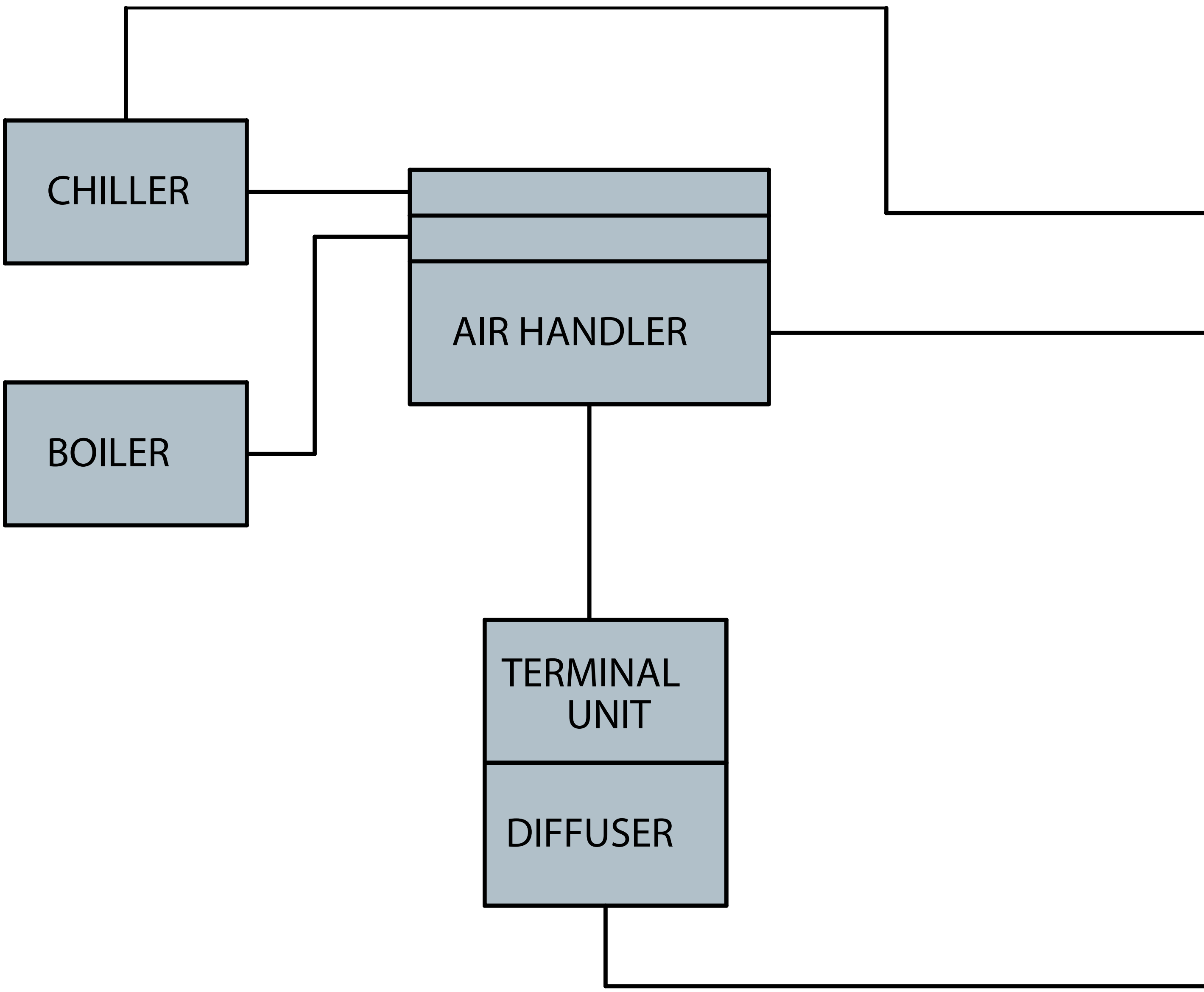
Absorption chillers efficiency – cop 8+
Water cooled centrifugal chiller with inverter controls – cop 7+
Water cooled screw chillers with inverter controls – cop 5+

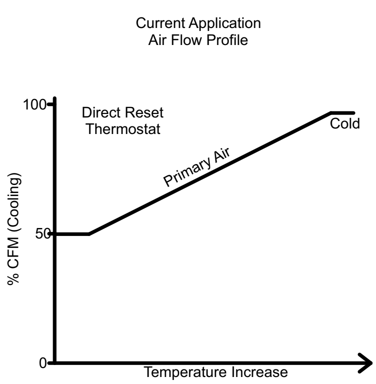
Change to variable speed drive
Change to variable pitch

Replace using chilled beam unit with hot & cold water coil
Refer to the terminal unit section of this guide on page 50 to select the unit best suited for your project



## SYSTEM POWERED VARIABLE VOLUME



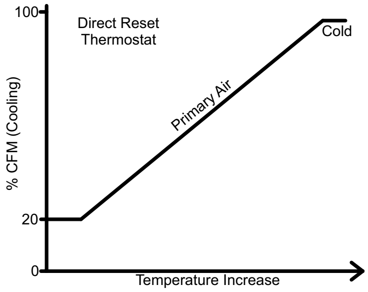
# RETROFIT SOLUTION

Absorption chillers efficiency – cop 8+
Water cooled centrifugal chiller with inverter controls – cop 7+
Water cooled screw chillers with inverter controls – cop 5+

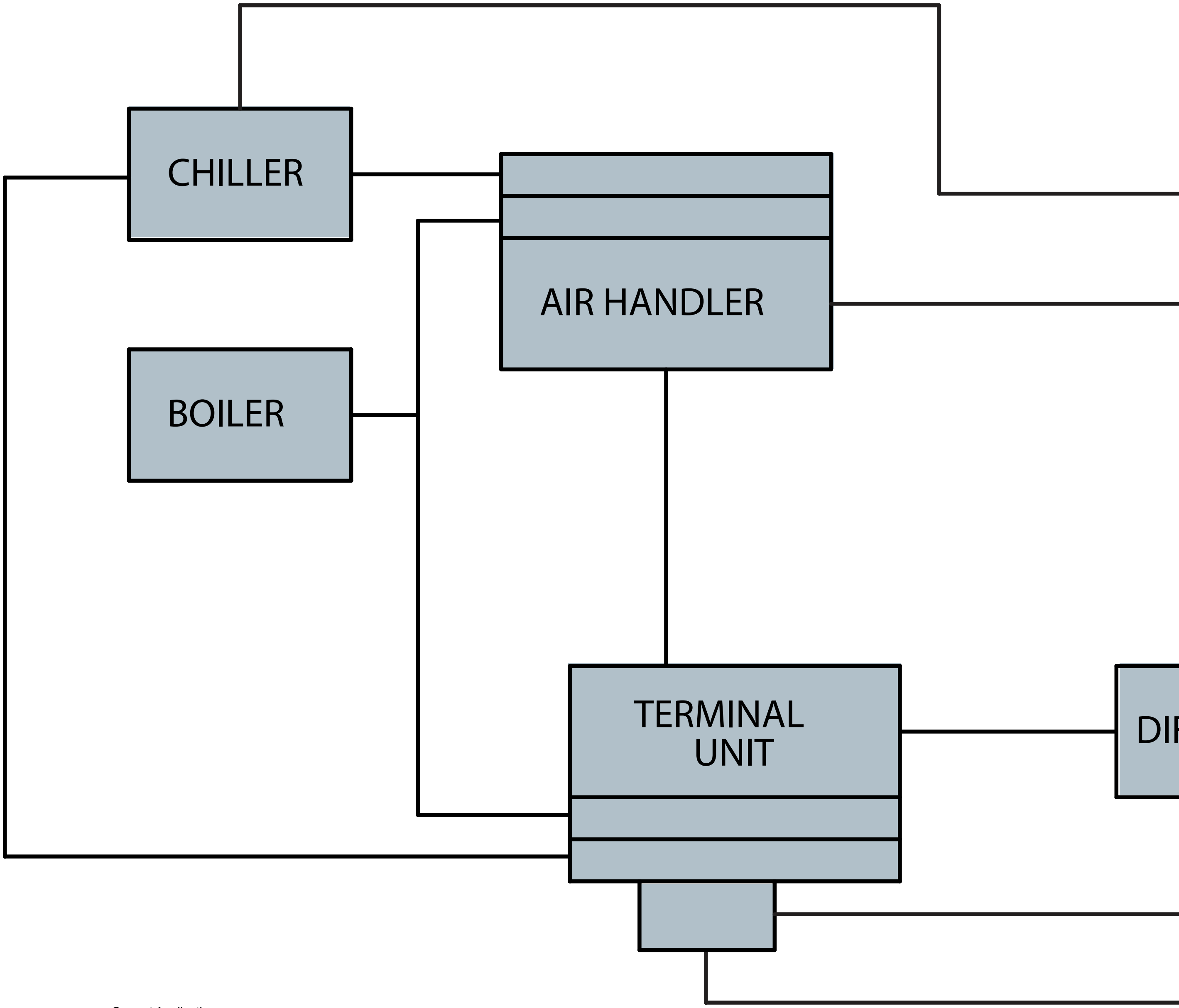
Change to variable speed drive
Change to variable pitch

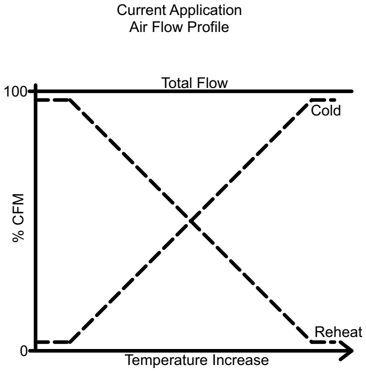
Remove controls & use Titus ECV to reduce system pressure and improve cfm range
Refer to the terminal unit section of this guide on pages 45-58 to select the unit best suited for your project

Retrofit
Air Flow Profile
(Lower Blower Pressure)



## MULTI-ZONE SYSTEM



## RETROFIT SOLUTION

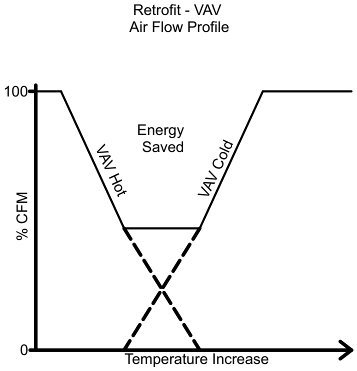
Absorption chillers efficiency – cop 8+
Water cooled centrifugal chiller with inverter controls – cop 7+
Water cooled screw chillers with inverter controls – cop 5+

Change to variable speed drive
Change to variable pitch

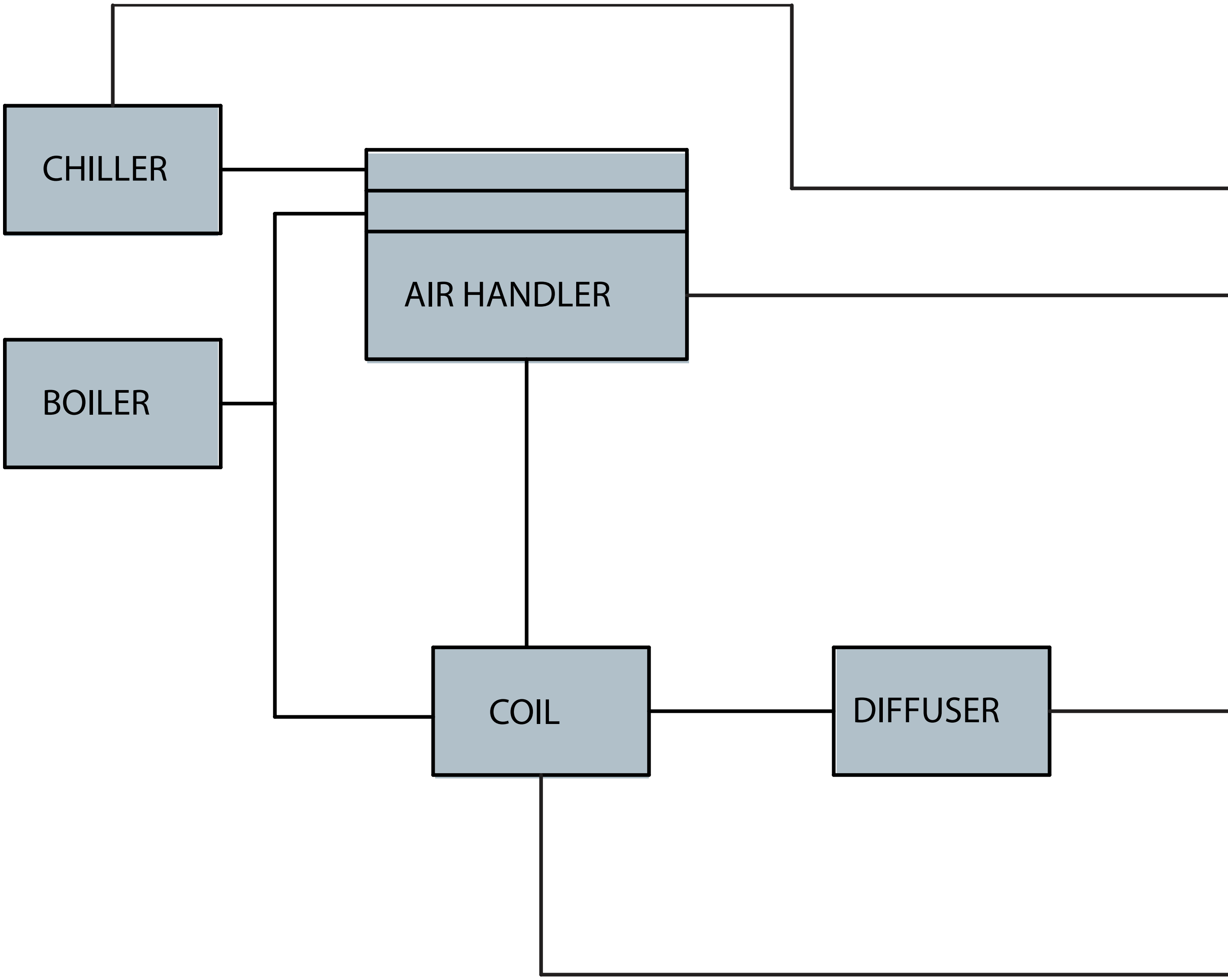
FFUSER

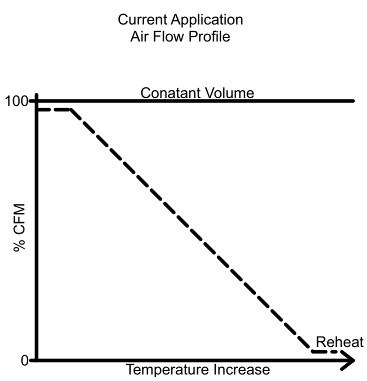
Refer to the diffuser section of this guide on pages 59-74 to select the unit best suited for your project

Retrofit using Titus QCV
Refer to the terminal unit section of this guide on page 51 to select the unit best suited for your project



# LOW-PRESSURE CONSTANT VOLUME REHEAT



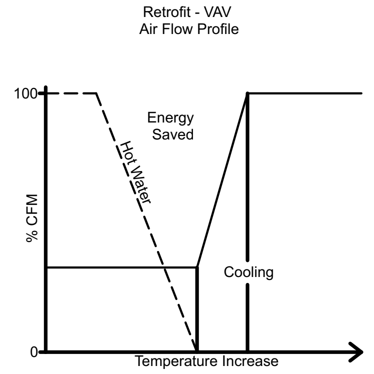
# RETROFIT SOLUTION

Absorption chillers efficiency – cop 8+
Water cooled centrifugal chiller with inverter controls – cop 7+
Water cooled screw chillers with inverter controls – cop 5+

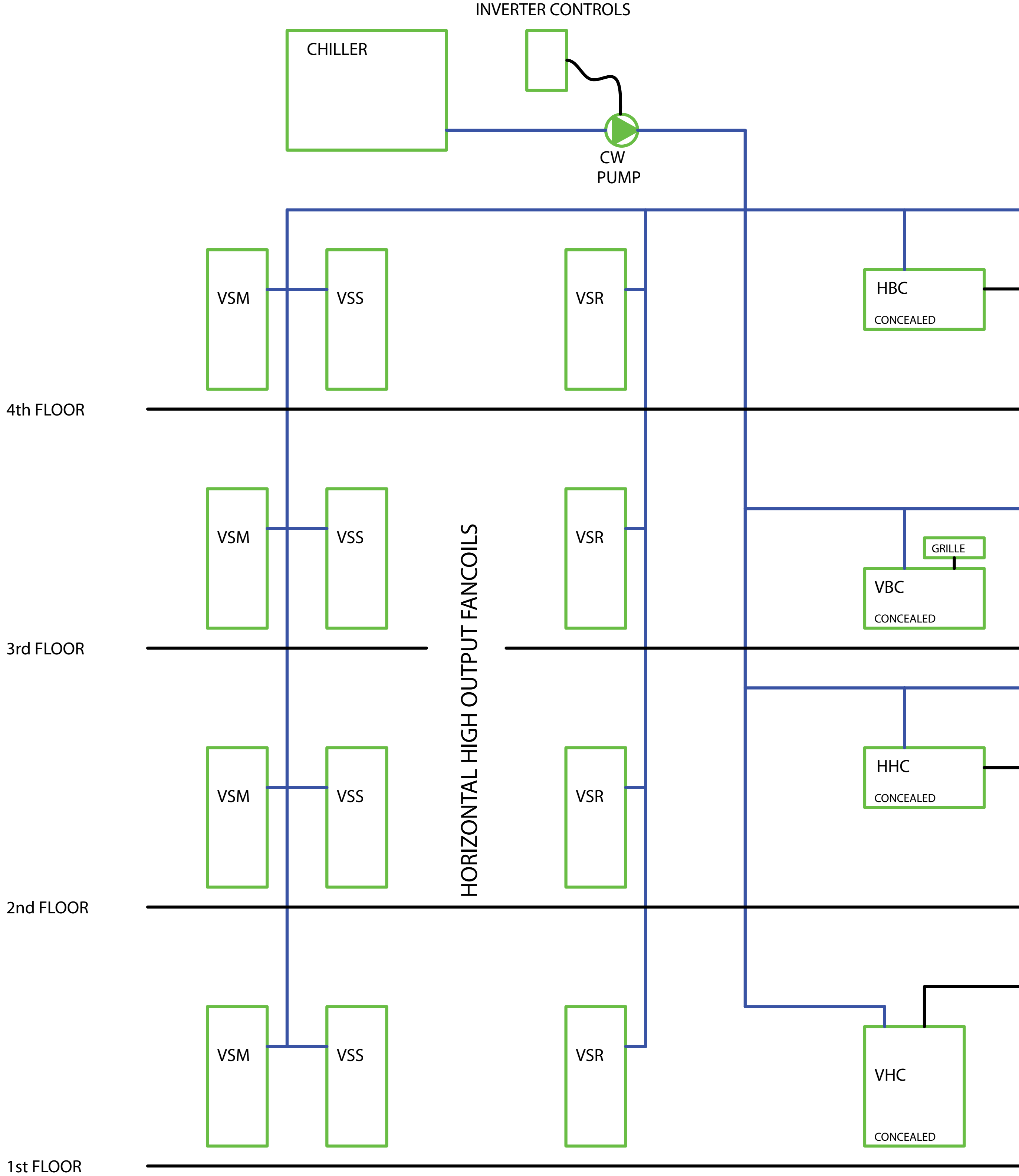
Change to variable speed drive
Change to variable pitch

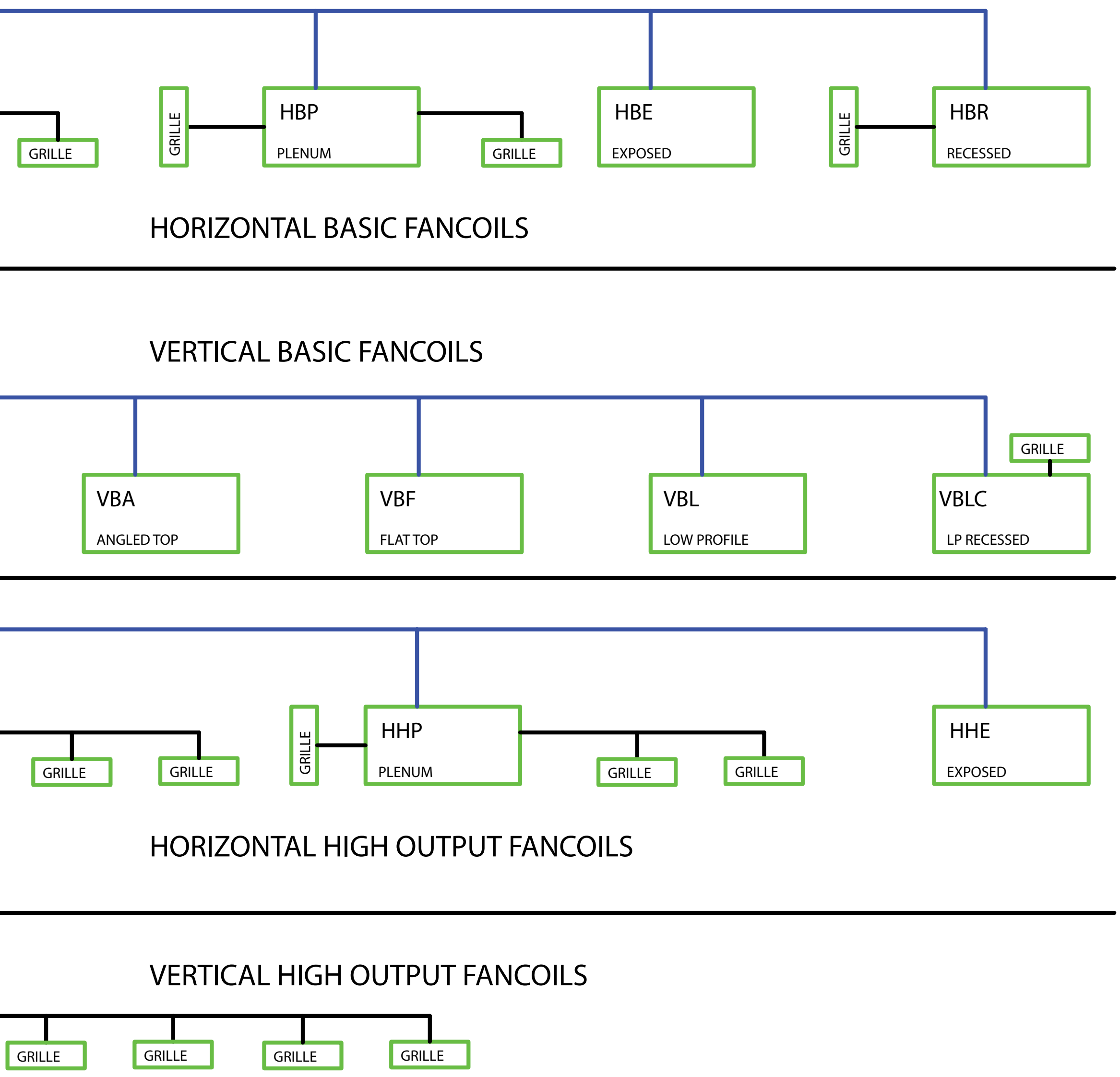
Refer to the diffuser section of this guide on pages 59-74 to select the unit best suited for your project

