

MAKING MODERN LIVING POSSIBLE



VLT[®] HVAC Drive Application Guide



www.danfossdrives.com

Contents

1 How to read this manual	3
Introduction	3
2 Variable Air Volume ventilation systems	5
Introduction	5
Installation	7
Energy savings estimation	9
Drive features	12
3 Single Zone Constant Air Volume ventilation systems	15
Introduction	15
Air volume control	15
Variable frequency drive advantages	17
Energy savings	18
Drive features	21
4 Cooling Tower Fan Control	23
Introduction	23
Fan Speed Control	23
Energy Savings	24
Drive Features	25
5 Condenser Water Pumping Systems	29
Introduction	29
Pump Control	29
Variable frequency drive advantages	31
Energy Savings	32
Drive Features	35
6 Primary Pumps in a Primary/Secondary Chilled Water Pumping System	37
Introduction	37
Primary Loop Control	37
Energy Savings	41
Drive Features	44

7 Secondary Pumps in a Primary/Secondary Chilled Water Pumping System	47
Introduction	47
Loop Pump Control	47
Sensors	50
Energy Savings	51
Drive Features	53
8 Variable Pumping Systems	55
Introduction	55
Variable Speed Pump	55
Sensors	57
Energy Savings Potential	58
Drive features	61
9 Booster Pumping Systems	63
Pressure Booster Pumping Systems	63
Booster Pump Control	65
Selection	67
Sensors	68
Energy Savings	68
Drive Features	71
Index	73

1 How to read this manual

1

1.1.1 Introduction

These HVAC application examples are meant to assist planners and technical staff in their efforts to build HVAC plants with different functionality. Eight typical HVAC applications are described along with their potential energy savings and FC specific features. Traditional solutions are compared with optimized Danfoss VLT®HVAC Drive solutions and advantages described.

The applications are:

- Variable Air Volume Ventilation Systems
- Single Zone Constant Air Volume Ventilation Systems
- Cooling Tower Fan Control
- Condenser Water Pumping Systems
- Primary Pumps in a Primary/Secondary Chilled Water Pumping System
- Secondary Pumps in a Primary/Secondary Chilled Water Pumping System
- Variable Pumping Systems
- Booster Pumping Systems

1.1.2 Available literature

- Operating Instructions MG.11.Ax.yy provide the necessary information for getting the variable frequency drive up and running.
- Design Guide MG.11.Bx.yy entails all technical information about the variable frequency drive and customer design and applications.
- Programming Guide MG.11.Cx.yy provides information on how to programme and includes complete parameter descriptions.
- Mounting Instruction, Analog I/O Option MCB109, MI.38.Bx.yy
- PC-based Configuration Tool MCT 10, MG.10.Ax.yy enables the user to configure the variable frequency drive from a Windows™ based PC environment.
- Danfoss VLT® Energy Box software at www.danfoss.com/BusinessAreas/DrivesSolutions then choose PC Software Download
- VLT® HVAC Drive Applications, MG.11.Tx.yy
- Operating Instructions VLT HVAC Drive BACnet, MG.11.Dx.yy
- Operating Instructions VLT HVAC Drive Profibus, MG.33.Cx.yy.
- Operating Instructions VLT HVAC Drive Device Net, MG.33.Dx.yy
- Operating Instructions VLT HVAC Drive LonWorks, MG.11.Ex.yy
- Operating Instructions VLT HVAC Drive High Power, MG.11.Fx.yy
- Operating Instructions VLT HVAC Drive Metasys, MG.11.Gx.yy
- Operating Instructions VLT HVAC Drive FLN, MG.11.Zx.yy

x = Revision number

yy = Language code

Danfoss technical literature is available in print from your local Danfoss Sales Office or online at:

www.danfoss.com/BusinessAreas/DrivesSolutions/Documentations/Technical+Documentation.htm