Retrofit using Titus QCV
Refer to the terminal unit section of this guide on page 53 to select the unit best suited for your project



# 2 Pipe System - Cooling Only with or without Electric Heaters

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EXPOSED
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RECESSED
HORIZONTAL BASIC FANCOILS
VERTICAL BASIC FANCOILS
VBA
ANGLED TOP
VBF
FLAT TOP
VBL
LOW PROFILE
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VBLC
LP RECESSED
GRILLE
GRILLE
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HHP
PLENUM
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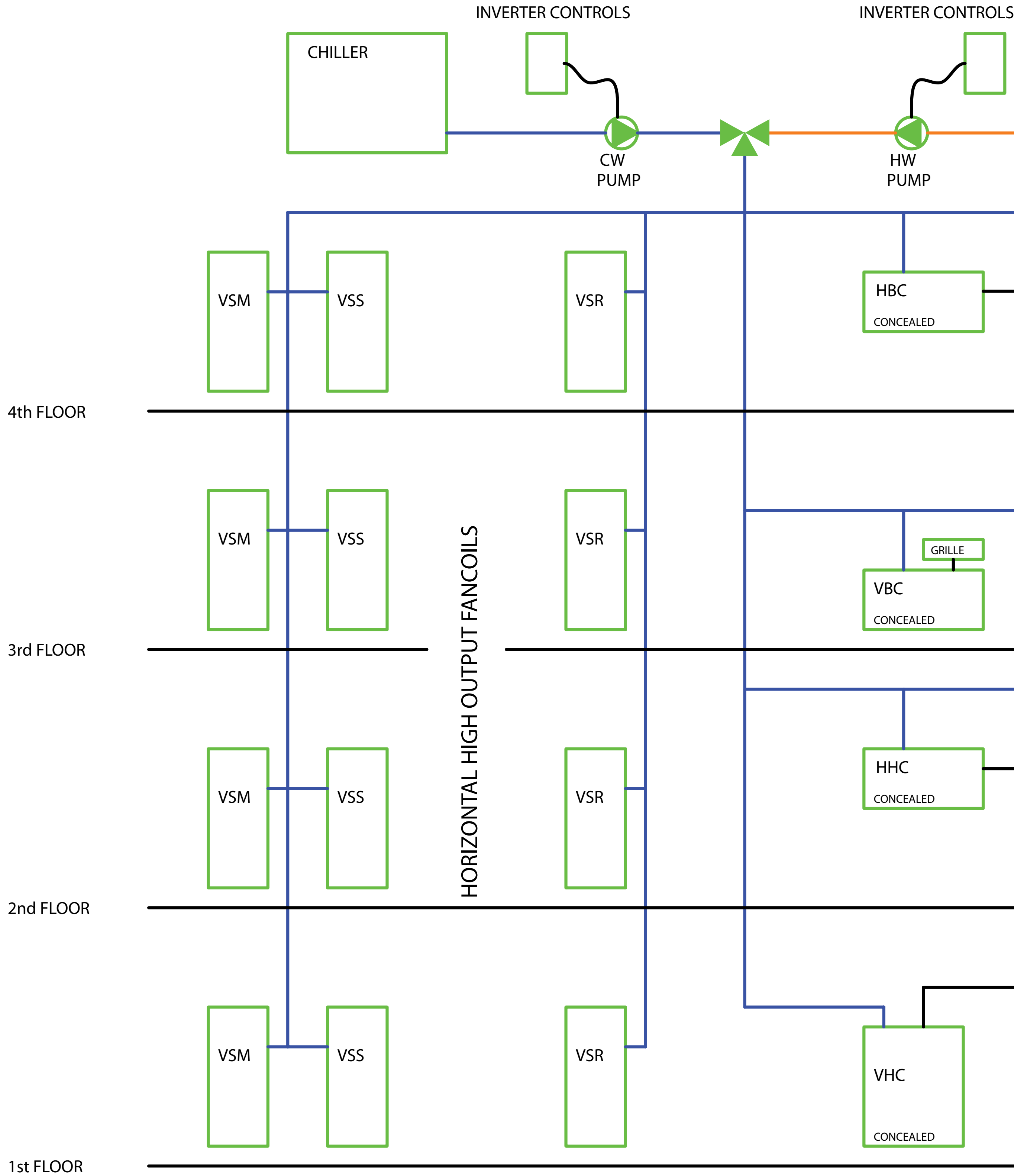
EXPOSED
HORIZONTAL HIGH OUTPUT FANCOILS
VERTICAL HIGH OUTPUT FANCOILS
GRILLE
GRILLE
GRILLE
GRILLE

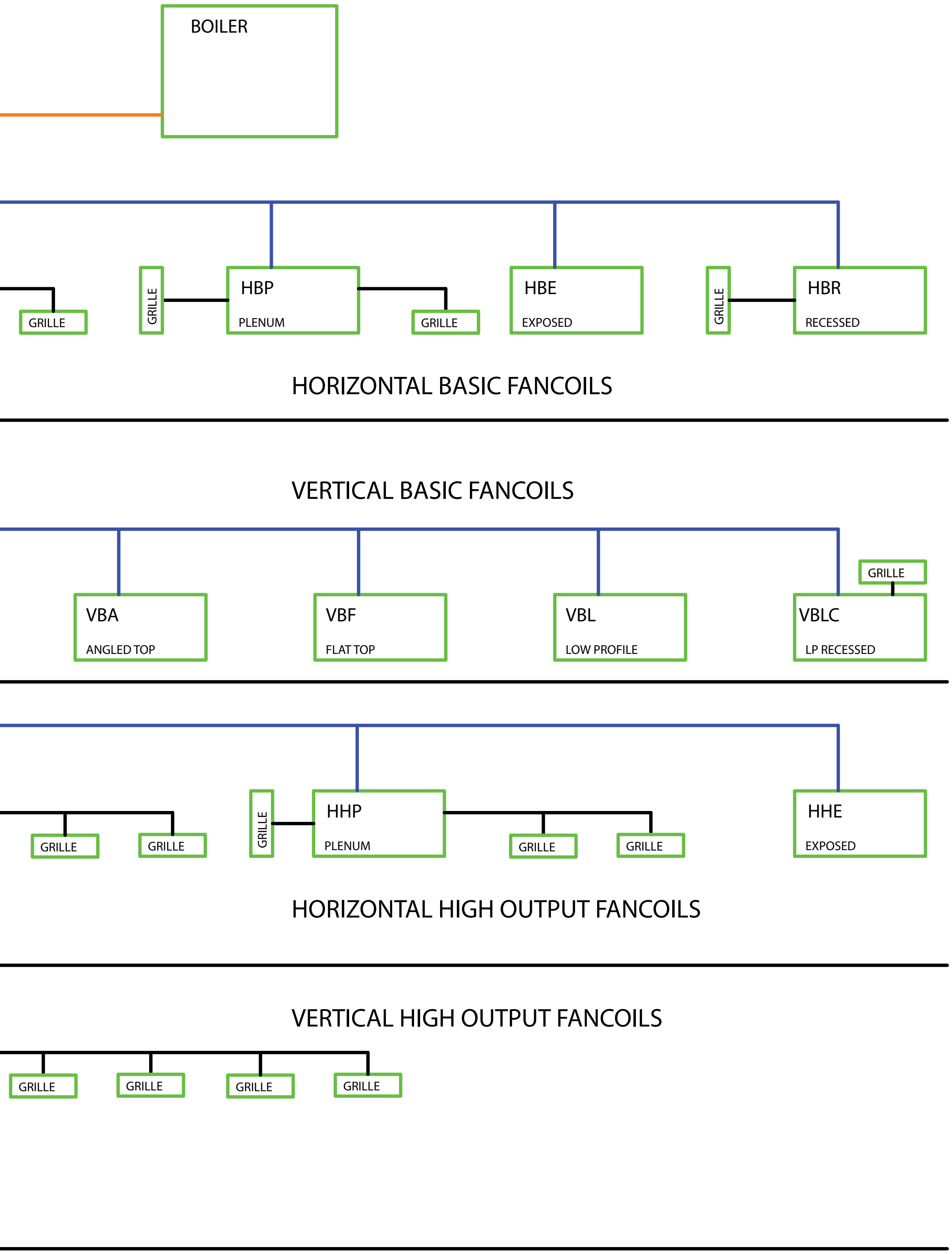
# 2 Pipe System - Cooling Only with or without Electric Heaters

| Retrofit Energy Improvement Alternatives | Potential Energy Improvement | Page Reference |
|---|---|---|
| **Chillers** | | |
| ◇ Absorption Chillers Efficiency – COP 8+ | 🍃🍃🍃🍃🍃 | by others |
| ◇ Water Cooled Centrifugal Chiller with Inverter Controls – COP 7+ | 🍃🍃🍃🍃 | by others |
| ◇ Water Cooled Screw Chillers with Inverter Controls – COP 5+ | 🍃🍃🍃 | by others |
| **Boilers** | | |
| ◇ Replace Electric Heaters in Fancoils with Chilled/Hot Water 2 Pipe System | 🍃🍃🍃🍃🍃 | by others |
| **Pumps** | | |
| ◇ Higher Efficiency Motor Pumps with Inverter Controls | 🍃🍃🍃🍃🍃 | by others |
| ◇ Higher Efficiency Motor Pumps | 🍃🍃🍃🍃 | by others |
| **System Strainers** | | |
| ◇ Strainers with large mesh areas to avoid high pressure drops | 🍃🍃🍃🍃🍃 | by others |
| **System Piping** | | |
| ◇ Water Treatment System to reduce Fouling Factor | 🍃🍃🍃🍃🍃 | by others |
| ◇ Improve Design and Fittings to lower the Friction Losses | 🍃🍃🍃🍃 | by others |
| **Duct System** | | |
| ◇ Improve Design to lower Air Friction Losses | 🍃🍃🍃🍃🍃 | by others |
| ◇ Minimize leakages | 🍃🍃🍃🍃 | by others |
| ◇ Retrofit Grilles with lower pressure drops | 🍃🍃🍃🍃🍃 | by others |
| **Fan Coil Units** | | |
| ◇ ECM Motors | 🍃🍃🍃🍃🍃 | page 96 |
| ◇ Modulated Water Control Valves | 🍃🍃🍃🍃🍃 | page 96 |
| ◇ Programmable Thermostats | 🍃🍃🍃🍃 | page 97 |
| ◇ Occupancy Sensors | 🍃🍃🍃🍃 | page 97 |
| ◇ Pleated Filters | 🍃🍃🍃 | page 97 |

## NOTES

# 2 Pipe System with Chilled and Hot Water




BOILER
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PLENUM
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HBR
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HORIZONTAL BASIC FANCOILS
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VBA
ANGLED TOP
VBF
FLAT TOP
VBL
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VBLC
LP RECESSED
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HHP
PLENUM
GRILLE
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HHE
EXPOSED
HORIZONTAL HIGH OUTPUT FANCOILS
VERTICAL HIGH OUTPUT FANCOILS
GRILLE
GRILLE
GRILLE
GRILLE

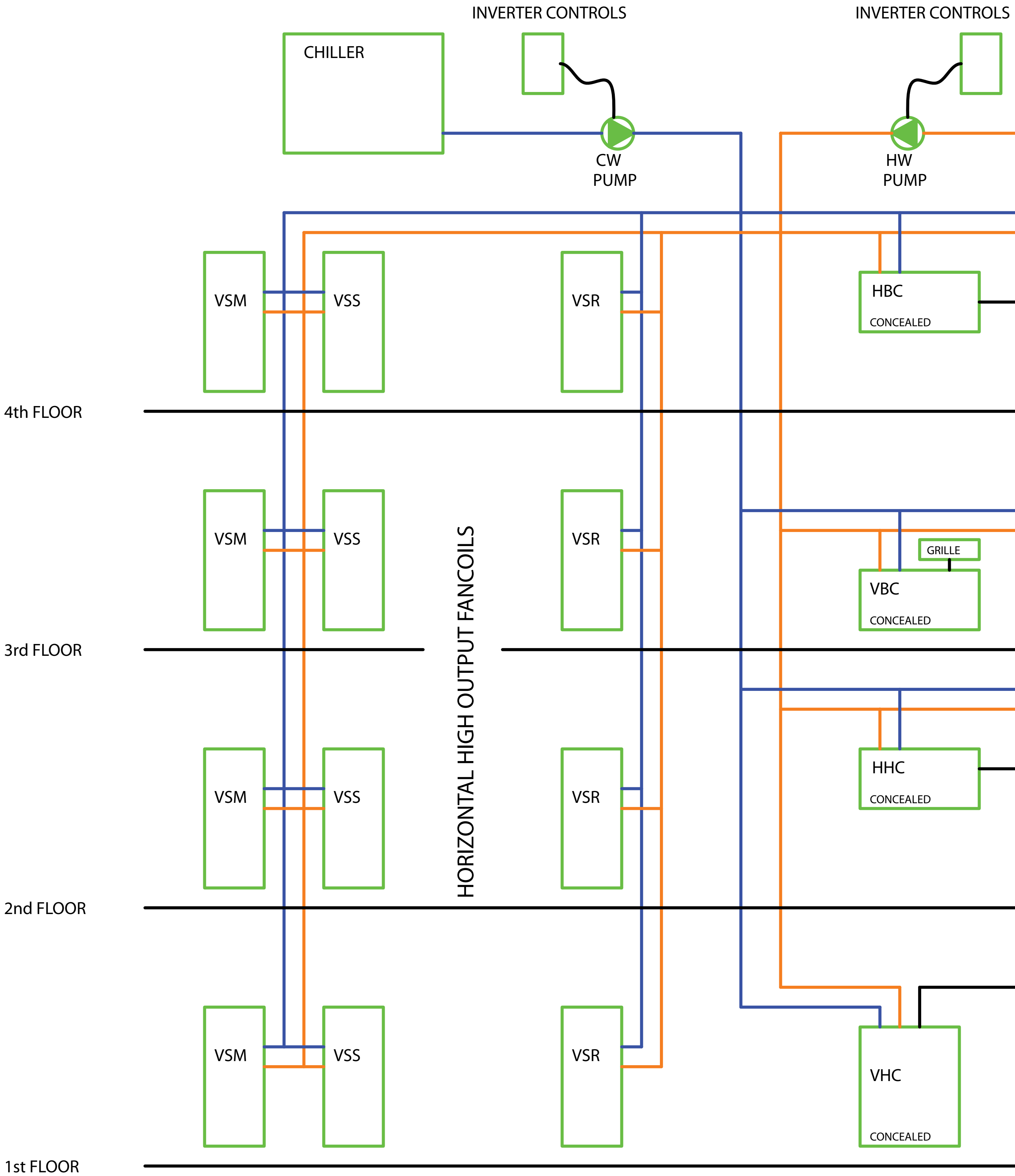
# 2 Pipe System with Chilled and Hot Water

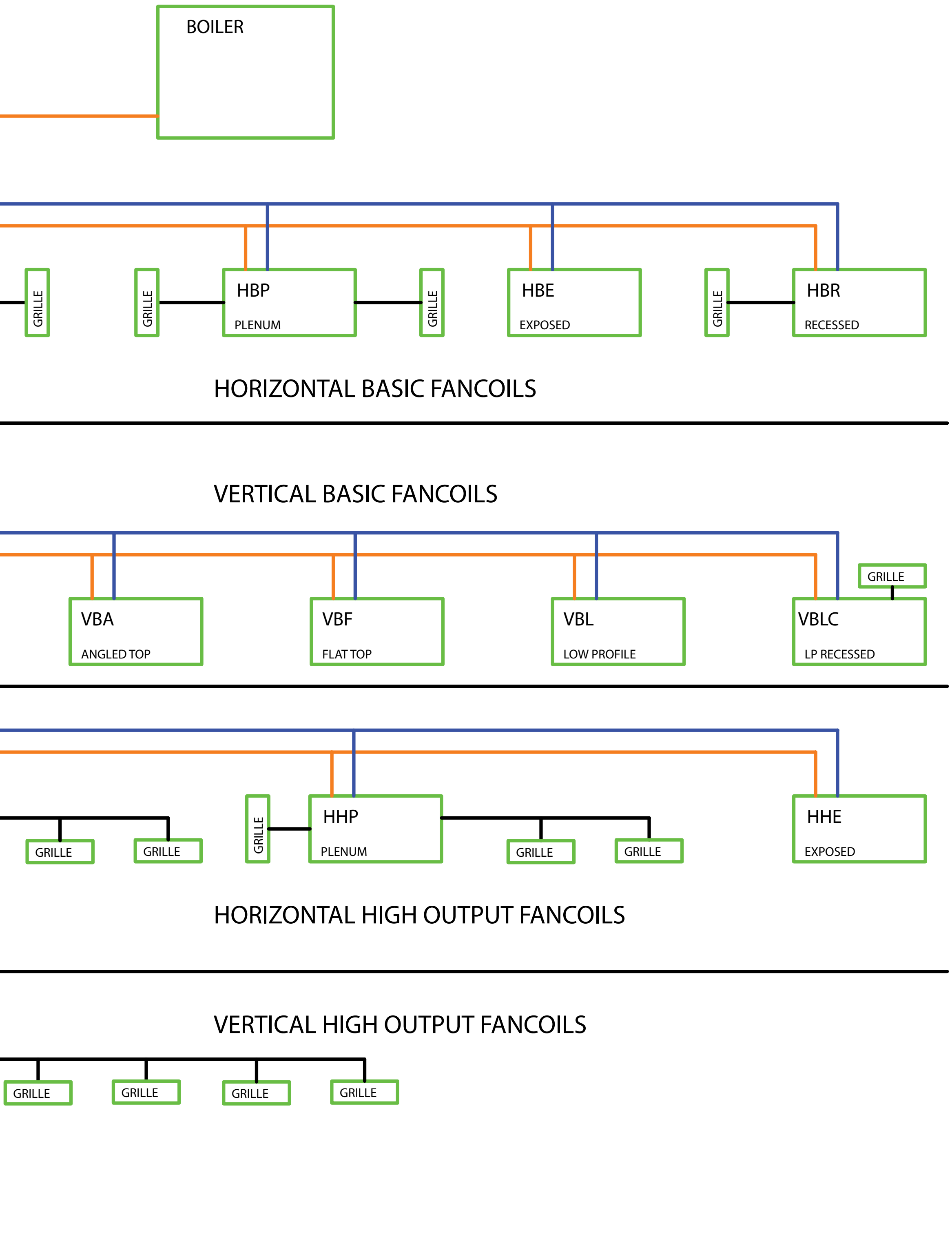
## Retrofit Energy Improvement Alternatives

| Alternative | Potential Energy Improvement | Page Reference |
|---|---|---|
| **Chillers** | | |
| ◇ Absorption Chillers Efficiency – COP 8+ | 🍃🍃🍃🍃🍃 | by others |
| ◇ Water Cooled Centrifugal Chiller with Inverter Controls – COP 7+ | 🍃🍃🍃🍃 | by others |
| ◇ Water Cooled Screw Chillers with Inverter Controls – COP 5+ | 🍃🍃🍃 | by others |
| **Boilers** | | |
| ◇ High Efficiency Boilers | 🍃🍃🍃🍃🍃 | by others |
| **Pumps** | | |
| ◇ Higher Efficiency Motor Pumps with Inverter Controls | 🍃🍃🍃🍃🍃 | by others |
| ◇ Higher Efficiency Motor Pumps | 🍃🍃🍃🍃 | by others |
| **System Strainers** | | |
| ◇ Strainers with large mesh areas to avoid high pressure drops | 🍃🍃🍃🍃🍃 | by others |
| **System Piping** | | |
| ◇ Water Treatment System to reduce Fouling Factor | 🍃🍃🍃🍃🍃 | by others |
| ◇ Improve Design and Fittings to lower the Friction Losses | 🍃🍃🍃🍃 | by others |
| **Duct System** | | |
| ◇ Improve Design to lower Air Friction Losses | 🍃🍃🍃🍃🍃 | by others |
| ◇ Minimize leakages | 🍃🍃🍃🍃 | by others |
| ◇ Retrofit Grilles with lower pressure drops | 🍃🍃🍃🍃🍃 | by others |
| **Fan Coil Units** | | |
| ◇ ECM Motors | 🍃🍃🍃🍃🍃 | page 96 |
| ◇ Modulated Water Control Valves | 🍃🍃🍃🍃🍃 | page 96 |
| ◇ Programmable Thermostats | 🍃🍃🍃🍃 | page 97 |
| ◇ Occupancy Sensors | 🍃🍃🍃🍃 | page 97 |
| ◇ Pleated Filters | 🍃🍃🍃 | page 97 |

## NOTES

## 4 Pipe System




BOILER
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PLENUM
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EXPOSED
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HORIZONTAL BASIC FANCOILS
VERTICAL BASIC FANCOILS
VBA
ANGLED TOP
VBF
FLAT TOP
VBL
LOW PROFILE
GRILLE
VBLC
LP RECESSED
GRILLE
GRILLE
GRILLE
HHP
PLENUM
GRILLE
GRILLE
HHE
EXPOSED
HORIZONTAL HIGH OUTPUT FANCOILS
VERTICAL HIGH OUTPUT FANCOILS
GRILLE
GRILLE
GRILLE
GRILLE

# 4 Pipe Systems

| Retrofit Energy Improvement Alternatives | Potential Energy Improvement | Page Reference |
|---|---|---|
| **Chillers** | | |
| ◇ Absorption Chillers Efficiency – COP 8+ | 🍃🍃🍃🍃🍃 | by others |
| ◇ Water Cooled Centrifugal Chiller with Inverter Controls – COP 7+ | 🍃🍃🍃🍃 | by others |
| ◇ Water Cooled Screw Chillers with Inverter Controls – COP 5+ | 🍃🍃🍃 | by others |
| **Boilers** | | |
| ◇ High Efficiency Boilers | 🍃🍃🍃🍃🍃 | by others |
| **Pumps** | | |
| ◇ Higher Efficiency Motor Pumps with Inverter Controls | 🍃🍃🍃🍃🍃 | by others |
| ◇ Higher Efficiency Motor Pumps | 🍃🍃🍃🍃 | by others |
| **System Strainers** | | |
| ◇ Strainers with large mesh areas to avoid high pressure drops | 🍃🍃🍃🍃🍃 | by others |
| **System Piping** | | |
| ◇ Water Treatment System to reduce Fouling Factor | 🍃🍃🍃🍃🍃 | by others |
| ◇ Improve Design and Fittings to lower the Friction Losses | 🍃🍃🍃🍃 | by others |
| **Duct System** | | |
| ◇ Improve Design to lower Air Friction Losses | 🍃🍃🍃🍃🍃 | by others |
| ◇ Minimize leakages | 🍃🍃🍃🍃 | by others |
| ◇ Retrofit Grilles with lower pressure drops | 🍃🍃🍃🍃🍃 | by others |
| **Fan Coil Units** | | |
| ◇ ECM Motors | 🍃🍃🍃🍃🍃 | page 96 |
| ◇ Modulated Water Control Valves | 🍃🍃🍃🍃🍃 | page 96 |
| ◇ Programmable Thermostats | 🍃🍃🍃🍃 | page 97 |
| ◇ Occupancy Sensors | 🍃🍃🍃🍃 | page 97 |
| ◇ Pleated Filters | 🍃🍃🍃 | page 97 |

## NOTES

# Then and Now; A History of Innovation in Retrofitting Solutions

Titus has a long history, with over 30 years of experience, in the United States commercial retrofit market. When the ASHRAE 90-75 standard was first adopted in 1975, Titus was busy developing many building energy reduction products for the market.

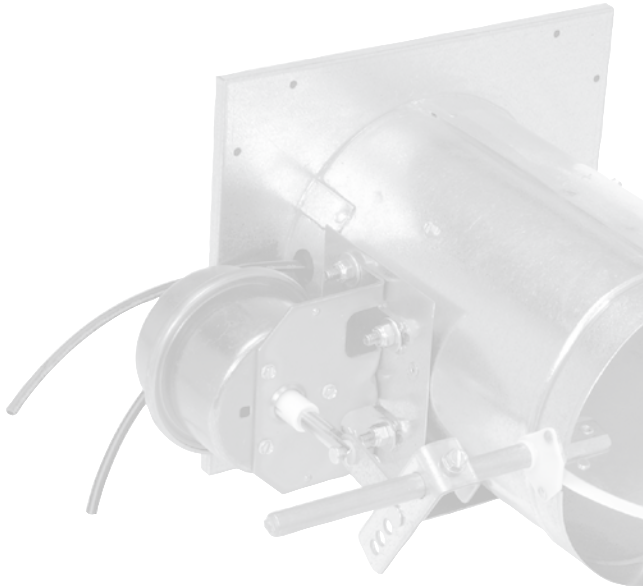
Early developments included the ESV, as we know it today, and the support beam of Titus energy reduction products, the reset velocity controller. These controls were and still are the pneumatic controls that allow for smaller-sized low-pressure-independent VAV terminal units with greater air flow control and turn down ratios. VAV terminal units built and sold by Titus prior to this date used the mostly larger and heavier mechanical constant volume regulators.

Titus' reset velocity controllers were redesigned in 1976 with the introduction the Titus I and again in 1978 with the launch of the Titus II control. During this time period, the commercial market transitioned to VAV as many building owners found that energy could be reduced with the shift.

Titus was so interested in this new avenue of energy savings that a bold new venture was undertaken to gather data and to promote the emerging retrofit market. Titus contacted various building owners in the Dallas market area and offered to retrofit their buildings at no cost. Under a contract, Titus retrofit the building's system and ran the building for a fixed number of years; during which the owner paid their old standard utility rates while Titus earned the savings difference after retrofit. Comfort was guaranteed, and buildings were studied monthly to determine the differences in cost to operate various types of buildings with new retrofit controls. A variety of control systems and processes were monitored and in some cases altered during the study. This bold step garnered great quantity of knowledge into retrofitting for energy savings, and many new retrofit controls were developed.

Today at Titus, we are still innovating to provide energy reduction devices that reduce building operational costs. We have developed special control devices, that not only convert terminal units with mechanical constant volume controls, but methods of energy reduction in induction systems, multi-zone, bypass systems and even some old system powered equipment among many other systems.

There are many exciting energy reduction solutions and retrofit innovations happening at Titus, where we design to reduce the energy consumption of commercial buildings and offer outstanding retrofit options.



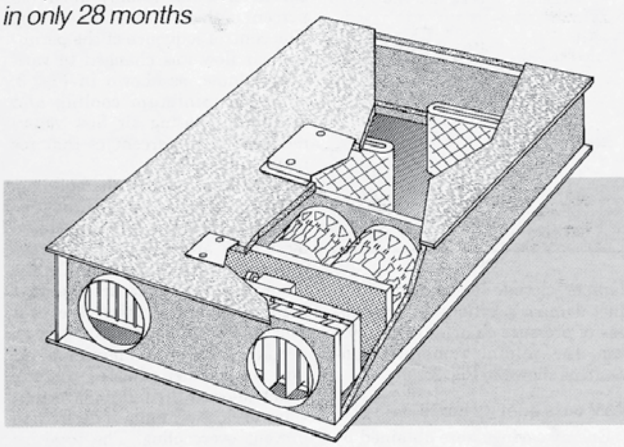
# Retrofit Archives

Article from HPAC Magazine
November 1990

HOSPITAL HVAC RETROFIT

## VAV Retrofit Slashes Utility Energy Costs

*By changing to a variable volume system, hospital saved enough to realize payback in only 28 months*



1. Cutaway view of mechanical dual-duct terminal unit showing inlet valves, mechanical constant-volume regulators, and mixing baffles.

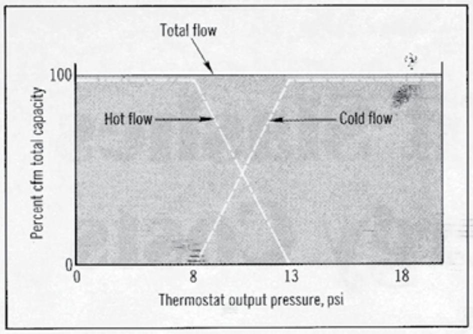
Because of spiraling energy costs at Our Lady of the Lake Regional Medical Center, Baton Rouge, La., Philip Crochet, assistant administrator, together with the hospital board of directors, ordered a change from an energy-hungry constant-volume HVAC system to an economical, low-pressure variable-volume system. Now that the building has been retrofitted with new variable-volume controls, utility energy costs have been reduced by an average of over $11,000 per month!

Built over 15 years ago, the building was served by a high-pressure, constant-volume, dual-duct system. The original dual-duct terminal units (Fig. 1) contained mechanical regulators with spring-loaded valves that opened or closed air flow passages to maintain a constant air flow, regardless of the system static pressure. Because of the spring loading, these regulators required a minimum static pressure of 0.50 to 1.0 in. WG, depending on the air flow, just to push the air through them. This pressure drop through a mechanical regulator is

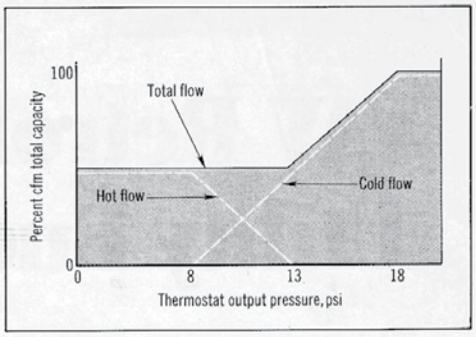

By LEON KLOOSTRA,
Product Manager–Retrofit,
Titus Div. of
Philips Industries Inc.,
Richardson, Tex.

Retrofit Archives (continued)

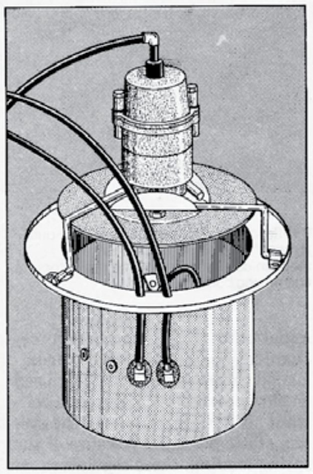
## Hospital HVAC retrofit




**2** Constant-volume, dual-duct control.




**3** Retrofitted dual-duct, variable-volume control.



**4** Retrofitting dual-duct unit.

additive to the other pressure drops through the terminal, with its inlet valves and mixing baffles. The typical minimum overall static pressure drop through a mechanical, constant-volume, dual-duct terminal is in the range of 0.75 to 1.2 in. WG static pressure or 1.0 to 1.5 in. WG total pressure. This results in high operating costs. Table 1 shows the typical energy savings that can be expected with various pressure drop reductions.

With the original system, the space temperature was controlled by a pneumatic thermostat that sent a signal to modulate an 8 to 13 psi actuator connected to the hot and cold duct inlet air valves, which were linked together. When the hot duct damper opened on a call for heating, the cold duct damper closed. Regardless of the inlet damper positions and regardless of pressure changes in the system, the volume remained constant, as shown in Fig. 2.

Table 1 — Annual power cost (in dollars), 1000 cfm at $0.05 per kilowatt-hour.

| Total pressure, in. WG | Fan total efficiency, percent | | |
|---|---|---|---|
| | 75 | 80 | 90 |
| 5 | $342 | $302 | $284 |
| 4 | 273 | 242 | 230 |
| 3 | 205 | 182 | 171 |
| 2 | 137 | 121 | 113 |
| 1 | 68 | 60 | 57 |
| 0.5 | 34 | 30 | 28 |
| 0.4 | 27 | 24 | 22 |
| 0.3 | 21 | 18 | 17 |

### VAV cuts energy costs

Energy savings were obtained by using the basic principles of variable volume and diversification, which recognize that the cooling load of the building follows the sun. These savings are accomplished by reducing total air flow and also shifting the maximum cooling air flow around the building skin as the sun moves from the east to the west. In the morning, the maximum cooling air flow is on the east side of the building and is reduced as the south and finally the west sides of the building require additional cooling. Consequently, maximum volume is not required for all sides of the building at the same time. Substantial savings can also occur at night and in winter months.

Because of the design of this hospital and its location in the southern portion of the United States, the required heating air flow in the perimeter zones is only about 50 percent of that required for cooling. The control sequence of the perimeter air flow was changed to variable volume, as shown in Fig. 3, with the minimum cooling and maximum heating air flow values reduced to 50 percent of that for maximum cooling.

In the core areas of the building, where no heating is required, the heating air valve was driven closed by simply applying 20 psi to the pneumatic mixing actuator. On the other hand, the core areas always require cooling to offset the heat generated by the lights, equipment, people, etc. Here the minimum air flow setting was adjusted to zero, which allowed the terminal retrofit valve to close off tight, if desired, to prevent overcooling. The total air flow at maximum load was recalculated, and it was found that the original air flow could be reduced by 15 percent.

Fig. 4 shows a typical dual-duct retrofit unit. This type of control device directs the hot or cold air to each zone in the volume required to handle the load.

In summary, by changing the system to variable air volume (VAV) operation, the maximum fan requirements were reduced by over 105,000 cfm. Along with the reduction in air flow, there were corresponding energy savings in the reduction in natural gas for hot water heat and in the reduction in chiller capacity.

### Retrofit implementation

Over 1000 mechanically regulated, constant-volume, dual-duct

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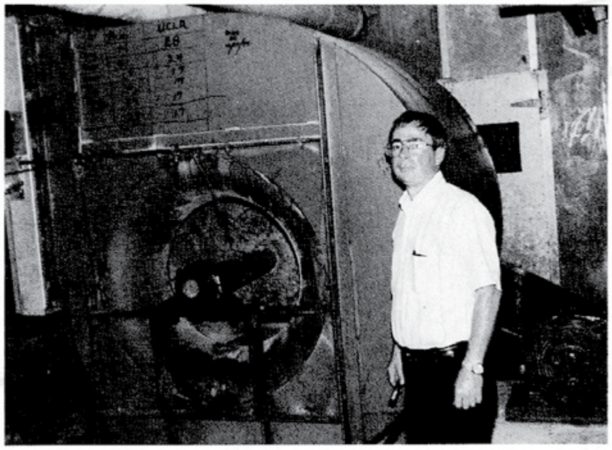
Retrofit Archives (continued)

terminals were converted to VAV control using the retrofit unit shown in Fig. 4. Each of the old constant-volume regulators was replaced by opening the access door and removing three screws that held the regulator in place. The retrofit unit was installed in the same location by reusing the same three screws.

According to Roy St. Paul, PE, president of Coastal Air Balance, Metairie, La., the system remained running as the boxes were retrofitted. He indicated that the procedure for removal, replacement, and air flow setting took about 30 min per box to complete. He added that most of the work was done during the day with patients in the rooms. In most cases, the patients were unaware that the work was being done. Fig. 5 shows the box with the access door removed and the retrofit unit installed, along with the velocity controller.

### Supply/return fans, controls

By changing the system over from constant volume to variable volume with diversification, the air flow was reduced by as much as 60 percent during winter operation. This alone saved a substantial amount of energy. In addition, the retrofit changed the system from high pressure to low pressure. As a result, one 100-hp cooling supply fan operating at 52,000 cfm at 7.5 in. WG static pressure and one 75-hp heating supply fan at 50,700 cfm at 6.5 in. WG static pressure could be shut down and used only for standby. Fig. 6 shows one of these fans with Wayne Schexnayder of Coastal Air Balance, which installed the retrofit system.

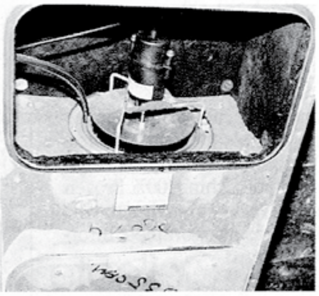


**6** One of two fans that were no longer required as a result of the retrofit.

Variable inlet vanes were installed on the remaining two 100-hp cooling supply fans, as shown in Fig. 7. A static pressure sensor located 60 percent downstream in the cold duct modulates the vanes in parallel from full cooling down to 45 percent. At 45 percent, one fan is de-energized, the backdraft damper closes, and the remaining fan modulates to maintain cooling conditions.

A variable-frequency speed controller was installed on the remaining 75-hp heating supply fan. A static pressure sensor located 60 percent downstream in the heating duct modulates the variable-frequency drive to satisfy conditions. This system is typical of two identical systems retrofitted in the hospital.

Variable-frequency speed controls are also being used on some of the smaller fan motors. An example is on the 6th floor of the hospital. The effectiveness of the speed control on this fan motor was based on the following: the current drawn by the motor before the retrofit measured 16.33 amps with a 480-v, three-phase power supply. Table 2 shows the amperage drawn after the retrofit program was completed on this portion of the system. A calculation of the air side savings is shown in Fig. 8.



**5** Retrofit unit installed in existing dual-duct terminal.

### Savings

The total cost of the retrofit project was about $317,000. This includes the VAV retrofit units, variable-frequency speed controls, new fan motors, inlet vanes, miscellaneous controls, and labor. The saving in electric power alone was found to be $137,361 per yr at a power cost of 5 cents per KWH. On this basis, full payback has been obtained after only 28 months of operation. The saving on natural gas to generate heat was additional.

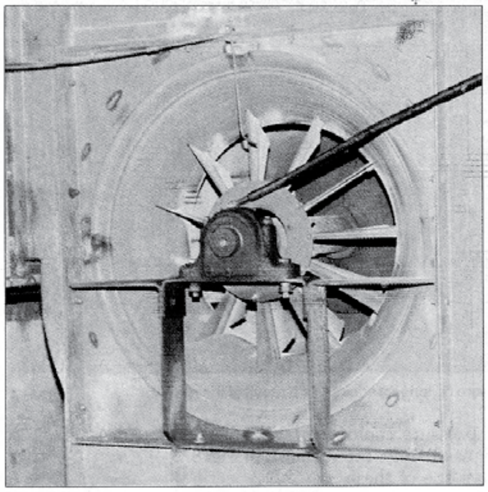
"Any building, such as a hospital, that operates a constant-volume

Table 2—Total measured ampere-hours for a 12-month period for AHU-2 on the 6th floor North.

| Outdoor temperature, F | Total hours | Measured average amps | Total amperage |
|---|---|---|---|
| 94 to 90 | 195 | 11.13 | 2,170.35 |
| 89 to 85 | 579 | 10.80 | 6,253.20 |
| 84 to 80 | 954 | 10.11 | 9,644.94 |
| 79 to 75 | 1428 | 9.19 | 13,123.32 |
| 74 to 70 | 1572 | 8.35 | 13,126.20 |
| 69 to 65 | 1101 | 8.34 | 9,182.34 |
| 64 to 60 | 813 | 8.25 | 6,707.25 |
| 59 to 55 | 648 | 7.95 | 5,151.60 |
| 54 to 50 | 465 | 7.40 | 3,441.00 |
| 49 to 45 | 336 | 7.13 | 2,395.68 |
| 44 to 40 | 276 | 7.12 | 1,965.12 |
| 39 to 35 | 189 | 6.95 | 1,313.55 |
| 34 to 30 | 135 | 6.50 | 877.50 |
| 29 to 25 | 51 | 6.33 | 322.93 |
| 24 to 20 | 18 | 6.13 | 110.34 |
| **Totals** | **8760** | **—** | **75,785.22** |

Retrofit Archives (continued)

## Hospital HVAC retrofit



7 Inlet vanes added to 52,000 cfm fan as part of retrofit.

**Pre-retrofit air side**

Original AHU-2 supply fan (measurements recorded and reported in original July 1985 study) 213,316.43 KWH per yr

Original return air fan-2

$$KWH = \frac{1.73 \times amps \times volts \times PF \times 1\ hr}{1000}$$

$$= \frac{1.73 \times 16.33 \times 486.5 \times 0.89 \times 1}{1000}$$

$$= 12.23 \text{ per hr} \times 8760 \text{ hr} = \quad 107{,}154.12 \text{ KWH per yr}$$

Total pre-retrofit air side KWH = 320,470.55 KWH per yr

**Retrofit air side**

$$KWH = \frac{1.73 \times amps \times volts \times PF \times 1\ hr}{1000}$$

$$= \frac{1.73 \times 75{,}785.22 \times 486.5 \times 0.89 \times 1}{1000}$$

Total retrofit air side KWH = 56,767.98 KWH per yr

**Total air side saving**

320,470.55 — 56,767.98 = 263,702.57 KWH per yr

8 Summary of retrofit cost savings.

system 24 hr a day and 7 days a week can reduce its energy costs by a tremendous amount," observes St. Paul. "Our Lady of the Lake Hospital is an excellent example of the savings that can be obtained by retrofitting to variable-air volume." Ω

**Acknowledgment**

*The engineer for the retrofit project was George Tucker and Associates, Baton Rouge, La. The installing contractor was Coastal Air Balance, Inc., Metairie, La.*

Retrofit Archives (continued)

Article from Titus Newsletter

TITUS® PRODUCTS

## Retrofit Cuts CFM in Half; Eliminates Reheat

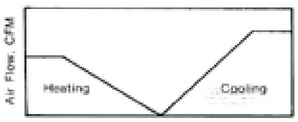
Converting this dual duct, constant volume HVAC system to variable volume has made it competitive with the latest designs in coping with today's energy costs.

Taking advantage of the building's diversity factor, the new variable volume operation has cut the design flow rate from the original 330,000 cfm to the present 160,000 cfm. Power savings are about 200 hp in fan load alone.

In addition, the redesigned distribution and control systems provide year-round comfort levels at least equal to past performance, *without reheat.*

Originally, as completed in 1965, both the interior and exterior zones were dual duct, constant volume, fed by central station air handlers (one factory built and three built-up) with hot and cold deck coils. Distribution was through Barber-Colman dual duct assemblies (boxes). Chilled water was supplied to the cooling coils by a steam absorption chiller.

The retrofit consisted mainly of modifying the original boxes with *Enviro-Master*® retrofit adapters so they continuously modulate the air flow in response to the room thermostats. The interior zone is now single duct, variable volume, cooling only. The exterior zone is still dual duct — but now variable volume with sequenced heating and cooling, as shown in the diagram.




This rearrangement of the exterior zone was accomplished by first disconnecting the linkage between the hot and cold deck dampers in each Barber-Colman box, then adding a separate cold deck damper actuator. The original damper actuator was left intact to operate the hot deck damper. Thus the hot and cold decks were made individually controllable.

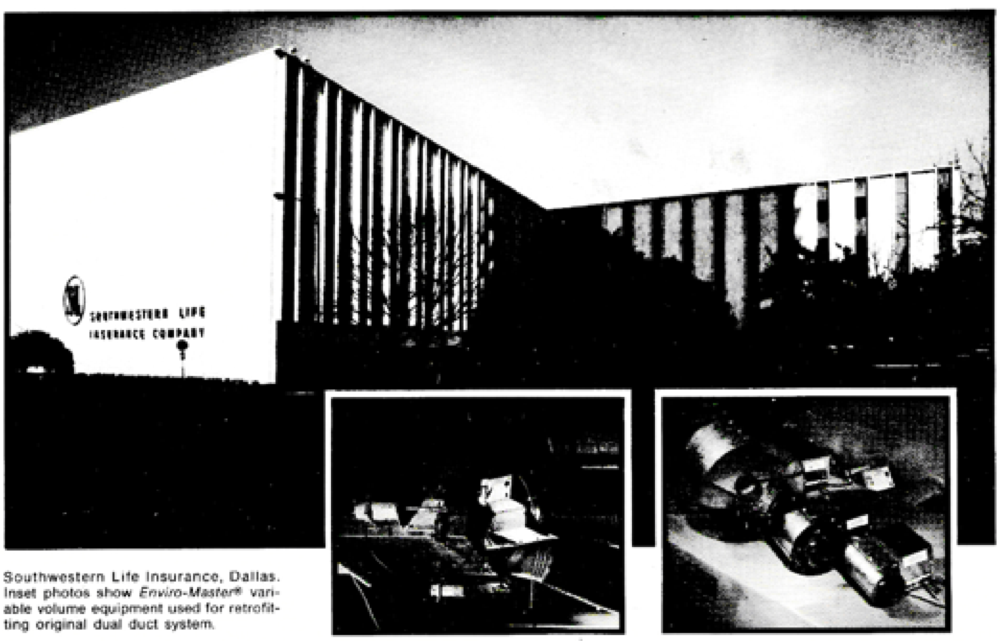
A Model ECX retrofit adapter was then added to the inlet of the hot deck, with the adapter's control air output connected to the original damper actuator.

In operation, the existing constant volume regulator in the cold deck limits the cold air cfm to a pre-set maximum when the thermostat calls for maximum cooling. As the room becomes still cooler, the cold deck damper closes tight and the hot deck damper begins to open. At this point the ECX adapter takes over, giving pressure *independent* VAV control over the entire heating range.

The *Titus® II* controller in the ECX can be set for any combination of minimum and maximum cfm limits within the capacity of that branch of the system. The minimum cfm settings can be adjusted so the heating and cooling modes are either as shown in the diagram above; or separated by a dead band; or overlapping to allow mixing.

The owners, Southwestern Life Insurance Company, were especially pleased with the relatively small amount of down time and disruption while the retrofit was in progress. Not only was most of the original air handling equipment left intact, but the work was performed almost entirely through lay-in ceiling tiles and existing access panels.