1.1.3 Abbreviation list

Abbreviation	Title	Description
AHU	Air Handling Unit	Air Handling Unit: Mechanical equipment that filters, heats, cools, humidifies, dehumidifies and circulates air in a building.
BMS	Building Management System	Building management system: A microprocessor-based controller that controls centrally located HVAC or unitary HVAC equipment throughout a building.
CAV	Constant Air Volume	Constant Air Volume System: Air handling system that provides a constant air flow while varying the supply air temperature to the space to meet heating and cooling needs.
DD	Discharge Dampers	Discharge dampers: A device used to control the capacity of a fan by creating a static pressure drop in the system, just downstream of the fan.
FC	Variable Frequency Drive	Variable Frequency Drive: A motor speed control that varies the frequency and voltage to an electric motor to vary the speed of the motor.
HOA	HOA Switch	Hand-Off-Auto Switch: A switch placed on the cover of the variable frequency drive to remove power from the device or provide manual or auto operation.
IGV	Inlet Guide Vanes	Inlet guide vanes: Devices used for controlling the angle of incidence of the inlet air, thus ensuring a variable volume of air delivered by the fan.
MSM	Multi set-point minimum	A feedback setting of the PID controller, causing the controller to choose the lowest feedback signal compared to its own set-point.
PID	Proportional-Integral-Differential Control	The PID Controller compares the value of the controlled variable to the set point and signals the controlled device for corrective action with proportional, integral and derivative action. Most HVAC loops perform satisfactorily with PI control alone.
RTD	Resistance Temperature Detector	Resistance Temperature Detectors are wire wound temperature measurement devices that are used in the HVAC industry because they are precise, linear over a wide range of temperatures and small to fit into HVAC components.
VAV	Variable Air Volume	Variable air volume system: An air handling system that controls space temperature by varying the quantity of the supply air to the space to meet heating and cooling needs.

1.2.1 Symbols

Symbols used in this manual:



NB!

Indicates something to be noted by the reader.



Indicates a general warning.



Indicates a high-voltage warning.



Indicates default setting

1.2.2 Fire Mode and Safe Stop

Refer to the Design Guide for further information about the correct use of Fire Mode and Safe Stop.

2 Variable Air Volume ventilation systems

2.1 Introduction

Variable air volume (VAV) systems are the most energy efficient method of maintaining building environmental conditions. These systems deliver air at a constant temperature while reducing or increasing air quantities to satisfy the changing room (or space) demands. The system is designed to maintain a constant static pressure in the supply duct to VAV boxes. Individual VAV boxes supply the conditioned air to the occupied space with a variable flow of constant temperature air.

In the past, discharge dampers or inlet guide vanes (IGV) were installed in an air handling unit to modulate the fan capacity. These devices reduced air flow by either creating a resistance to the air entering the fan discharge duct-work or by pre-spinning air entering the fan to limit performance. Each method provided some amount of energy reduction but input power remained relatively high because the speed of the motor was constant.

Today, variable frequency drives are the most common method of air flow control. The drive adjusts the speed of the fan motor and capacity directly as the building load varies. Higher system efficiency is obtained with variable frequency drives because of the fan affinity laws. When motor speed is decreased, the power required is reduced by the ratio of the speed cubed. Additional system savings come from heating or cooling a smaller volume of air.

2.1.1 Air volume control

Air Handling Units (AHU's) typically bring in outside air to mix with return air to maintain room conditions. The mixed air passes through a filter, across heating and/or cooling coils, and through the fan into duct-work for distribution throughout the building. Individual zone thermostats modulate a VAV box damper to vary the flow of air in each room maintaining the desired temperature.