The retrofit job was sold by Ed Paschall of Welco Sales, Inc., Dallas. The engineer was Purdy-McGuire, Inc.; the mechanical contractor was Farwell Corporation; the control contractor was Control Services, Inc.; the balancing contractor was Engineered Air Balance Company, Inc.; all are in Dallas. ★




Southwestern Life Insurance, Dallas. Inset photos show *Enviro-Master*® variable volume equipment used for retrofitting original dual duct system.

Retrofit Archives (continued)

## Titus HVAC retrofit cuts utility costs.

**Akron-Canton Airport.** Converted from medium pressure double duct to variable volume. Resulting energy savings allowed 50' x 150' terminal addition to be built without adding heating or cooling capacity to central system. Note how one man on ladder is able to install *Enviro-Master®* variable volume assembly through opening in existing ceiling. Original system, installed in early 1950's, included about 60 individually controlled air distribution zones.

**Questor Building, Toledo, Ohio.** Owner, Questor Corporation, parent company of Spalding, sports equipment manufacturer. Photo below shows *Enviro-Master®* assembly used in converting constant volume single duct reheat to variable air volume system. Control shroud has been removed to show Flow Logic Analyzer and pneumatic actuator. Installation is above suspended T-bar ceiling.

Environmental Elements Corporation
P.O. Box 2350
Richardson, Texas 75080
(214) 699-1030 Telex: RCHN-730972

Environmental Elements *Titus®* variable volume air distribution equipment is built in sizes and types to meet both the usual and the unusual conditions found in retrofit projects.

Titus
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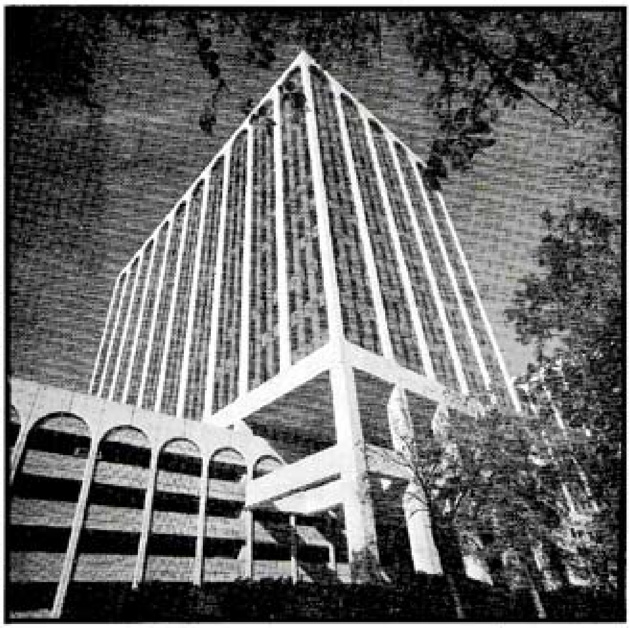
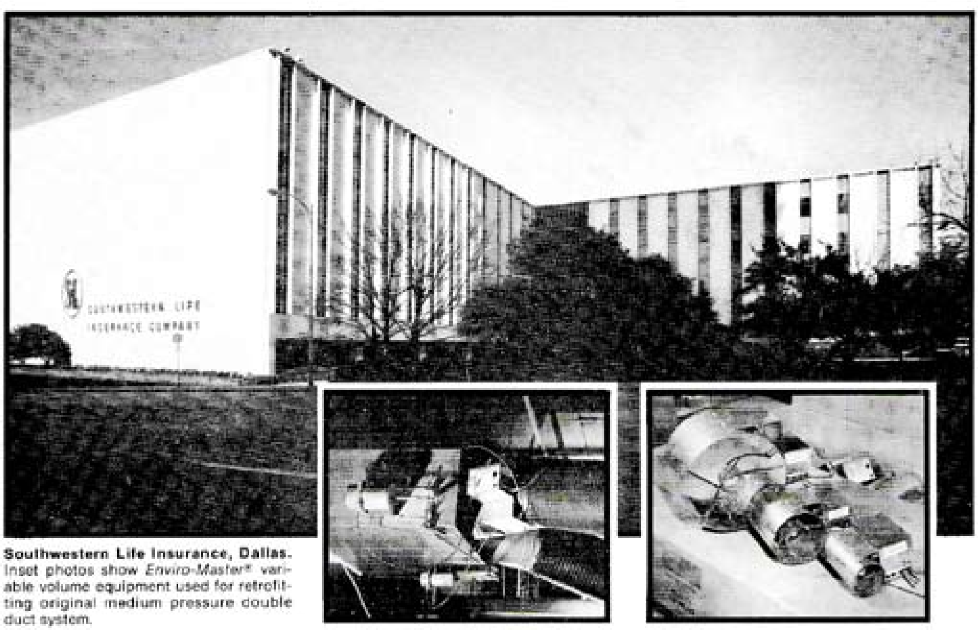
Retrofit Archives (continued)

## The owners of these buildings are profiting from HVAC retrofit.



**Park Tower South, Houston.** Owner, Tenneco Realty, Inc. Major tenant, Exxon Chemical, U.S.A. Original constant volume reheat system retrofitted to variable volume. *Total* annual energy usage was reduced 38%. Consequently, owner ordered similar retrofit of building's twin, Park Tower North.



**Southwestern Life Insurance, Dallas.** Inset photos show *Enviro-Master®* variable volume equipment used for retrofitting original medium pressure double duct system.

Retrofit Archives (continued)

Article from HPAC Magazine
December 1979

# VAV system saves 38% of energy usage

The 12 story Park Tower South Building in Houston, Tex.

Conversion to a low pressure variable air volume system eliminates duplicate energy usage and produces energy savings

By **LEON KLOOSTRA,** Manager of Sales Engineering,
Air Handling Systems Group,
Environmental Elements Corporation,
Titus® Products

**Spiraling energy costs** caused the owner of the Park Tower South Building in Houston, Texas, to change the building's heating and air conditioning system from an energy hungry constant volume type to a low pressure, economical variable volume system. After the building was retrofitted with the VAV air distribution assemblies, the total energy usage for gas and electricity was reduced by 38%. This translates into an average annual saving of $72,942.31 since May 1978.

The building complex is owned by Tenneco Realty, Inc., a subsidiary of Tenneco, Inc. The major tenant in the 12 story tower is Exxon Chemical, U.S.A. Both companies are heavily involved in the energy business and committed to energy conservation.

In 1976, the building owner asked C.J. Grunewald Consulting Engineers of Houston, to make an energy study of the power consumption of this building. The study's purpose was to analyze systems in use in the building and to assess methods of reducing utility consumption. The results were presented to Tenneco Realty, Inc. in the middle of 1976. The study

Heating/Piping/Air Conditioning, December 1979

Retrofit Archives (continued)

## VAV system saves 38% of energy usage

concluded that a retrofit program would effectively decrease the cost of operation of the building. Based on 1976 utility rates, the study showed that the change from a constant volume reheat system to a low pressure variable air volume system would pay for itself in 30 months.

### Constant vs. variable volume

A constant volume reheat system delivers a constant volume of air. The air is first cooled to approximately 55 F and then reheated at each terminal zone for the required air temperature.

A constant volume reheat system is always supplied with 100% cool air; the cool air is then heated from 55 F to various control temperatures. When the zone or room load is 0% or when the room temperature is satisfied, there is a tremendous energy waste. As many Btus are required to reheat the cool air as were required to cool the air to 55 F originally. At this particular operational zone load, we have a 100% duplication in energy usage.

By definition, a 100% cooling or 100% zone load exists only 2% of the year. Thus, this type of control is, needless to say, very wasteful.

As the name implies, a variable air volume system incorporates a means of changing the air volume. Once again 55 F air is normally used, but the air flow volume is increased or decreased according to the room temperature required. This system does not duplicate energy usage and is much more economical.

### Preliminary study

The original heating and air conditioning design in the Park Tower Complex incorporated a single duct, low pressure constant volume reheat system on each floor. A 5 hp air handling device serves the interior zones, and a 10 hp handler serves exterior zones. Each floor's area is approximately 18,500 sq ft and divided into 10 zones. The original design called for 23,500 cfm per floor or 1.3 cfm per sq ft. Before and after retrofitting, the building was in use 12 hours per day, five days a week, and six hours on Saturday.

Despite the study data showing that the retrofit program would pay for itself in 30 months, the building owner was still concerned about the program. Questions remained concerning comfort levels. What about occupant comfort in the building with a variable volume system? Would the occupants notice a difference? Would they complain about the variable volume system and maybe prefer to give up the lease?

To make a closer evaluation of both energy consumption and occupancy acceptance levels, a new study was proposed. A typical floor was chosen to be retrofitted. It was

Table 1 — Comparison of utility bills before and after the retrofit.

| | | Gas (Mcf) | | | | Electricity (KWH) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | | *Usage before | Usage after | Actual Cost, $ per Mcf | Savings | *Usage before | Usage after | Actual Cost, $ per KWH | Savings |
| June | 78 | 1139 | 244 | 3.30 | $ 2953.50 | 519,630 | 447,360 | 0.0265 | $ 1915.15 |
| July | 78 | 934 | 104 | 3.51 | $ 2913.30 | 539,424 | 474,144 | 0.0277 | $ 1808.26 |
| August | 78 | 879 | 45 | 3.51 | $ 2927.34 | 561,792 | 433,344 | 0.0302 | $ 3879.13 |
| September | 78 | 810 | 40 | 3.24 | $ 2494.80 | 557,328 | 482,400 | 0.0261 | $ 1955.62 |
| October | 78 | 926 | 40 | 3.26 | $ 2888.36 | 518,784 | 421,536 | 0.0277 | $ 2693.77 |
| November | 78 | 1001 | 46 | 3.21 | $ 3065.55 | 523,344 | 377,280 | 0.0293 | $ 4279.67 |
| December | 78 | 1794 | 293 | 2.87 | $ 4307.87 | 573,264 | 371,520 | 0.0282 | $ 5689.18 |
| January | 79 | 2118 | 1104 | 3.16 | $ 3204.24 | 551,806 | 465,420 | 0.0304 | $ 2626.13 |
| February | 79 | 3225 | 2103 | 3.22 | $ 3612.84 | 575,856 | 484,872 | 0.0312 | $ 2838.70 |
| March | 79 | 2735 | 1738 | 3.21 | $ 3200.37 | 510,053 | 410,784 | 0.0354 | $ 3514.12 |
| April | 79 | 1195 | 802 | 3.33 | $ 1308.69 | 496,272 | 417,984 | 0.0346 | $ 2708.76 |
| May | 79 | 1305 | 439 | 3.35 | $ 2901.10 | 497,424 | 404,928 | 0.0352 | $ 3255.86 |
| Total | | | | | $35,777.96 | | | | $37,164.35 |

*The consumption values shown here are the average for the previous two years before the retrofit program.

Retrofit Archives (continued)

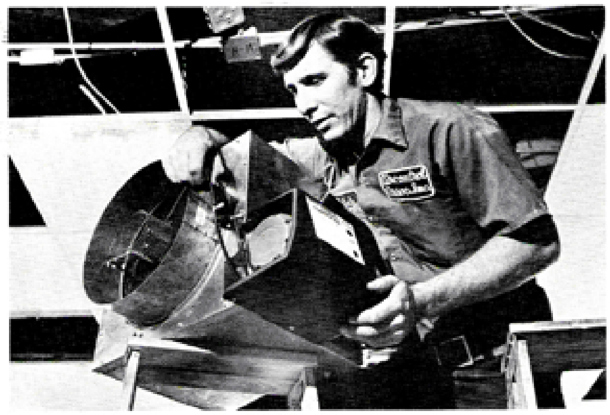
ideal to make such a study in this building since each floor had its own system.

The tenth floor was retrofitted with a variable volume system during a vacation period in the summer of 1977. Energy and comfort evaluations were conducted during the month of Aügust.

The test floor was retorfitted by using 10 independent, single duct VAV control assemblies that operate at extremely low fan pressures. In the retrofit program, four zones on the interior portion of the building were set for maximum air flows to be varied down to 20%. The reheat coils on the interior zones were disconnected. The exterior six zones were set to operate again in a variable air volume manner from maximum flow down to 40% flow. (During winter operation, the reheat coils are used at the 40% minimum air flow volume.)

The air handler blowers on each floor are the forward curved type and can ride the fan curves without additional inlet vanes or control devices. An additional saving was found in the tenth floor evaluation from the blower motor horsepower. Originally, this saving was not calculated in the 30 month payback.

During the test period, all of the hot water coils serving the tenth floor were shut off. The occupants were not advised about the two types of systems being evaluated. A typical comment received from the tenants on the retrofitted floor was, "The air conditioning system has never worked so well." As expressed by the tenants, the occupancy comfort level was excellent on the tenth floor. The building owners were impressed with the results of the retrofit test program.



One of the variable volume air handling systems installed in the Park Tower South.

**The retrofit and savings**

After the preliminary study of the tenth floor, the owner decided to retrofit the entire Park Tower South Building. The retrofit, completed in May 1978, reduced the year's actual utility bills during the period of June 1978 to May 1979 compared to averaged Mcf and KWH consumption for the two years prior to the retrofit program. Gas consumption was reduced approximately 61%; electricity consumption was reduced approximately 19%. Before the retrofit program, the total building energy budget was 171,000 Btu per sq ft per year. After the retrofit, energy usage has decreased to 105,400 Btu per sq ft per year. This is a reduction of 38%.

The annual saving at 1978 and 1979 rates was $72,942.31. The total cost of retrofitting the building was $90,649.00 for 127 zones. Therefore, the actual payback period will now be 15 months instead of the original estimate of 30 months.

Because of this substantial saving, the Park Tower North twin tower has now been retrofitted with the same variable volume system. Similar savings are expected.

The contractor for the retrofit work was Aircontrol Associates, Inc., Houston, Tex. Ω

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ret-ro-fit

# titus retrofit energy solutions

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## terminal units

# Energy Savings through Titus Retrofit Terminal Units

Energy consumption in the U.S. has increased for 10 straight years of which energy consumption in the U.S. is 98.8 quads with 1 quad = $10^{15}$ BTU's. Residential & commercial buildings used 36.4% of this energy in 2000. Most buildings constructed pre-1970's have huge energy savings potential through the heating and air conditioning system.

Most buildings during this time period are utilizing different types of energy hungry constant volume systems. Titus has over 60 years of experience retrofitting these types of systems to optimize energy efficiency.

One of the main sources of energy consumption in commercial buildings is the main system blowers. The energy consumption with retrofit can alter these energy requirements in a couple of ways.

The first and most powerful retrofitting solution to convert constant volume buildings is to convert the blowers to VAV variable speed control units. In VAV Systems, the flow may be reduced to the minimum flow required for operation. This value can and will change depending upon the season and or the time of day.

Secondly, fan energy is also a retrofit solution. It is directly related to the $CFM^3$. For instance, if the flow can be reduced 20% then the energy required in general is:

.8 x .8 x .8 = 50% Energy Reduction

$Pressure^2$ is also related to fan energy. When the system pressure is lowered, the fan uses less energy. An example of this reduction is shown below.

Titus retrofit projects for these older systems are:

- ◇ Park Tower South Building (Houston, TX)
- ◇ Southwestern Life Insurance (Dallas, TX)
- ◇ Akron-Canton Airport (Akron, OH)
- ◇ Questor Building (Cleveland, OH)
- ◇ Lady of the Lake Regional Medical Center (Baton Rouge, LA)

By converting these older buildings from high pressure constant volume systems to economical low-pressure variable volume systems, utility energy costs were greatly reduced. An example of the amount of energy saved is the Lady of the Lake Regional Medical Center in Baton Rouge, LA. (Please reference the HPAC magazine study written by Leon Kloostra Sr. Chief Engineer of Titus located in the archives for full details). The hospital board of directors ordered a change from their current HVAC system and agreed to go with a Titus low pressure variable volume conversion.

The original system utilized over 1000 dual-duct high pressure, constant volume units of which Titus used the ECT to retrofit the system. By changing the system from constant volume to variable volume, the airflow was reduced by as much as 60% during winter operation. By switching from constant to variable volume, the system is also changed from high pressure to low pressure. As a result, one 100-hp cooling supply fan operating at 52,000 cfm at 7.5 in. wg static pressure and one 75 hp heating supply fan at 50,700 cfm at 6.5 in wg static pressure could be shut down and used only for standby.

The total cost of the retrofit project was about $317,000 including labor. The saving in electric power alone $137,361 per year at a cost of 5 cent per kwh. Full payback was obtained after only 28 months of operation.

## Energy Savings through Total Pressure Reduction

A supply fan handles 1000 cfm at 2.0 in. total pressure. Assume a total efficiency of 75%.

Using the equation from the 1976 ASHRAE Systems Handbook, page 3.5(Fan Energy),

BHP = 0.000157 x cfm x TP / Eff
= 0.00057 x 1000 x 2.0 / 0.75
= 0.418

BHP is fan brake horsepower, cfm is airflow rate in cubic feet per minute. TP is total pressure in inches of water. Eff is total fan efficiency.

Since there are 0.7457 KW per horsepower and 8760 hours per year,

KWH/yr = 0.418 x 0.7457 x 8760
= 2730.51

At a cost of $0.06 per kilowatt-hour

Dollars = (KWH/yr) x 0.06
= 2730.51 x 0.06
= $164.00

However, if we reduce the total pressure to 0.5 inches wg - a reduction of 1.5 inches wg - and repeat the above calculations, we find that the power cost is now only $41.00 per year.

$164.00/1000cfm at 2.0"TP
<u>-41.00/1000cfm at 0.5"TP</u>
$123.00/1000cfm savings per year

The table below shows power costs for various total pressures and total efficiencies. It demonstrates the substantial reduction in power cost that can be realized through system pressure reduction.

| | Power cost/1000cfm @ $0.06/KWH/yr | | |
|---|---|---|---|
| TP or ∆TP | $Eff_t$ .75 | .85 | .9 |
| 5 | $410 | $363 | $341 |
| 4 | 328 | 291 | 273 |
| 3 | 246 | 218 | 205 |
| 2 | 164 | 145 | 136 |
| 1 | 82 | 72 | 68 |
| .5 | 41 | 36 | 34 |
| .4 | 33 | 29 | 27 |
| .3 | 25 | 22 | 20 |
| .2 | 16 | 15 | 14 |
| .1 | 8 | 7 | 7 |

# Existing Terminal Unit System Types

- ◇ Mechanical Constant Air Volume
- ◇ Bypass Systems
- ◇ Induction Systems
- ◇ System Powered Variable Air Volume
- ◇ Multi-Zone Systems
- ◇ Low Pressure Single Duct Re-Heat

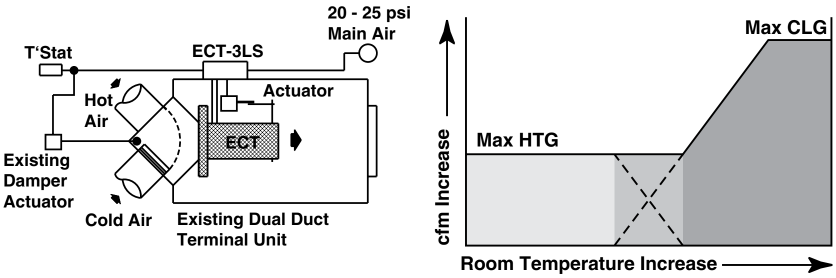
Titus has several types of solutions for each of the above system types. The internal solution involves modifications to the existing terminal unit. The external solution involves modifications to the duct systems connected to the existing terminal units and in some of the above systems, changes can be made to both the duct system and the existing terminal unit together.

## Mechanical Constant Air Volume

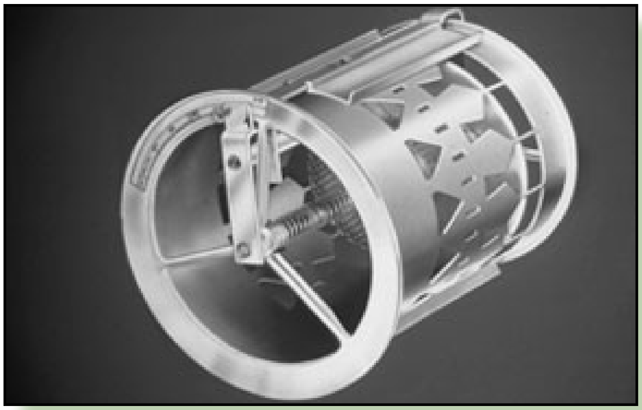
### Internal Retrofit Solution
### Dual Duct Constant Volume

This type of system is typically a dual duct system which can be retro-fitted by replacing the internal mechanical regulators inside the existing dual duct unit with the Titus ECT per the diagram below. This process only takes ½ hr per unit. By removing internal regulators, you are removing 1" of static pressure per unit which will reduce your air handler capacity. The Titus ECT-3LS provides pressure independent control for both heating and cooling. The dual duct function is retained for use in the interior and exterior zones. The existing mixing dampers on the unit will still be used. This is a pneumatic solution. You can reference the ECT product documentation and the end of the terminal unit section. See below for the retrofit diagram.

Converting Dual Duct Constant Volume to Dual Duct VAV (Minimum Mix and Equal to Maximum Heating




Refer to the topic, "Internal Retrofit" in this section for piping details.



Internal Mechanical Regulator

Variable Air Volume Valve

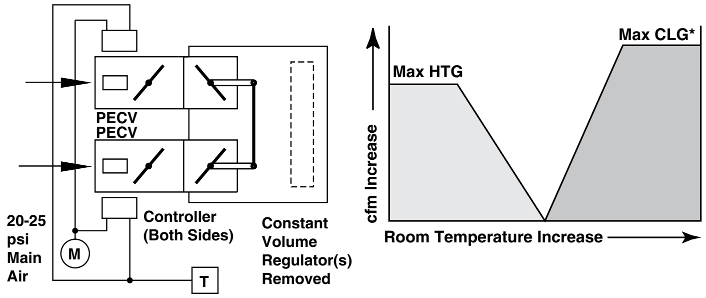
Existing Terminal Unit System Types (continued)

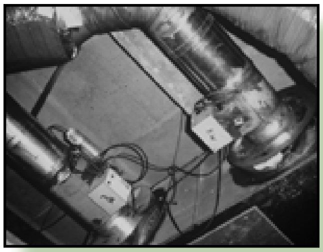
## External Retrofit Solution
## Dual Duct Variable Air Volume

The external retrofit solution would be putting the Titus ECV product in the flex duct providing there is room. The internal regulators will be completely removed from the existing dual duct unit and the mixing dampers can be eliminated as well. This solution can be analog, digital, or pneumatic. See below.