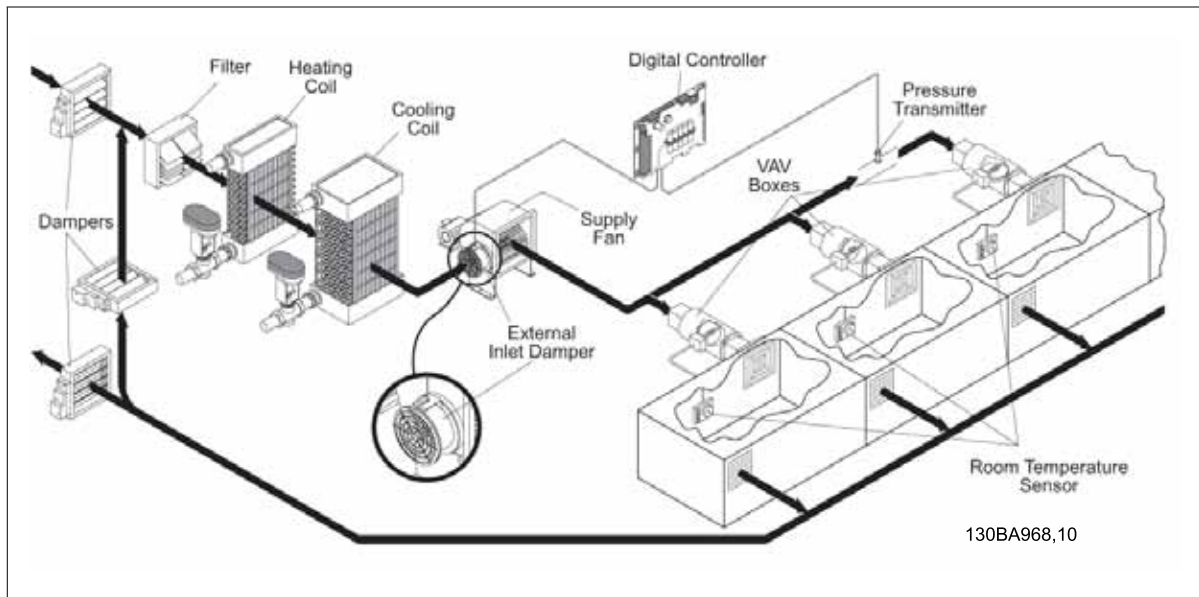


Illustration 2.1: VAV System with Inlet Guide Vanes

As the conditioned space temperature becomes satisfied, the VAV box damper modulates toward a closed position, reducing air flow. As a result, the pressure in the duct-work begins to rise.

The system static pressure sensor senses this higher static pressure and sends a signal to a controller to reduce air volume. Discharge dampers or inlet guide vanes partially close, introducing a system pressure drop and causing the fan volume to decrease. A variable frequency drive will reduce the speed of the motor to reduce fan volume.

When the space temperature increases, the VAV box damper modulates toward the open position, increasing air flow. The pressure in the duct-work begins to reduce. Discharge dampers or inlet guide vanes partially open, reducing the system pressure drop and causing the fan volume to increase. A variable frequency drive will increase the speed of the motor to increase fan volume.

2

2.1.2 Variable frequency drive advantages

Variable frequency drives improve system control and provide the greatest energy savings for variable air volume systems. Instead of creating an artificial pressure drop with dampers, or causing a decrease in fan performance with inlet guide vanes, the drive controls fan motor speed and volume directly. Varying the fan motor speed provides precise airflow control and the necessary duct static pressure to satisfy the VAV box control.