Variable Air Volume Valve

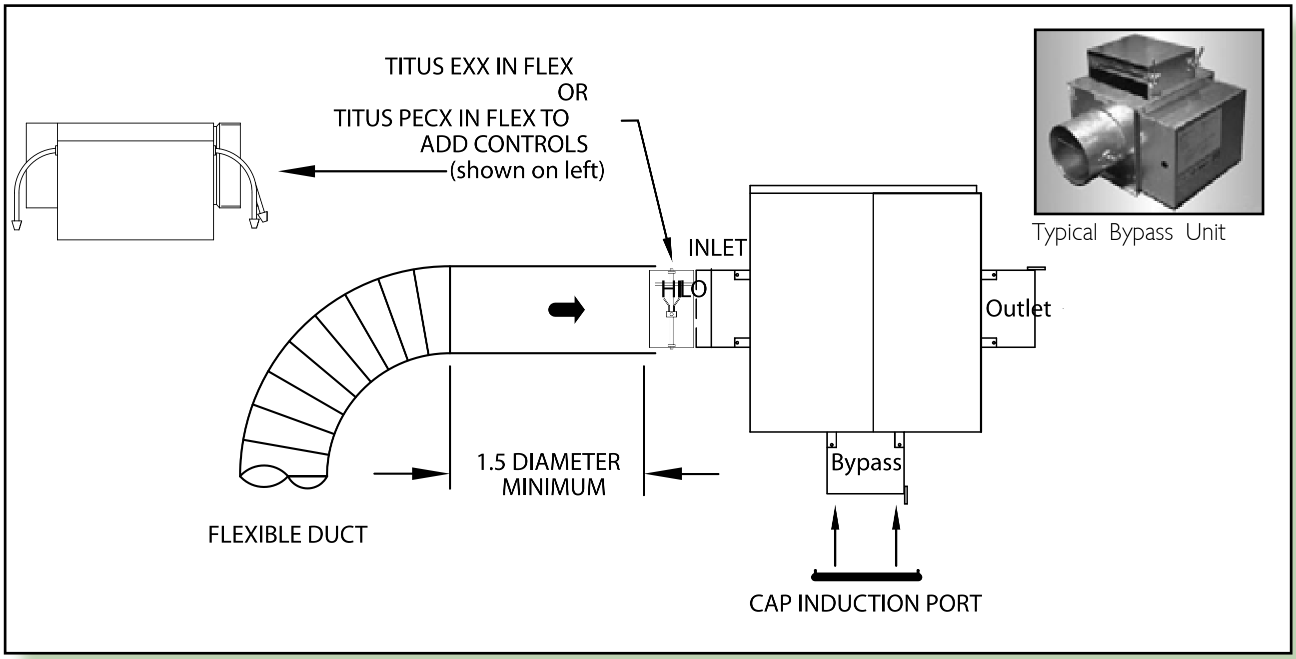
Converting Pneumatic Dual Duct VAV with Existing Damper and Actuator Not Used



## Bypass System
## Internal Retrofit Solution

In a bypass system, the inefficiency occurs as a portion of the supply airflow is diverted to the plenum either through a duct to return ductwork or directly into a return air plenum. The bypass duct can be capped to prevent wasting airflow to the plenum and with the addition of controls make a pressure independent system using the Titus PECX. A digital solution would require the Titus EXX. See below.



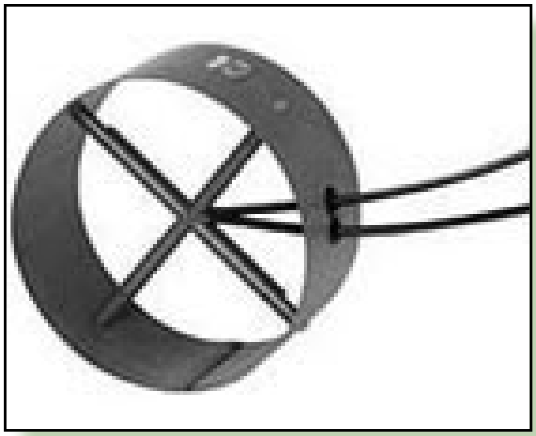

Typical Bypass Unit

Existing Terminal Unit System Types (continued)

# Induction System - High Static Pressure

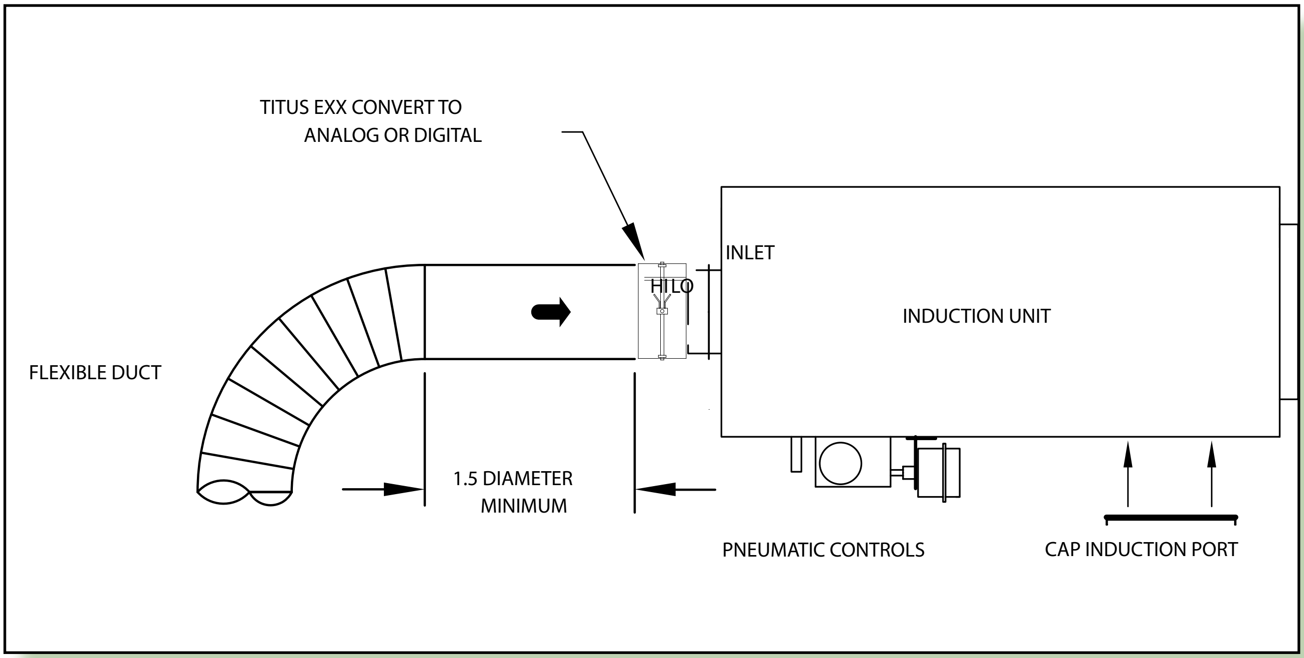
## Ceiling System

This system uses 1 ½" – 3" of static pressure. This system has higher energy consumption due to increased power required by the primary pressure drop in the terminal units. This system can be retrofitted by capping the induction port which will make it a VAV system. The controls can be left as pneumatic or switched to analog or digital.



Measuring Station

Note - Measuring Station works with both Bypass Systems and Induction Ceiling Systems.



Existing Terminal Unit System Types (continued)

## Under Window Systems (TRANE)

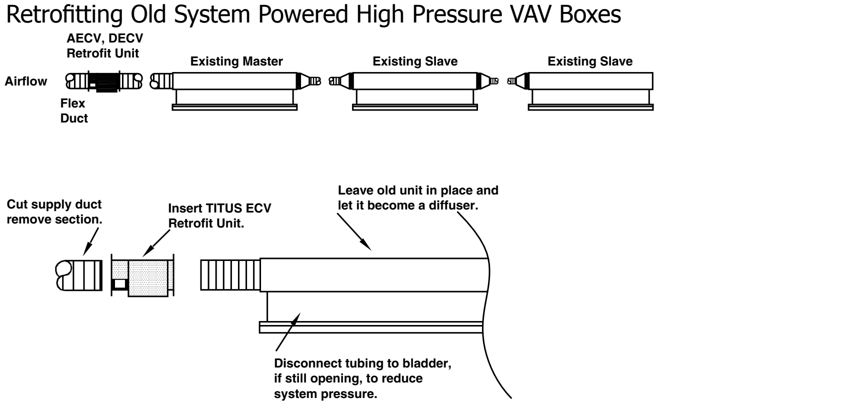
This system is a high pressure duct fed system with a 2 or 4 pipe Hydronics System. It takes a minimum of 2” wg. static air pressure to make the system work. Some systems may go up to 6” wg. static air pressure.

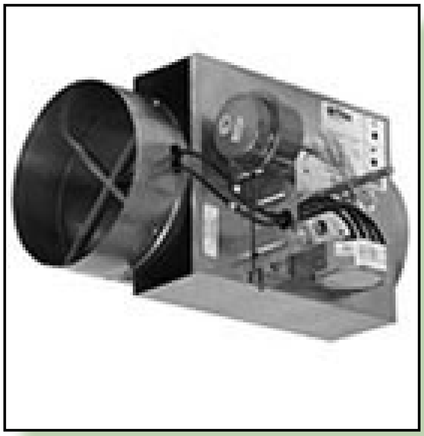
The goal is to either confirm a static pressure at 2” wg. by retrofitting with the Titus Active Chilled Terminal; or lower the static pressure to below 1” wg. to accommodate a Titus Active Chilled Beam. Available also as Modular Chilled Beam. In either case the existing supply lines (air and water) would be utilized for the new high efficient energy savings induction systems.

## System Powered Variable Air Volume

This system takes 1 ½” of static pressure to make the system function properly. This system can be retrofitted by pulling the bladder out of the units and controls. Using the Titus ECV in the flex duct ahead of the units will enable the system to operate at lower static pressure. The perimeter zones can be controlled with one thermostat, avoiding simultaneous heating and cooling.

Retrofitting Old System Powered High Pressure VAV Boxes



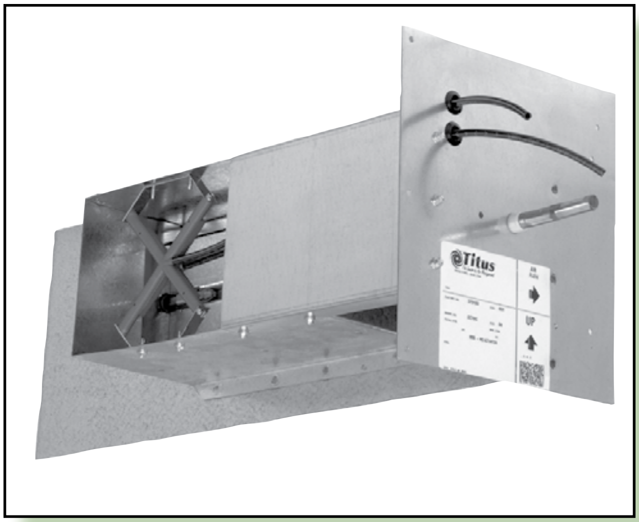
Variable Air Volume Valve

Existing Terminal Unit System Types (continued)

# Multi-Zone System - Constant Air Volume

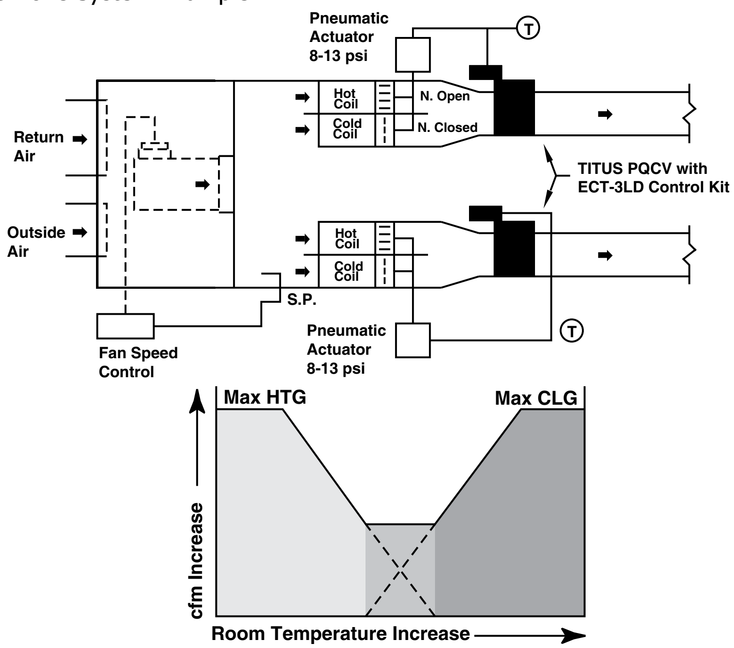
## External Solution

The Multi-Zone System is a prime candidate for retrofit. Multi-Zone air handlers use a constant volume fan that blows air into a hot and cold air coil chamber. A great amount of fan energy is lost as the fan velocity is reduced. The air flow and pressure losses through the system vary greatly as the system dampers modulate. The Titus QCV retrofit terminal is the ideal to convert the system to variable air volume operation. It can be installed in the discharge duct work as shown below. The cost of operation will be reduced as the cooling and heating will require less air flow. The blower will also consume less power as the flow varies. Zone humidity control is also improved during summer. With variable speed controls the fan horsepower will typically be reduced from 30-50%.



Slide-In Retrofit Valve

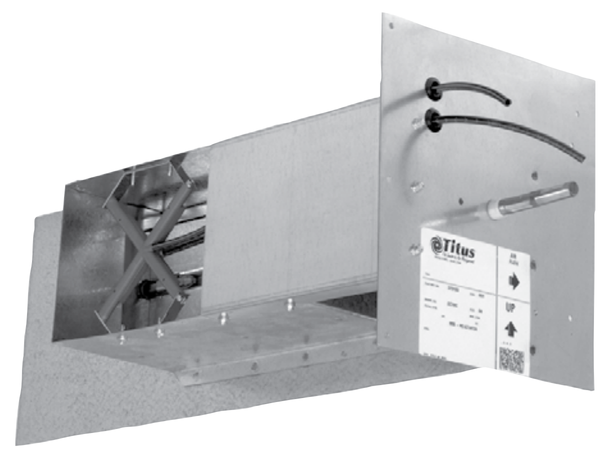
Multi-Zone System Example




Existing Terminal Unit System Types (continued)

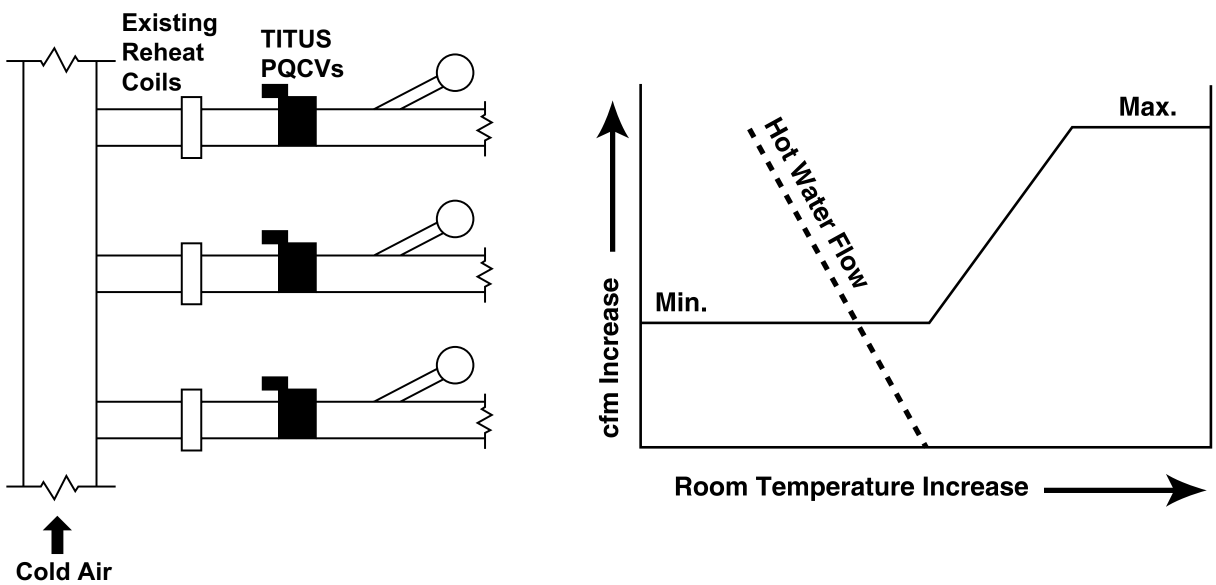
## Low Pressure Constant Volume Reheat - Single Duct

This system operates at 1" of static pressure. We will reduce the system pressure and have a higher turn down ratio which reduces fan operation cost. By converting the system to a low pressure variable volume reheat system, we will accomplish this by putting the Titus QCV terminal unit in the system per the diagram below.



Slide-In Retrofit Valve

Low Pressure, Constant volume Reheat System Example



# Optional Terminal Unit Solutions

## ECM - Electronically Commutated Motor - Kits

A vast majority of pre-existing fan powered terminal units can be retrofitted to use ecm motor assemblies preconfigured by Titus for energy savings.

- ◇ Motor Life is 90,000 hrs. compared to 50,000 std. psc motors.
- ◇ Slow start up for less wear and tear.
- ◇ Up to 70% efficient across entire operating range.
- ◇ Uses considerable less watts than standard psc motors (see table below).
- ◇ Available with optional remote pwm (speed control) for integration with building management system.

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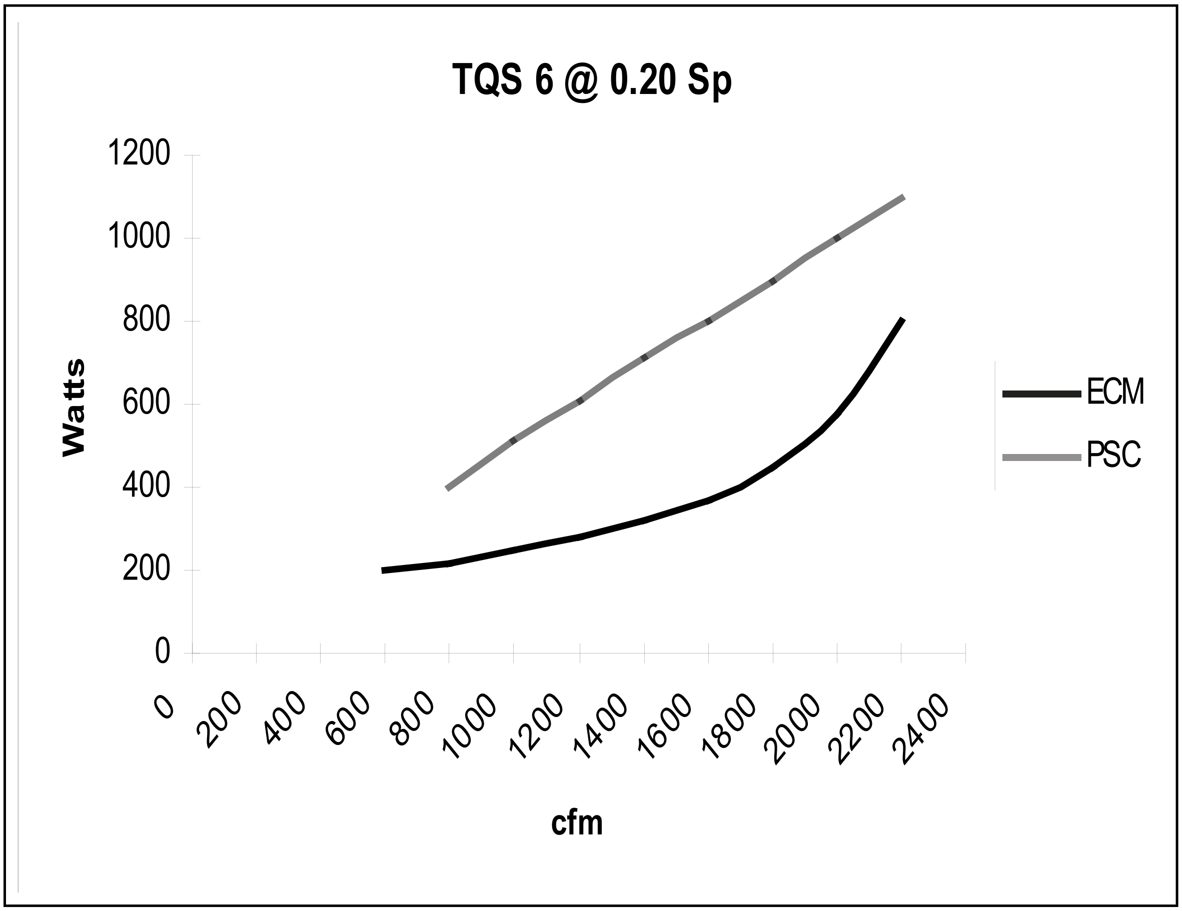
Energy savings chart based on the Titus series fan powered terminal unit TQS size-6. Table compares watt usage between the standard PSC motor used on all fan powered terminal units and usage with an ECM motor. At 1400 cfm, there is a 300 watt savings between the two motor types per unit.



Optional Terminal Unit Solutions (continued)

## $T_3SQ$ - Variable Air Volume Diffuser

Ideal for use with any constant volume system or large VAV zones. Provides zoned comfort control and used in hard to control areas in the buildings. Excellent for VAV retrofit projects.

- ◇ Provides individual comfort control for LEED Indoor Environmental Quality Credit 6.2 if seeking LEED accreditation.
- ◇ The Thermal $T_3SQ$ requires no electrical power and the analog version uses less power than a typical fan powered VAV system to help achieve LEED Energy and Atmosphere Credit 1.
- ◇ Does not require cutting into ductwork to install, saving time and money.

| VAV Box Installation Assumptions | Total CFM |
|---|---|
| Based on 1.20 CFM per square foot | 144,000 cfm |
| VAV box for each 1000 Sq. ft. - flow per box | 1,200 cfm |
| Number of diffusers per VAV box | 5 |
| Supply air per diffuser | 240 cfm |
| Number of perimeter series fan powered VAV boxes | 78 |
| Installed hp per fan powered VAV box | 0.33 hp |
| VAV box fan motor efficiency (ASHRAE 2001 f29.7) | 54% |
| Inlet static pressure to fan powered VAV box | 0.20 ins. Wg |
| Number of internal zone single duct VAV boxes | 42 |
| Inlet static pressure to single duct VAV boxes | 0.75 ins. Wg. |
| Main supply air fan efficiency | 75% |
| Main supply air fan motor efficiency | 90% |
| VAV box primary air damper actuator | 2.0 watts |
| Variable geometry VAV diffuser system details | |
| Supply air per VAV diffuser at maximum flow rate | 240 cfm |
| Diffuser input power | 2.0 watts |
| VAV diffuser supply air duct static pressure | 0.12 ins. Wg. |

Optional Terminal Unit Solutions (continued)

| $T_3$SQ Energy Efficiency Comparison | |
|---|---|
| **VAV box input power requirements:** | **Power Req.** |
| Series fan powered VAV box input power | 45.5 hp |
| Main fan input power - fan powered VAV box inlet pressure | 3.9 hp |
| Main fn input power - single duct VAV box inlet pressure | 7.9 hp |
| VAV box actuator input power | 0.3 hp |
| Total cooling load attributable to VAV box power input | 43.0 kW |
| Additional chiller drive motor power | 10.9 hp |
| Total input power – VAV boxes and chiller | **68.5 hp** |
| **Variable geometry VAV system power requirements:** | |
| Main fan input power - VAV diffuser duct pressure | 4.0 hp |
| Input power for VAV diffuser actuators | 0.9 hp |
| Total cooling load attributable to VAV diffuser input power | 3.7 kW |
| Additional chiller drive motor power | 0.9 hp |
| **Total input power – VAV diffusers and chiller** | **5.9 hp** |
| **Input power & cooling load savings:** | |
| Total input power savings – hp/kW | **62.6 / 46.9** |
| Total cooling load savings– kW/TONS | **39.3 / 11.2** |
| | |
| Annual cost savings based on 12 hours/day 5 days/week @ 8c/kW | **$11,706.24** |
| Building lifetime savings based on a 20 year life expectancy | **$234,124.80** |

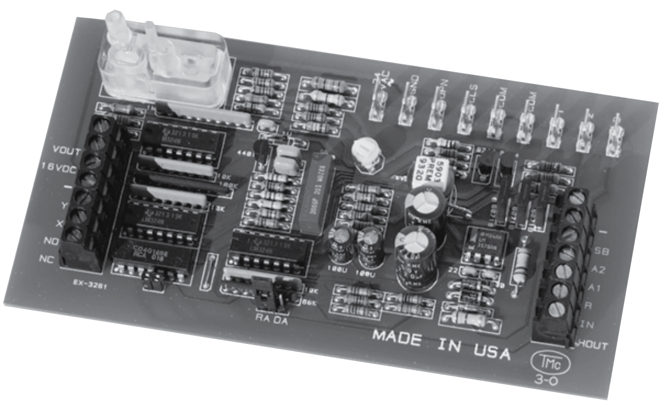
Optional Terminal Unit Solutions (continued)

## Titus Controls Solutions

### Digital Solution (Siemens Predator 587-102)


- ◇ Controls can be preconfigured with min/max cfm's and unit i.d. at the Titus factory on existing terminal units.
- ◇ Provides capability of upgrading older pneumatic or analog system to Lonworks based protocol
- ◇ Provides lower energy costs, finer temperature control, lower maintenance cost
- ◇ Ability to read very small increments of airflow changes allowing the system to automatically adjust room temperatures efficiently.

### Analog Solution (Titus TA1)



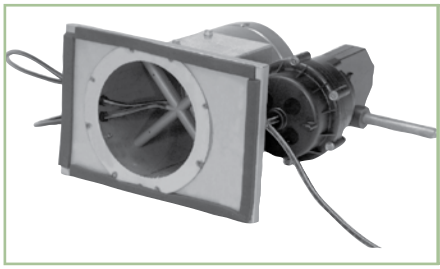

- ◇ Low cost analog solution as one model handles all control strategies
- ◇ Compatible with multipoint center averaging flow sensors for accuracy
- ◇ Pressure independent VAV damper control
- ◇ No programming required. Has easy installation and balancing.

### Pneumatic Solution (Titus II)

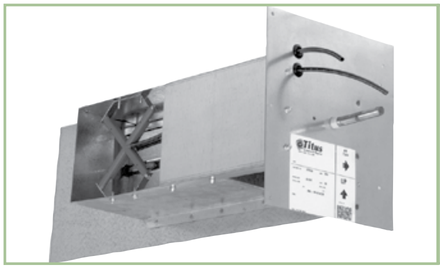

- ◇ The Titus II Controller has led the industry in precision pneumatic velocity control since it's introduction in 1978.
- ◇ Operates at low pressures which make it ideal for retrofitting high pressure systems.
- ◇ Thermostat switch changes the action from direct acting to reverse acting without additional calibration. No additional relays required – great for quick retrofit installation.

## Titus Retrofit Solutions vs. The Competition

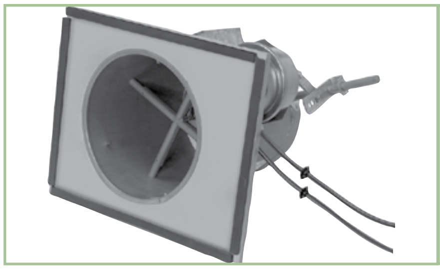
Although some VAV companies have a few retrofit products, Titus is the only company with an all-encompassing retrofit product line for terminal unit products by other companies. The Titus retrofit terminal unit products are compatible with the some of the following terminal units:



Anemostat Terminals
(Titus ECT-AN)



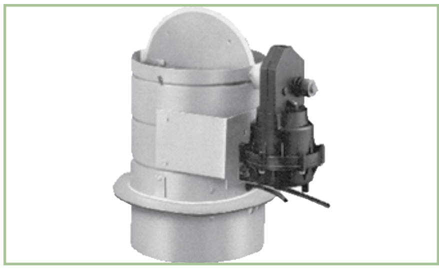
Barber-Colman Terminals
(Titus ECT-BC)



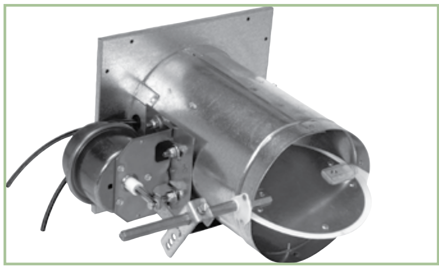
Buensod Terminals
(Titus ECT-BU)

Conner Terminals
(Titus ECT-CN)

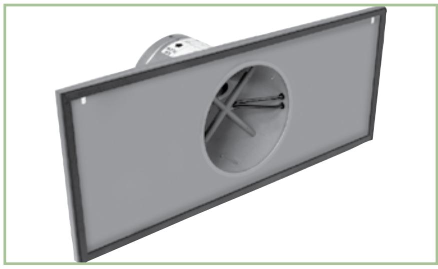
Titus Retrofit Solutions vs. The Competition (continued)



Titus Terminals
(Titus ECT-HC)



Krueger Terminals
(Titus ECT-KR)



Tuttle & Bailey Terminals
(Titus ECT-TB)

Refer to the Titus Catalog for Selection Details ret-ro-fit

t-ro-fit

ret-ro-fi

# titus retrofit energy solutions

www.titus-hvac.com

## grilles & diffusers

# Grille & Diffuser Solutions Overview

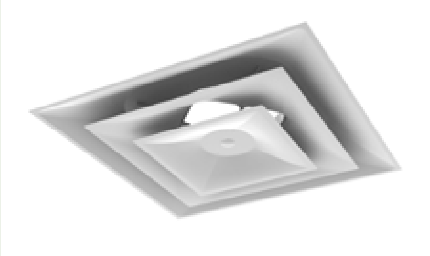
Retrofit options for air distribution products in existing buildings provide the opportunity for product selection based on application and ROI in the form of energy savings.

There are several different types of ceiling diffusers and sidewall grilles available for interior and perimeter zone air distribution. However, specific grille or diffuser minimum pressure requirements are often overlooked during design.

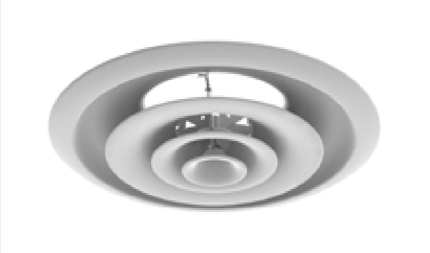
With so many air outlets on projects, the pressure factor can greatly affect operating costs. Pressure differences between different grilles and diffusers may be small but there may be thousands of units on a project. The cost can add up over the life of a building.

With the drive toward reducing energy usage in buildings, annual operating costs are becoming more important than ever before. The cost of pressure for various Titus grilles and diffusers is listed below and should be considered when selecting air outlets for retrofit applications.

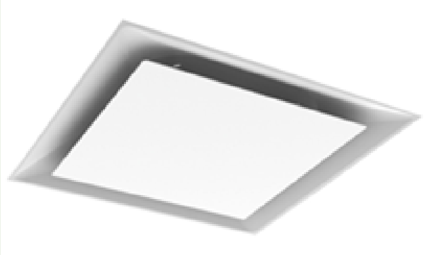
## Interior Zone - Diffuser Solutions - Ceiling Applications



TMS - square, stamped core

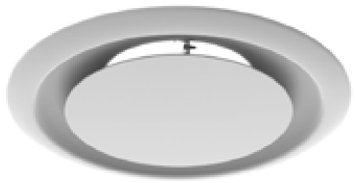


TMRA - round, multi-cone

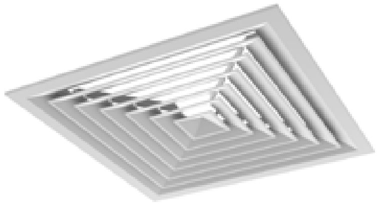


OMNI - square, architectural plaque

Diffuser Solutions (continued)



R-OMNI - round, architectural plaque



TDC - square, louver face

PSS - square, perforated face

PAS - square, perforated face

Diffuser Solutions (continued)

| Cost of Pressure - Ceiling Diffusers | | | | |
|---|---|---|---|---|
| Titus Diffuser Model | Supply Airflow (cfm) | Total Pressure (Tp) | Electricity cost 0.08/KW | Annual Tp cost per diffuser |
| TMS | 400 | 0.06 | $0.08 | $0.94 |
| R-OMNI | | 0.06 | | $0.94 |
| TMRA | | 0.07 | | $1.09 |
| OMNI | | 0.09 | | $1.41 |
| TDC | | 0.11 | | $1.72 |
| PSS | | 0.12 | | $1.88 |
| PAS | | 0.18 | | $2.81 |

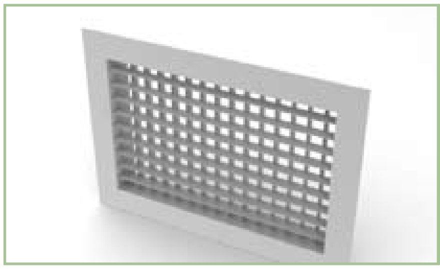
| Product Comparison Pressure Cost vs. Product Cost | | |
|---|---|---|
| model | Pressure Cost | Product Cost |
| TMS | $ | $$ |
| R-OMNI | $ | $$$$$ |
| TMRA | $$ | $$$$ |
| OMNI | $$$ | $$$ |
| TDC | $$$$ | $$$ |
| PSS | $$$$ | $ |
| PAS | $$$$$ | $ |

Calculation assumptions:

Diffuser: 24" x 24", 10" inlet
75% fan static efficiency
0.8 motor power factor
$.08KW
2500 annual operating hrs

Note: Ranking of pressure cost and product cost are on a scale of 1 to 5 with 1 being the lowest and 5 the highest.

## Interior Zone - Grille Solutions - Sidewall Applications



272FL - Airfoil blade supply grille - double deflection

300RL - Standard blade supply grille - double deflection

Grille Solutions (continued)

| Cost of Pressure - Sidewall Grilles | | | | |
|---|---|---|---|---|
| Titus Grille Model | Supply Airflow (cfm) | Total Pressure (Tp) | Electricity cost 0.08/KW | Annual Tp cost per grille |
| 272FL | 400 | 0.09 | $0.08 | $1.41 |
| 300RL | | 0.16 | | $2.50 |

Calculation assumptions:

Grille: 12" x 6", double deflection
no damper
75% fan static efficiency
0.8 motor power factor
$.08KW
2500 annual operating hrs

| Product Comparison<br>Pressure Cost vs. Product Cost | | |
|---|---|---|
| model | Pressure Cost | Product Cost |
| 272FL | $ | $$ |
| 300RL | $$ | $ |

Note: Ranking of pressure cost and product cost are on a scale of 1 to 5 with 1 being the lowest and 5 the highest.

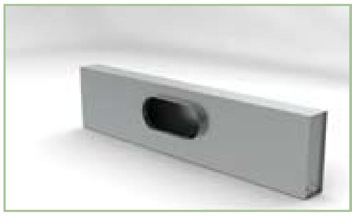
## Perimeter Zone - Diffuser Solutions - Ceiling Applications

FL-10 - FlowBar Architectural linear

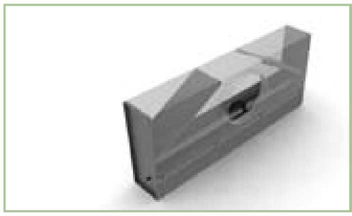
ML-39 - Modulinear - adjustable

Diffuser Solutions (continued)

TBD-30 - Plenum Slot - adjustable



TBD-80 - Plenum Slot - adjustable



TDF - Auto-changeover plenum slot

| Cost of Pressure - Linear Diffusers | | | | |
|---|---|---|---|---|
| Titus Diffuser Model | Supply Airflow (cfm) | Total Pressure (Tp) | Electricity cost 0.08/KW | Annual Tp cost per diffuser |
| FL-10 | | 0.12 | | $0.94 |
| ML-39 | | 0.20 | | $1.56 |
| TBD-30 | 200 | 0.16 | $0.08 | $1.25 |
| TBD-80 | | 0.17 | | $1.33 |
| TDF | | 0.08 | | $0.63 |

| Product Comparison Pressure Cost vs. Product Cost | | |
|---|---|---|
| model | Pressure Cost | Product Cost |
| TDF | $ | $$$$$ |
| FL-10 | $$ | $$$$$ |
| TBD-30 | $$$ | $$ |
| TBD-80 | $$$ | $$ |
| ML-39 | $$$$$ | $$$$ |

Calculation assumptions:

Diffuser: 4' length, 10" inlet with factory plenum
75% fan static efficiency
0.8 motor power factor
$.08KW
2500 annual operating hrs

Note: Ranking of pressure cost and product cost are on a scale of 1 to 5 with 1 being the lowest and 5 the highest.

The TDF "DynaFuser" saves energy in perimeter applications when compared to manually adjustable linear diffusers. The following page provides information and lab test results on the energy savings the DynaFuser can provide in perimeter applications.

Diffuser Solutions (continued)

## DynaFuser Saves Energy During Heating Cycle

Most perimeter areas of commercial buildings require both heating and cooling. Typically a split overhead system uses two slot diffusers mounted end to end or one diffuser with multiple slots. In the two diffuser system, one diffuser is set for horizontal discharge and the other for vertical. With a multiple slot diffuser, half of the slots are set to discharge horizontally and half discharge vertically.

Even though these methods work, they are not the optimum solution. In both the heating and cooling modes, half the supply air is being discharged in the wrong direction. During heating, half the air is discharged horizontally which causes stratification along the ceiling. In cooling, half the air is discharged vertically causing unwanted drafts along the floor.

The Titus DynaFuser was designed to solve the perimeter challenge. The DynaFuser automatically changes the air discharge pattern to the correct position for heating and cooling applications. This allows 100% of the supply air to be utilized in either application to achieve optimum comfort in the occupied zone.

The DynaFuser not only increases the comfort level by correctly discharging supply air in both heating and cooling modes, it does so without the use of an internal or external power source which translates to energy savings for the building owner. When 100% of the supply air is utilized, the room temperature reaches the set-point faster requiring the HVAC system to run for a shorter duration of time, which saves energy. Lab tests indicate energy savings from 10-40% during heating, which can help achieve the LEED-NC 2.2, Optimize Energy Performance credit.

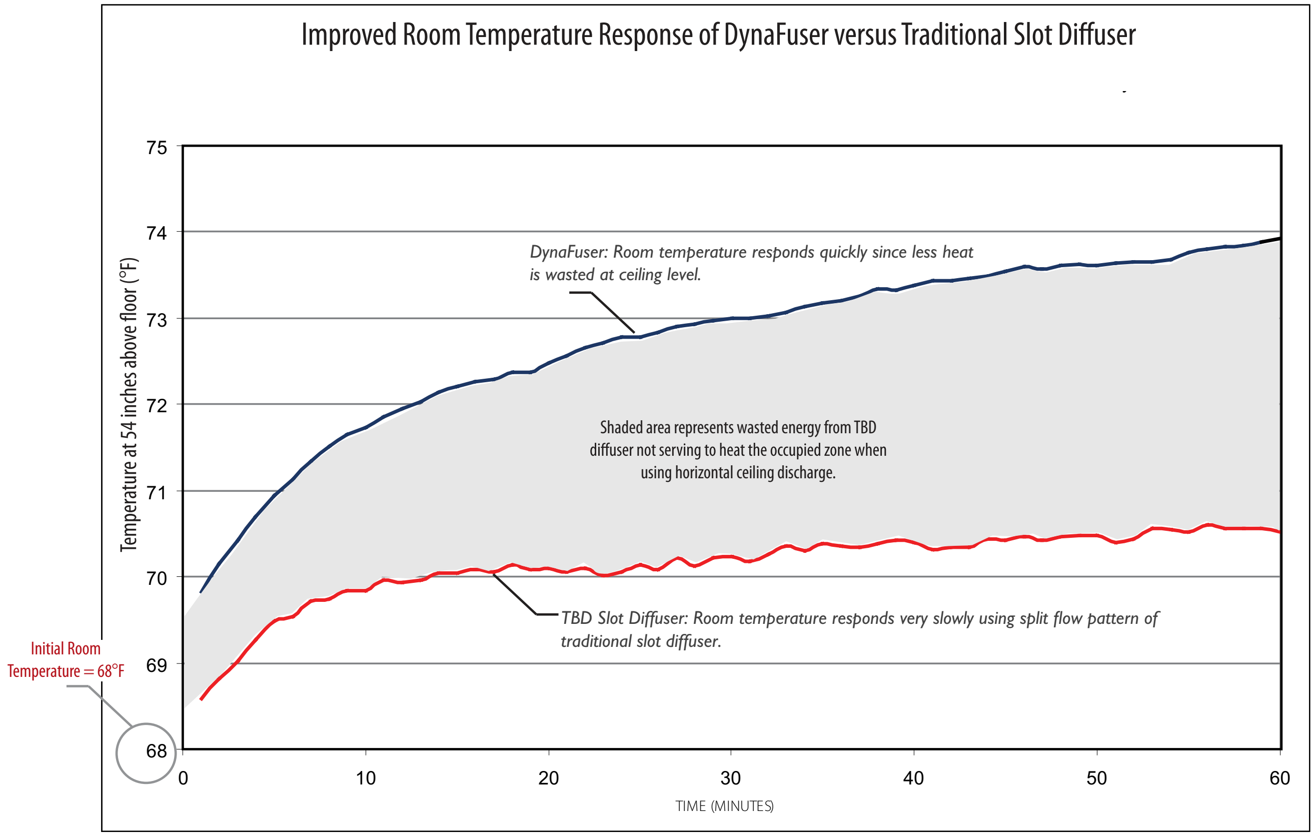
The graph on the next page shows the average room temperature as a function of time for the DynaFuser compared to a TBD-30 set in the split flow position. The test was setup in a 12ft x 19 ft room with a cold chamber with a 0.5 U value set at 29°F. Supply airflow is 170 cfm and 92°F.

During the 1 hour test, the TBD-30 in the split position never achieved an average room temperature over 71°F while the DynaFuser achieved 72°F in 13 minutes. If the room setpoint was 72°F, the thermostat would have been satisfied within 13 minutes with the DynaFuser, while the TBD-30 in the split flow position would run for over an hour. This longer running time is wasted energy.

Return temperature was also measured during this test. With the TBD-30 in the split flow position, the return temperature was 3.25°F higher than during the DynaFuser test.  This equates to a loss of 26.5% of energy directly to the return because half of the airflow in the TBD-30 in the split flow position is directed to the ceiling and never reaches the occupied zone.

Diffuser Solutions (continued)

## DynaFuser vs. Traditional Slot Diffuser in Average Room Temperature Test



# Grille & Diffuser Accessories & Energy Savings

## FlexRight Elbow

On every ceiling mounted supply grille and diffuser in a building that has a flexible duct connection, the FlexRight elbow should be used. FlexRight is a 90 degree elbow that improves the inlet condition for air entering the grille or diffuser inlet. This reduces the pressure loss and ensures more uniform airflow – which equates to energy savings during the life of the building.

FlexRight Elbow

The purpose of heating, ventilation and air conditioning systems is to provide thermal comfort to the occupied space. The ability of an HVAC system to perform this function depends on several factors including system design, equipment, air outlet type, and inlet conditions. Of all of these, proper inlet conditions at the air outlet is perhaps the simplest and most overlooked factor and one that has a direct affect on the level of thermal comfort in the occupied space.

When air distribution is designed for an occupied space, the outlet velocity of the supply air from a diffuser is assumed to be uniform. This is the case when the supply duct connection at the diffuser inlet has a sufficient amount of straight duct to ensure the supply air enters the diffuser in a uniform pattern. In reality, inlet duct connections in the field rarely have an adequate amount of straight duct to ensure an even flow of supply air into the diffuser. For the most part, this is due to limitations in space in the ceiling plenum, increased costs, and time constraints during installation. In addition, the use of flex duct as a replacement for hard duct has compounded the problem. As a result, a less than optimum duct connection at the diffuser is being used that provides a non-uniform air pattern in the occupied space with a decrease in thermal comfort (Figure 1).

To address this problem, a simple and easy solution called the "FlexRight" is available from Titus. FlexRight is a plastic 90 degree elbow that connects the flex duct to the diffuser inlet with a gentle 90 degree transition. This eliminates the problem of kinking or improper positioning of the flex duct that is so often found in the field when connected to supply diffusers (Figure 2).

FlexRight is made of 100% recycled materials, is UL listed and saves energy by improving airflow. The universal design accommodates all flexible duct sizes and diffuser inlets from 4" to 16". It provides a less expensive alternative to hard duct transitions and is easy to transport and install. With its simple and universal design, FlexRight is a great choice for both new construction and retrofit applications.

Figure 1

Kinked duct on inlet without the use of FlexRight.

Figure 2

Gentle 90° duct on inlet with the use of FlexRight.