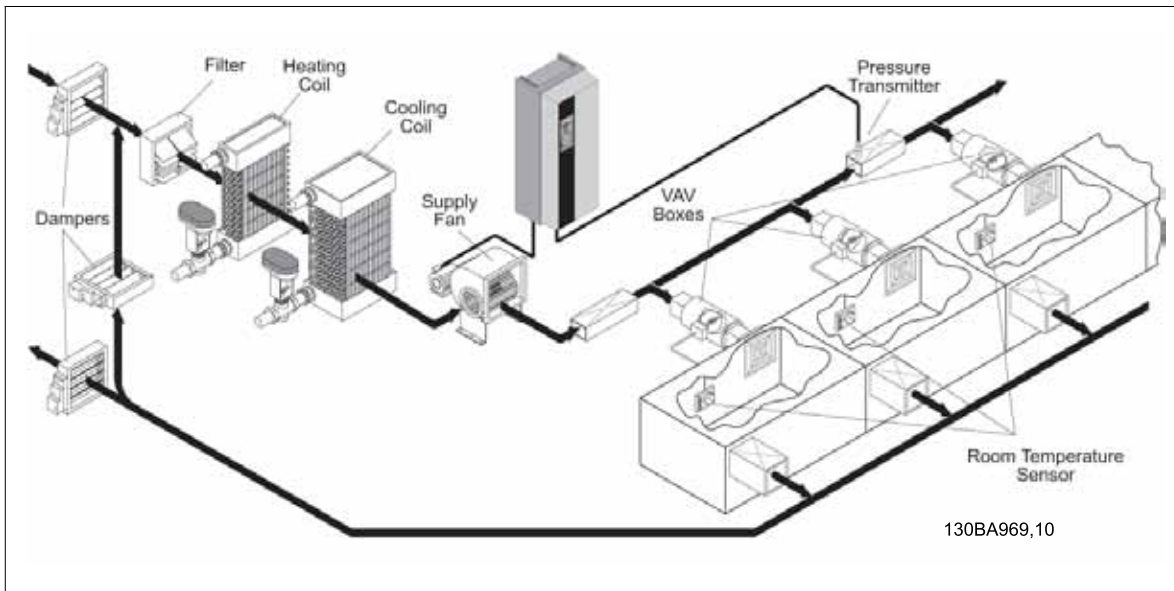


Illustration 2.2: VAV System with Adjustable Speed Drive

An internal drive PID controller provides accurate fan speed control, eliminating the need for an external controller or power supply. Duct static pressure transmitters can be connected directly to the variable frequency drive for control of the fan motor.

Additional PID controllers, RTD temperature sensor inputs and analog outputs allow for control of additional system components, such as dampers or control valves. Features, such as broken belt detection, built-in HOA switch and safety interlock provide additional system control capability.

The illustration below shows the relative energy consumption of different fan volume control methods for variable air volume system control. A variable frequency drive (curve 2) most closely approximates the energy consumption for the fan affinity laws having the greatest energy efficiency at reduced flows.