Diffuser Solutions (continued)

## FlexRight Energy Savings - Through a Reduction in Total Pressure

| FlexRight Energy Savings Example 1 | | | |
|---|---|---|---|
| Flex Duct dia. | 8″ | 10″ | 10″ |
| Velocity (fpm) | 800 | 800 | 800 |
| CFM | 280 | 440 | 800 |
| | | | |
| Elect. Cost/kwH | Energy Savings | | |
| $0.06 | $4.50 | $7.06 | $13.81 |
| | | | |
| $0.10 | $7.50 | $11.76 | $23.04 |
| | | | |
| $0.14 | $10.48 | $16.50 | $32.26 |

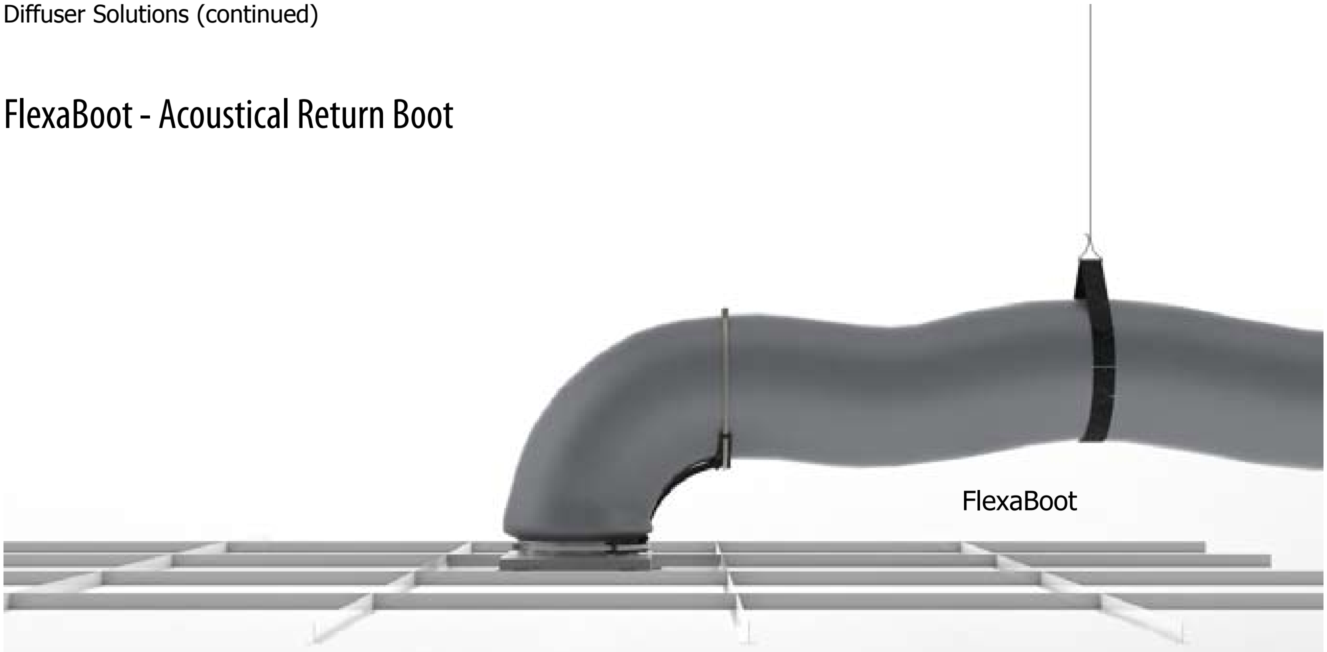
◇ Calculations based on 8760 hours.
◇ 365 days x 24 hrs

| FlexRight Energy Savings Example 2 | | | |
|---|---|---|---|
| Flex Duct dia. | 8″ | 10″ | 10″ |
| Velocity (fpm) | 800 | 800 | 800 |
| CFM | 280 | 440 | 800 |
| | | | |
| Elect. Cost/kwH | Energy Savings | | |
| $0.06 | $1.54 | $2.47 | $4.73 |
| | | | |
| $0.10 | $2.57 | $4.03 | $7.89 |
| | | | |
| $0.14 | $3.59 | $5.65 | $11.05 |

◇ Calculations based on 3000 hours.
◇ 250 days x 12 hrs

◇ Cost savings formula from ASHRAE Handbook

## FlexaBoot - Acoustical Return Boot




When considering air distribution for retrofit applications, the noise criteria (NC) factor is always considered for supply air outlets but often overlooked for return air outlets. Most HVAC applications include an open plenum design for the return air. The return device is located in the ceiling and the return air is exhausted into the plenum space above the ceiling. This can allow sound transfer to occur between different rooms in a building through the ceiling return air system. The additional noise is a problem that must be addressed in buildings such as medical offices, schools, and executive offices where privacy is a major concern. To address this issue, Titus offers an acoustical return sound boot that is inexpensive, lightweight, and easy to install. The FlexaBoot assembly consists of a 5’ piece of acoustical flex duct, a FlexRight elbow, and all necessary hardware for installation. Benefits include:

- ◇ Acoustically tested assembly
- ◇ Eliminates sound transfer in open plenum ceilings
- ◇ Low cost option to standard metal return boots
- ◇ Lightweight – easy to handle
- ◇ Can easily be transported and installed by one person

| FLEXABOOT COMPARISON | SHEET METAL BOOT | TITUS FLEXIBLE RETURN BOOT |
|---|---|---|
| Average installed cost each for Contractor? | $175 | $75 |
| Assembly acoustically tested? | No | Yes |
| Weight per boot? | 47 lbs | 9 lbs |
| Hangers to structure required per boot? | 3-4 | 1 |
| Number of workers required to install? | 2 | 1 |
| Material handling - Boots one worker can carry? | 1 | 4 |
| Fibrous materials exposed to air stream? | Yes | No |
| Flexibility and adjustability to fit plenum space? | No | Yes |
| Number of directions boot can be pointed? | 4 | 360 Degrees |
| Purchase and deliver to jobsite from factory | No | Yes |

## titus retrofit energy solutions

### ASHRAE Atlanta Headquarters in Atlanta, Georgia

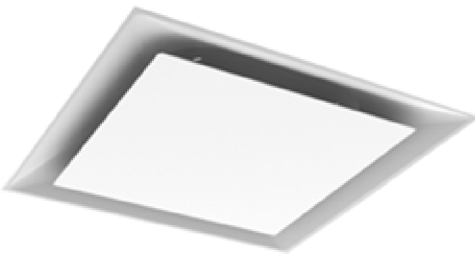
The ASHRAE Headquarters located in Atlanta, Georgia, recently completed a massive renovation of their facility. Originally built in 1965 and occupied by ASHRAE since 1981, this building will serve as a "living lab."

The "living lab" concept was created to heavily monitor the building's performance and to provide data online to all of its members. The overall goal for this renovation was to achieve the LEED certification levels of LEED-EB Gold and LEED-NC 2.2.

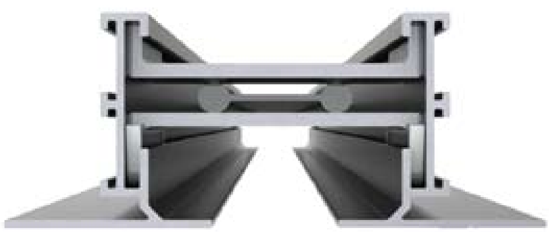
The Titus products selected to provide the airflow

# grilles & diffusers case study

ASHRAE Atlanta Headquarters



OMNI



FlowBar

for this renovation project and to assist them in reaching their goals were the OMNI and FlowBar diffusers.

The FlowBar architectural linear diffuser system maximizes engineering performance without distracting from the interior design of the building. It delivers higher airflow than conventional linear duffusers with low noise levels. The OMNI diffuser provides a uniform

360 degree air pattern without excessive noise or pressure drop. It is an excellent unit to use in a variable air volume system.

# titus retrofit energy solutions

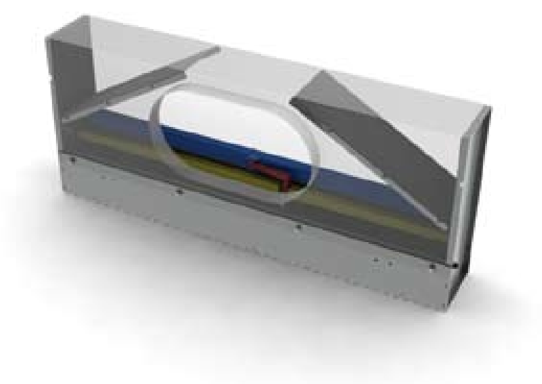
## US Green Building Council (USGBC) Headquarters in Washington, D.C.

The U.S. Green Building Council (USGBC), creators of the LEED Green Building Rating System, recently opened their new Headquarters building in Washington, D.C. The new building features an open work space theme with central common areas and multi-functional work spaces.

The unique design underscores USGBC's commitment to green building innovations and designs by providing a highly functional, healthy, and enjoyable work environment. The new office demonstrates how environmentally preferred green materials and highly efficient systems can transform an ordinary work space into an excep-

# grilles & diffusers case study

US Green Building Council (USGBC)



DynaFuser

tional work place.

The perimeter of this building presented a unique problem that Titus already had a solution for - The DynaFuser. It is a linear slot diffuser used in overhead heating and cooling perimeter applications. By using the supply air, the DynaFuser's auto-changeover ability automatically changes directional pat-

tern controllers to the correct position. The DynaFuser is a GreenSpec Listed product that saves energy and is a great compliment to the other green products used in this renovation.

## NOTES

Titus
The Leader in Air Management

ret-ro-fit

# titus retrofit energy solutions


www.titus-hvac.com

## underfloor, displacement ventilation & chilled beam products

# Energy Savings through Titus UnderFloor Systems

The interest in underfloor air distribution (UFAD) has increased significantly over the last decade. There is currently several million square feet of access floor air distribution systems being designed across the country. In 1997 Titus introduced the TAF-R diffuser and the TAF-G grommet, which were installed in the Owens Corning World Headquarters. Since then, Titus, ASHRAE, and the engineering community have continued to learn about UFAD systems. In the decade that Titus has participated in UFAD designs in the US, we have continued to introduce new products to meet the needs of this unique application.

In this section you will find the following:

- First Costs & Installation Costs
- UFAD System Economics
- Titus UFAD Products Overview
- Titus UFAD Installation References

The typical application for a UFAD system is the open plan office. Floor space is at a premium in a cubicle so a smaller clear area around the diffuser will allow more usable space in the cubicle. The UFAD diffuser manufacturer defines the required clear area that their diffuser needs to achieve the ASHRAE recommended temperature and velocity.

Originally UFAD systems were for computer rooms. The design intent was to cool computer equipment and not to provide comfort. The computer room design concept typically provides too cold of a space for comfort.

There has been a growth of UFAD systems used in offices and headquarters in U.S. It is estimated that 10% of U.S. construction will utilize access floors within a few years.

The growing interest in UFAD systems is primarily due to companies' need to easily rearrange office layouts, information and communications based offices, economics of ownership, and green building programs such as LEED.

For full documentation and literature for any of the products listed or more solutions, please reference the Titus website at www.titus-hvac.com

## First Costs & Installation Costs

UFAD systems can be designed with plenum returns using the same floor to floor height as conventional systems by shifting the occupied zone up into where the ceiling plenum would normally be.

The cost of floor, typically $5-7 per sq.ft. is offset by the fact that less ductwork is required. The installation costs are usually lower because the HVAC and data / power work is done at floor level. A 1996 study in HPAC magazine showed a $2.13/sq.ft. first cost savings using UFAD systems.

In a conventional system, ductwork must go to every diffuser. UFAD systems use a pressurized plenum to supply each diffuser, so less ductwork is required. In a UFAD system, the only ducting in the underfloor plenum is the ductwork required to supply the diffusers that are more than 50-75 feet away from the dampers or the separation for the perimeter. See diagrams below which illustrate how much less ductwork is needed in an underfloor system as opposed to a conventional overhead ceiling system.

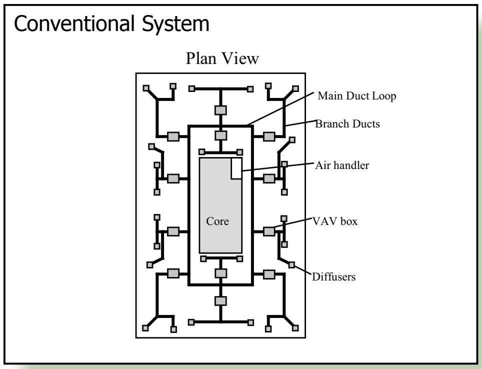



Figure 1. Conventional System Ductwork

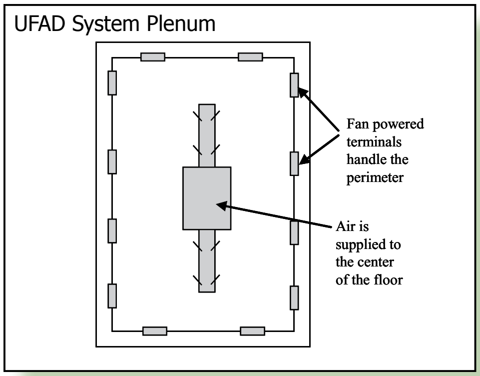



Figure 2. UFAD System Plenum

## UFAD System Economics

The main economic considerations for a UFAD system are reduced first costs & installation costs, higher HVAC equipment efficiency, lower horsepower fans, better heat and pollutant removal, quick to install and easy to rearrange office layouts, and lower life-cycle building costs.

### Higher HVAC Equipment Efficiency

In an UFAD system, supply air enters directly into the occupied zone at the floor level. In a conventional system, the supply air temperature is usually 55°F because it must mix with the warm air at the ceiling before it enters the occupied zone.

UFAD systems typically use 63-68°F supply air temperatures. This warmer supply air can reduce energy consumption of the HVAC equipment. Some DX equipment cannot supply air at this high temperature, so this must be considered when selecting the HVAC equipment.

### Lower Horsepower Fans

UFAD systems move a larger volume of air with overall lower pressure drops. The diffusers used in UFAD systems operate around 0.1" wg or less, so lower horsepower fan can be used, reducing energy costs.

### Easy Installation and Relocation

UFAD diffusers are installed through the floor panel after flooring and carpet installation is complete. Little attention needs to be placed on diffuser location until office furniture layout is finalized.

Typical churn in an office is 33%, meaning that everyone moves every three years. Diffusers are rearranged by moving entire floor panel to a new location. This reduces the time and labor costs of relocation and renovation in an office.

### Lower Life Cycle Costs

Several factors of the UFAD system contribute to potential life cycle savings. The building should have an energy savings from the use of lower horsepower fans. The owner should see reduced costs for office layout changes.

In addition to these, he concrete structural slab can be used to lower peak cooling demand. The use of the underfloor plenum as a supply duct allows the use of the thermal mass of the structure as an energy "flywheel".

By ventilating the underfloor plenum with cool air at night, the structure can be cooled to the point where the load during the early part of the day is significantly lowered. A number of strategies can be employed to take advantage of the potential for stored "cool", resulting in lowered energy use and off-peak energy use.

There are also costs savings associated with increased thermal comfort for occupants. Because the diffusers are occupant adjustable, the facility staff should see fewer complaints about thermal comfort.

Increased employee satisfaction potentially results in increased productivity. Labor costs are typically 10 times the cost of property. A 1% productivity improvement is the equivalent of 22 hours, or almost three days, of gained productivity.

For a company with 115 employees earning $35,000 a year, 30 employees earning $60,000 a year, and 5 employees earning $80,000 a year, a 1% improvement would worth be almost $70,000. This is a substantial payback for a building owner.

UnderFloor (continued)

## UnderFloor Air Distribution Products

### TAF Series Diffusers

TAF-R, TAF-R-FR, TAF-G
- ◇ Architecturally appealing
- ◇ Interchangeable TAF-G grommet

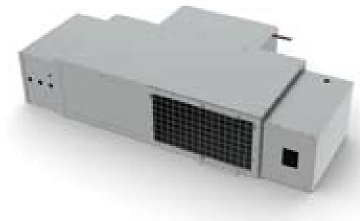
TAF-L-V, TAF-L-W, TAF-L-H, TAF-L-R, CT-TAF-L
- ◇ Continuous perimeter system
- ◇ Cooling, heating and return plenums

TAF-D, TAF-V, TAF-HC, CT-TAF-(480, 481, PP0, PP3)
- ◇ Heavy gauge diffuser plenum
- ◇ Installs into floor panel

UnderFloor (continued)

## Fan Powered Series

ALHK, DLHK
- ◇ Designed to fit around pedestals of any access floor system
- ◇ 10½ or 14 inch overall height
- ◇ 400 to 1200 cfm flow range



DPFC
- ◇ Designed to fit around pedestals of any access floor system
- ◇ 14 or 16 inches tall
- ◇ 600 to 2800 cfm flow range

## titus retrofit energy solutions

### New York Times Building in New York City, New York

The New York Times is committed to bringing the viewer all of the quality news and information from around the world either in print or online. The building is 1.6 million square feet and spans 856 feet into the sky.

The all glass curtain wall with a ceramic sunscreen will be the first of its kind built in the United States. This innovative design uses natural light to maximize energy savings through daylight harvesting.

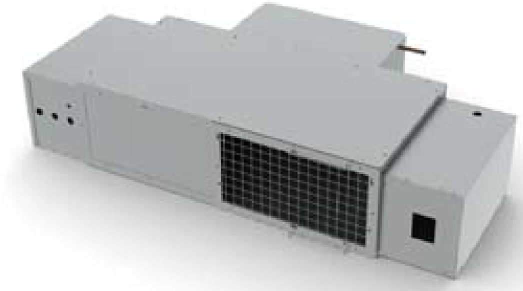
To assist in their efforts toward energy conservation, Titus recommended the DLHK terminal

# underfloor case study

New York Times Building

DLHK

TAF-R



DPFC

unit. It is a Fan Powered Terminal Unit that is designed to be installed in the underfloor plenum of underfloor grid systems and houses an energy efficient fan motor that is mounted in vibration isolators.

The TAF-R diffuser is designed for underfloor applications and is constructed of a high impact, polymeric material that is durable

enough to resist foot traffic. it integrates well architecturally and provides the necessary airflow for this state-of-the-art building. The DPFC is a booster terminal unit for perimeter applications. It's used when systems cannot achieve constant plenum pressure.

# titus retrofit energy solutions

## Visteon Village Corporate Headquarters in Van Buren Township, Michigan

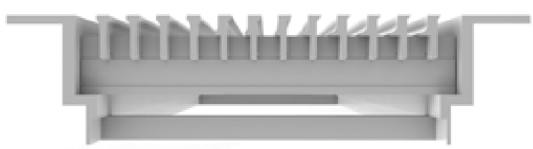
The Visteon Corporation is a leading innovator in the automotive design industry and produces components, systems, and modules that appeal to drivers and passengers throughout the world. Their corporate headquarters is a unique collection of buildings designed to create a community-style work environment while promoting green building concepts.

Visteon preserved the wetlands on the site and also conserves energy by utilizing extensive day-light harvesting. The Titus underfloor products used to provide the air distribution are the DLHK terminal unit, the CT-TAF-L linear bar grille, and

# underfloor case study

Visteon Village Corporate Headquarters

DLHK



CT-TAF-L

TAF-R

the TAF-R underfloor plenum in numerous locations along the perimeter of the building's interior to provide the necessary air flow for the load requirement.

## Christman Headquarters Building in Lansing, Michigan

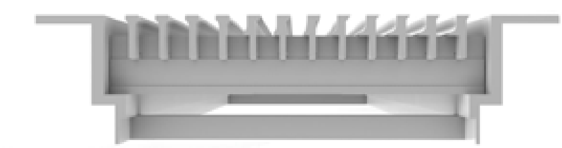
Built in 1928, and originally known as the Mutual Building, the new Christman Company Headquarters is a revitalized landmark building located in downtown Lansing.

With rich history and captivating interior design, the Christman team faced a unique challenge of preserving the past while blending in technology from the present. The end result was a historic preservation of design from a time long since forgotten that incorporates today's Green Building concepts to take the Christman Building into the future.

# underfloor case study

Christman Corporate Headquarters

TAF-L-W



CT-TAF-L

TAF-L-V

To assist in their efforts toward being recognized as the world's first building to achieve "Double Platinum" LEED certification, the Titus underfloor products selected were the TAF-L-W, CT-TAF-L, and the TAF-L-V.

The TAF-L-W is a fixed linear bar diffuser plenum and the TAF-L-V is a variable linear bar diffuser plenum. Both units integrate with


the CT-TAF-L from the top surface and provide the necessary airflow for the building.

# Displacement Ventilation Overview

For retrofit applications, displacement ventilation is a great alternative to conventional overhead ceiling supply systems. Displacement ventilation provides design flexibility, energy savings, and the highest level of indoor air quality (IAQ).

## Energy Savings with Displacement Ventilation

- ◇ Higher supply air temperature provides savings from downsizing central air system and ductwork
- ◇ Savings from extended economizer range (due to warmer supply air)
- ◇ Higher equipment efficiency – less work to reach temperature and pressure
- ◇ Heat sources outside the occupied zone may not be considered in load calculations
- ◇ Air change effectiveness of 1.2 (ASHRAE 62.1) saves energy

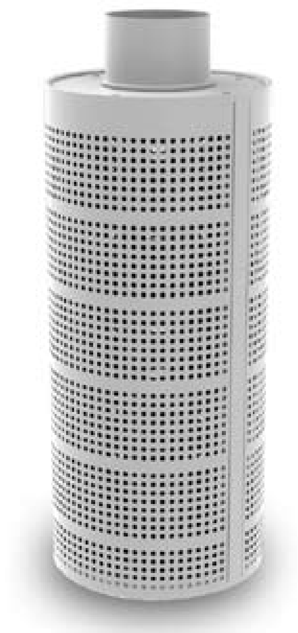
## Retrofit Applications for Displacement Ventilation

Offices
Cafeterias
Lecture halls
Computer rooms
Conference rooms
Libraries
Lobbies
Large open spaces

Additional design considerations:

- ◇ Ceiling heights should be a minimum of 9 feet.
- ◇ Building should have tight envelope with high performance windows
- ◇ Adequate floor space for diffuser placement
- ◇ Low noise requirements
- ◇ Improved air quality requirements

Displacement can easily be combined with overhead mixing systems to provide an efficient and energy savings approach in retrofit applications.



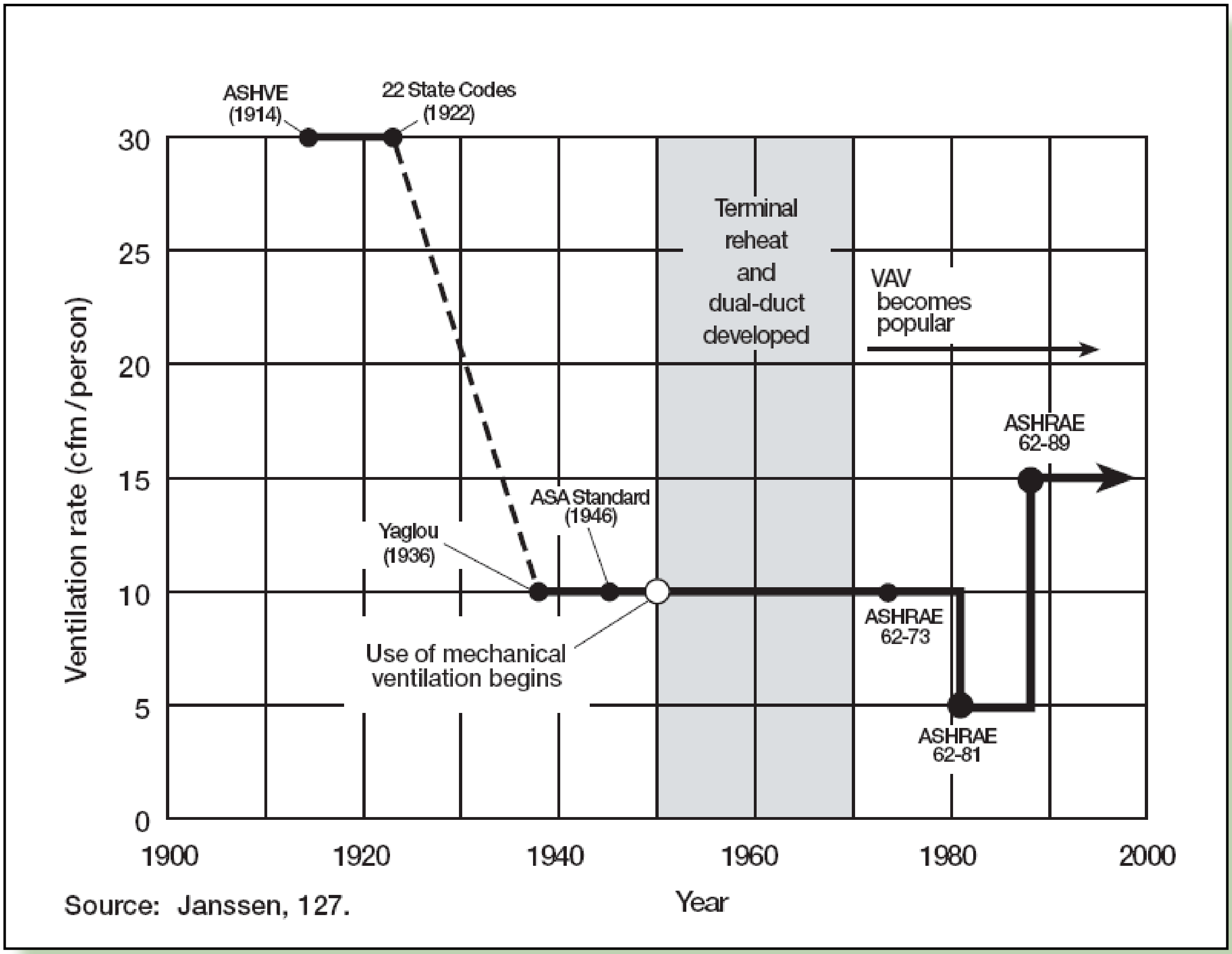
Displacement Ventilation (continued)

Displacement Ventilation has an "Air Change Effectiveness" rating of 1.2 as compared to a rating of 1.0 for overhead mixing systems. This additional 20% factor translates to 20% energy savings when using displacement ventilation to satisfy minimum ventilation rates.

The current minimum ventilation rate for typical offices is 17 CFM/person (ASHRAE 62.1-2007). With displacement, the system only needs to supply 80% of the 17 CFM/person to maintain the Standard - due to the 1.2 air change effectiveness factor. The result is energy savings while still maintaining proper ventilation requirements and comfort in the building space.

When considering displacement ventilation for retrofit projects, it is important to consider when the building was built as well as the minimum ventilation rate at that time. The chart below shows the minimum ventilation rates from 1914 to 2000. If the existing building's HVAC system was designed for the minimum ventilation rate for the year the building was built, then it will be difficult to achieve the current 17 CFM/person standard when retrofitting. However, by using displacement ventilation, you will get an additional 20% in the process.

## Ventilation Rates - ASHRAE History

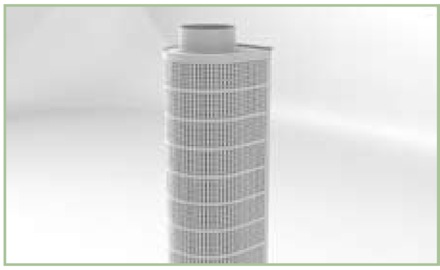


Displacement Ventilation (continued)

## Displacement Ventilation Diffusers

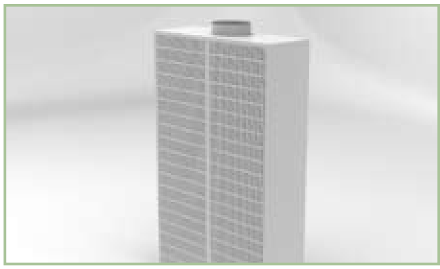
DVBC
- ◇ Rectangular displacement diffuser with curved face for wall mount applications.
- ◇ 250 - 1800 cfm.

DVCP
- ◇ Circular displacement diffuser with 360° air discharge pattern for floor installation.
- ◇ 120 - 2500 cfm.

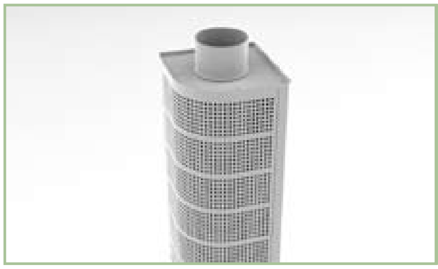


DVHC
- ◇ Semi-circular displacement diffuser with 180° air discharge pattern for wall or surface mount applications.
- ◇ 120 - 3700 cfm.

DVIR
- ◇ Rectangular displacement diffuser with 1-way discharge designed for flush mount applications.
- ◇ 450 - 2400 cfm.



DVRI
- ◇ Rectangular displacement diffuser that can be positioned against a wall in a flush or surface mount orientation.
- ◇ 75 - 380 cfm.



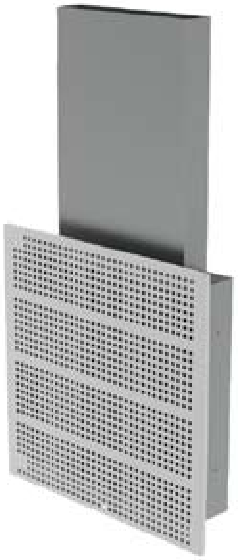
DVVC
- ◇ The DVVC is a displacement diffuser with 90° air discharge pattern for corner mount applications.
- ◇ 100 - 1200 cfm.

## *titus retrofit energy solutions*

### Willard Elementary School in Concord, Massachusetts

The new Willard Elementary School, which opened its doors for the first time this year, is a state-of-the-art building designed by the Office of Michael Rosenfeld, Inc (OMA) Architects. This award winning, full-service architectural firm listened to and incorporated many design elements from the clients to create a new education facility for young minds to grow and prosper.

The students, faculty and staff wanted their new building to be something that their previous one wasn't - to be an energy efficient and safe structure that everyone would be proud of. OMA created a green learning environment for all students - grades K-5 to learn from. Touch screens monitor the elementary school's energy consumption as well



DVIR

as the students have created and produced podcasts and brochures that highlight additional sustainable features. The library, which is located in the heart of the school, benefits from an abundance of natural light. The natural light is able to penetrate deep into the building by light shelves that are located in the classroom.

The DVIR is a rectangular displacement diffuser with a 1-way discharge designed for flush mount

applications. It provides air distribution by supplying a large volume of air at a low velocity to the occupied zone. The deflector nozzles within the unit are easily adjustable which creates a different airflow pattern.

# Chilled Beam Overview

Chilled beam diffusers utilize water coils to condition the air and remove the sensible load in the occupied space. They provide energy savings, excellent comfort, and quiet operation.

## Energy Savings with Chilled Beams

Higher chilled water temperature than conventional cooling system – translates to 15%-20% higher efficiency for chiller.

When used with dedicated outdoor air systems (DOAS), cooling and ventilation energy consumption is reduced by 25-30% relative to VAV system.

At least 50% less ductwork than conventional systems.

Fan energy savings from downsized central air handler.

Re-circulated air can be used to help satisfy load requirements.

| Simulated VAV Energy Comparison | |
|---|---|
| Category | % Energy Saved vs VAV |
| Heating | 8 - 12% |
| Cooling | 15 - 20% |
| Ventilation | 20 - 30% |

## Retrofit Applications for Chilled Beams

Offices
Laboratories
Schools/universities
Training/conference rooms
Computer/equipment rooms
Open plan spaces
Buildings with limited ceiling plenum space
Supplementary cooling with existing HVAC system

In most cases retrofitting with chilled beam requires a complete change of the building's HVAC equipment. This will result in smaller air handlers, smaller ductwork, new CB diffusers and piping. However, if the existing HVAC equipment can be used, chilled beam can be used to supplement the cooling load requirements.

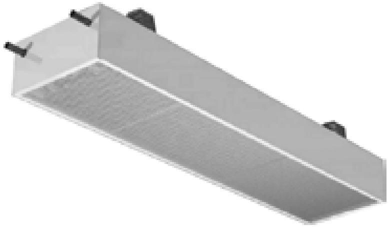
## Chilled Beam and VAV Comparison

| Active Chilled Beam and Variable Air Volume Comparison | | | |
|---|---|---|---|
| Component | ACB | VAV | Net for ACB |
| Air Handler | small | large | + |
| Ductwork | small | large | + |
| Risers | small | large | + |
| Ceiling Space | small | large | + |
| Piping | large | small | - |
| Fan Energy | low | high | + |
| Pump energy | high | low | - |
| Supply outlet (diffuser) cost | high | low | - |
| Water side system cost | high | low | - |
| Thermal comfort | high | low | + |
| Individual control | high | low | + |
| Occupant satisfaction | high | low | + |

## Chilled Beam Products

TCM2, TCMS
- ◇ Active beam
- ◇ Modular design
- ◇ 4-way or 1-way pattern
- ◇ Flush mount

LCB2, LCBS
- ◇ Active beam
- ◇ Linear design
- ◇ 2-way or 1-way pattern
- ◇ Flush mount



LPF2, LPE2
- ◇ Passive beam
- ◇ Linear design
- ◇ Flush or exposed mount

RCP
- ◇ Radiant ceiling panels
- ◇ Linear design
- ◇ Flush or exposed mount

## Dee and Charles Wyly Theatre in Dallas, Texas

The Dallas Center for the Performing Arts has a new venue to hold performances. The Dee and Charles Wyly Theatre is an 80,300 square foot facility for both classical and experimental productions.

The 11-story building designed by Rem Koolhaas of OMA breaks out of the traditional theater layout by featuring an advanced vertically stacked design. At its base, the auditorium space is a three-sided glass enclosure, allowing the remainder of the building to rise as if floating over the performance space. The 575-seat multi-form theater has the ability to transform itself into a

# chilled beam case study

Dee and Charles Wyly Theatre

LPB2

variety of configurations including: a proscenium, thrust, traverse, arena, flat floor, and black box.

When considering the comfort of the occupants, the Titus' Chilled Beam technology was selected to offer maximum comfort for maximum efficiency.

The LPB2, a Passive Chilled Beam Diffuser was selected to provide the air distribution for this unique structure. This diffuser has no supply air connection, but cools by utilizing a water coil and natural convection.

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## AstraZeneca Research & Development in Waltham, Massachusetts

The AstraZeneca Research and Development Boston facility located in Waltham, Massachusetts, consists of three five-story wings linked by a multi-level corridor. The large windows allow natural light to penetrate the interior of the textured limestone building, which lowers energy costs.

In order to provide maximum comfort for the occupants, Titus selected the TCM2. The Thermal Comfort Module (TCM2) operates like a chilled beam, but offers a 4-way air distribution pattern like a ceiling diffuser. It is also adjustable on each side. This feature provides an extremely versatile

# chilled beam case study



TCM2

and flexible comfort module for an invigorating indoor climate while offering the highest degree of comfort.

The level of system generated sound is low because the TCM2 manages the indoor climate entirely without moving parts. This unique element provides for minimal maintenance costs now and into the future for

AstraZeneca because the diffuser does not contain any fan, filter, or drainage piping. The TCM2 offers great flexilbility for changes in room configurations now and into the future.

## NOTES

Titus
The Leader in Air Management

ret-ro-fit

# titus retrofit energy solutions

www.titus-hvac.com

## fan coils

# Fan Coil Solutions Overview

Fan Coil units utilize chilled and or hot water coils to condition the air and remove the latent and sensible loads in the occupied space. They provide energy savings, excellent comfort, and quiet operation. Of existing fan coil installations and options selected for those installations, there are several energy efficient options that can improve the overall system efficiency and therefore reduce overall operating costs.

## Retrofit Applications for Fan Coils

Offices
Hotels
Schools/universities
Training/conference rooms
Computer/equipment rooms
Open plan spaces

## Existing Fan Coil Unit Installation Energy Improvement Opportunities

- ◇ Fan Cycle Temperature Control
- ◇ ON/OFF Motorized Control Valves
- ◇ PSC Constant Speed Fan Motor
- ◇ High Static Pressure Filters
- ◇ Low Cost/Inefficient Thermostats

## Fan Cycle Temperature Control

This is a method of controlling the temperature in a space which was widely used 10 to 20 years ago. The control of the temperature set-point in the space is achieved by cycling the fan motor on and off in a fan coil unit where no water control valves are installed and water flows continuously thru the heat exchanger coil.

Inadequate temperature control is typically a result of the Motor/Blower assembly coming to a stop once the set point in the space is reached. This makes it difficult to maintain the occupied space temperature at or near the room set point.

Noise is also an issue with this method of control as typically units are oversized resulting in cycling the Motor/Blower more often; resulting in noise discomfort for the occupants.

Due to the absence of control of the Chilled or Hot water through the Heat Exchanger Coils and typical heat losses in the system combined with poor insulation techniques applied to the system piping, these systems are prone to high energy costs as water is constantly being pumped through the entire water system.

One other potential risk is mold growth in the condensate pans as Chilled water is constantly running through the Heat Exchanger coil. This causes a constant de-humidification of the air surrounding the Heat Exchanger coil which will provide a steady flow of condensation and moisture presence in the condensate pans, increasing the potential for Mold growth.

The advantage of this control design was the low initial capital investment for the equipment and the reduced maintenance required due to the lack of motorized valves in the water system.

## ON/OFF Motorized Control Valves

Many fan coil control systems use valves which open 100% on a demand for cooling or heating no matter the load requirements in the conditioned space.

This type of control method does not control the conditioned space temperature properly due to too much cooling or heating being transferred into the space independently of load requirements. As a result this system is also prone to high energy costs due to spikes in temperature in the conditioned space and occupant discomfort.

The advantage of this control design is the low initial capital investment for the equipment and low cost maintenance required as only simple controls are necessary.

## PSC Constant Speed Fan Motors

PSC Motors are typically 20% to 60% efficient at full demand, however at partial demand the efficiency can also be substantially reduced up to 30%.

Regardless of the occupied space heating and cooling load requirements, the motor/blower delivers 100% of the airflow required to meet the worst case occupied space load design conditions. Less than 100% capacity heating and cooling demand is often needed at any given time, resulting unnecessary higher operating costs.

HVAC systems only need to run at partial heating and cooling loads most of the year and with using PSC motors, too much air is discharged into the conditioned space at partial load requirements creating unnecessary drafts and noise resulting in occupant discomfort.

Typically units installed with PSC motors are energy inefficient and with average building installations of 250 or more Fan Coil units, the overall energy operating cost of a building will be higher when compared with other technologies available.

## High Static Pressure Filters

Fan Coil unit internal filters with high static pressures typically require more power to overcome this resistance resulting in a requirement for larger motors. These larger motors are more expensive to purchase and have higher energy operating costs.

Larger motors also generate more noise and as a direct result, more acoustic materials will have to be incorporated in the design of the fan coil unit at a higher cost to the overall product.

## Low Cost/Inefficient Thermostats

The typical and most common Fan Coil installation uses controls that have on/off, temperature setting and three speed fan switches. This is a very basic thermostat that is simple to operate, has a low initial cost with minimal wiring required. While in many cases this is an appealing choice due to the low initial component and installation costs, long term savings and Green initiatives will be difficult if not impossible to realize.

Due to the thermostat only having the ability to be turned ‘on’ or ‘off’, the Fan Coil motor (which is by far the highest consumer of energy inside the unit) will run continuously whether or not cooling/heating is required. This leads to potential situations where the motor runs 24 hours per day; possibly for several days at a time unnecessarily.

These thermostats also do not allow for upgradeability in the future for more sophisticated building management systems and would have to be completely replaced.

While the cost conscience owner will see immediately see the benefits to a basic on/off thermostat, a long term cost conscience owner may not see these thermostats as the best choice in achieving satisfactory results over an extended period of time.

Fan Coil Solutions (continued)

## Titus Solutions

◇ Modulated Control Valves
◇ Electronically Commutated Speed Fan Motors
◇ Low Static Pressure Filters / Monitoring System
◇ PID Controls with supported Accessories

( ) Good energy savings.
( ) Better energy savings.
( ) Best energy savings.

Low installation costs. ($)
Medium installation costs. ($$)
High installation costs. ($$$)

### Modulated Control Valves ( ) ($$)

The modulated valve actuator control device increases Chiller and Boiler efficiency by 15-20% with substantial Energy savings by meeting exact conditioned space load requirements. In addition by modulating water through the heat exchanger coil, the modulated valve actuator will reduce the system water flow demand therefore decreasing the system pump power requirements.

In addition the modulated control valve increases the Delta Temperature across the water coil, thereby heating and cooling more occupied space with smaller water coils or fewer fan coil units.

The overall net effect of modulated control valves adjusting the water flow rate to meet occupied space load requirements as they change, is increased occupant comfort in the conditioned space while reducing system energy costs.

### Electronically Commutated Speed Fan Motors ( ) ($$$)

Most ECM motors currently in the market have a 70% motor efficiency at full and partial loads which substantially reduces Energy costs. The ECM motor also has the ability to modulate the airflow to meet partial load requirements thereby further reducing the energy requirements of a building.

The low operating temperature of the ECM motor also requires very little energy to offset the heat gain from the motor to the cooled airstream, thus also reducing the building energy requirements.

Most HVAC equipment operates at partial load levels most of the year and the ability of reducing the CFM with an ECM motor allow for substantial noise reductions.

In addition maintaining a constant movement of air through the conditioned space will also increase the IAQ by maintaining humidity levels at a satisfactory level.

Fan Coil Solutions (continued)

## PID Controls + Accessories (🌳) ($$)

All fan coil units require some form of control and there is a wide variety of controllers, sensors and programs that can allow a fan coil unit to operate much more efficiently and with lower energy costs.

One of the easiest ways to save energy and money is to upgrade to a programmable thermostat. These thermostats allow the fan coil unit to be programmed to run only at specific times of the day at specific temperatures. Programming the thermostat to shut down or reduce the cooling/heating demands during periods of time when the occupant is typically away will quickly begin reducing costs after installation. The occupant can always temporary override the program during these times if necessary.

The next better step in improving the efficiency and energy consumption of the fan coil unit is to install a programmable thermostat with occupancy sensors. Notes and instructions can be left for occupants to please turn fan coil units off while not needed, but this gives unreliable results. Hotel guests often have little time to review notes or remember to turn the fan coil units off when not needed and hotel staff while are typically better at remembering to turn equipment off, may still forget while performing their daily tasks.

A wide variety of occupancy sensors are available from infrared to key card types and can automatically tell the thermostat if an occupant is present. The thermostat can be programmed to gradually reduce the cooling/heating demand to a pre-specified point if an occupant is not present. By using these sensors in conjunction with a programmable thermostat, tighter control of the energy consumption of a fan coil unit can be maintained.

One of the best available control options is a building management system (BMS) with occupancy sensors. All the advantages of the above programmable thermostat are available with a BMS but with the added ability to tie all of the fan coil units in a building to a central control system. This allows for continuous monitoring of all the fan coil units and real time analysis of the cooling/heating demands and energy savings associated with this level of control.

## Low Pressure Drop Filters/Monitoring System (🌳) ($)

Using low pressure drop filters, smaller fan motor sizes can be used due to lower static pressure losses. In addition a filter monitoring system will reduce the fan motor energy requirement due to reducing excessively dirty filter conditions. By using low pressure drop filters and replacing them regularly, improved IAQ conditions can also be achieved.

# titus retrofit energy solutions

## Rosen Shingle Creek Hotel in Orlando, Florida

The Rosen Shingle Creek Hotel is one of the largest convention hotels in Central Florida. Totaling 1,711,063 square-feet of space, and situated on 230-acres, this hotel offers state-of-the-art amenities that includes 445,000 square-feet dedicated meeting and event space, a spa and treatment facility, ballrooms, fitness center, and so much more.

Titus was pleased to provide the HVAC fan coil products for this breath-taking facility. The fan coil products selected for this project were from the Vertical Stack group. The vertical stack units are designed for free-blow or ducted, concealed

# fan coils case study

Rosen Shingle Creek Hotel

VS

installations which work well in a variety of projects and high end facilities like the Rosen Shingle Creek resort. The vertical stack units primarily used for this installation utilized a specialized control sequence to maximize the use of outside air to balance fresh air, humidity and occupant comfort.  With this feature higher operating efficiencies can be achieved

while allowing a comfortable outside fresh air supply into the guest space.

# titus retrofit energy solutions

## Gaylord National Hotel & Convention Center in Washington, D.C.

The Gaylord National Hotel and Convention Center is the premiere destination getaway for the Washington DC region. It offers a wide range of experiences for everyone which includes fine dining, shopping, a 20,000 square-foot spa and fitness center, and a two-story rooftop lounge that offers the best late-night excitement in the area.

The VSM and VSS vertical stack units were selected for this project due to the high number of rooms used in this installation as well as the energy efficiency and cost effectiveness of two separate fan coil units utilizing one set of hot and cold water piping. In addition a building man-

# fan coils case study

Gaylord National Hotel

agement system is used to help accurately control and minimize the heating and cooling losses during periods when rooms are unoccupied.

The vertical stack units were coupled together in pairs and are installed to provide free blow heating and cooling airflow to two separate rooms at any given time.  With this type

of installation and control sequence, minimum equipment operating costs and high efficiency can be maintained while providing the resort guests with unequalled comfort.

VSM/VSS

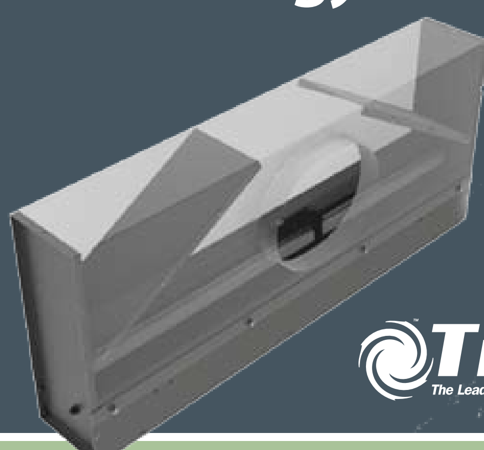
# ret-ro-fit

1. to furnish (as a computer, airplane, or building) with new or modified parts or equipment not available or considered necessary at the time of manufacture

2. to install (new or modified parts or equipment) in something previously manufactured or constructed

3. to adapt to a new purpose or need: modify

*titus retrofit energy solutions*



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