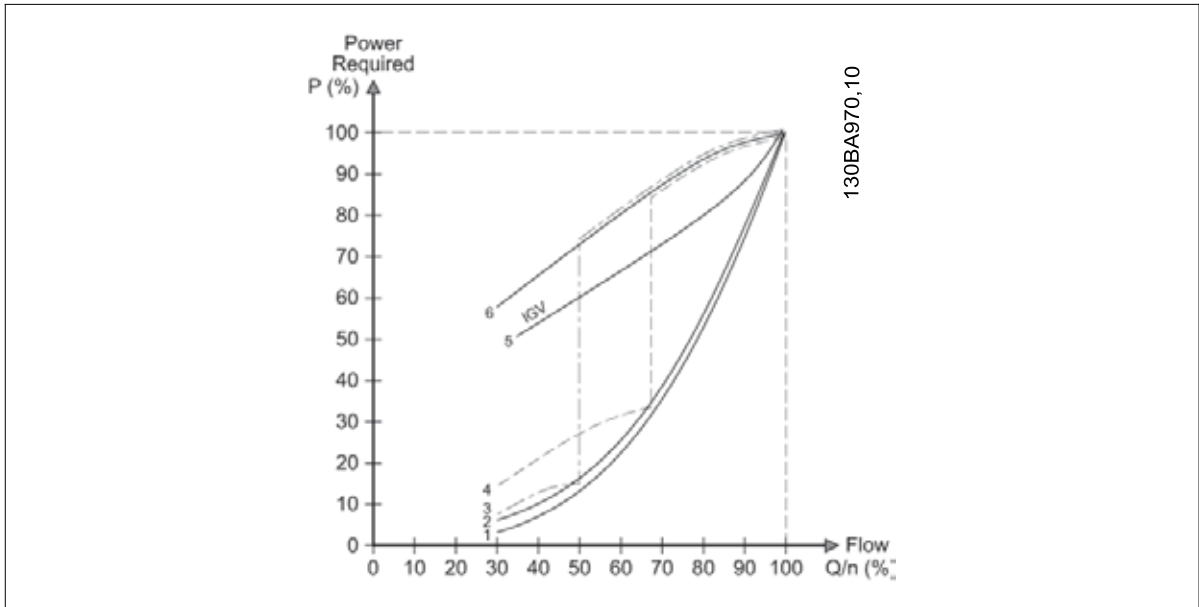


Illustration 2.3: Fan Power Requirements

1. Theoretical Energy Consumption
2. Variable frequency drive
3. 2-speed (50/100%) motor
4. 2-speed (67/100%) motor
5. Inlet Guide Vane (IGV)
6. Discharge Damper

2.2 Installation

2.2.1 Sensor placement

While the energy savings of a properly installed variable frequency drive is significant, the location of the duct static pressure sensor is critical for proper control of the supply fan and to achieve the most energy savings.

The purpose of supply fan speed control is to maintain the minimum required duct static pressure at the inlet of all the VAV boxes. This allows the VAV boxes to operate properly and distribute the proper air quantity to the controlled zone. If the duct static pressure is too low at the VAV box, airflow is less than required. Excessive duct static pressure wastes energy and can cause sound problems at the outlet diffusers of the VAV boxes.

The system static pressure requirement is calculated by adding the static pressure required by the VAV boxes to the pressure drop expected between the box and the controlled zone. A safety margin is often applied to compensate for design modifications during installation. To conserve fan energy, the static pressure set-point should be set at the lowest possible setting to maintain proper air distribution.

A pressure sensor should be placed approximately $2/3^{\text{s}}$ of the distance from the supply fan and the furthest VAV terminal box (see right illustration below). This placement allows the pressure sensor to measure the effect of static pressure changes from VAV boxes that are closest to the fan and boxes at the end of the supply duct. The result is a lower set-point value and a lower static pressure at the fan discharge during low flow conditions.

2

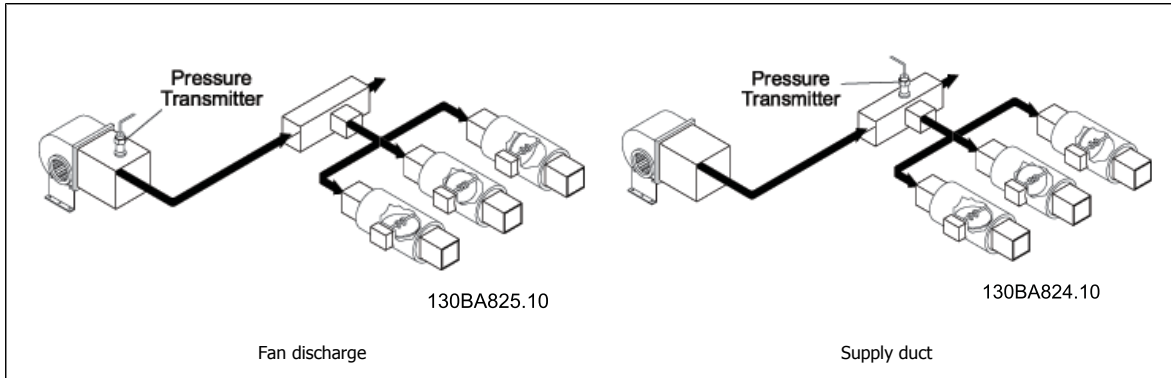


Table 2.1: Pressure transmitter placement

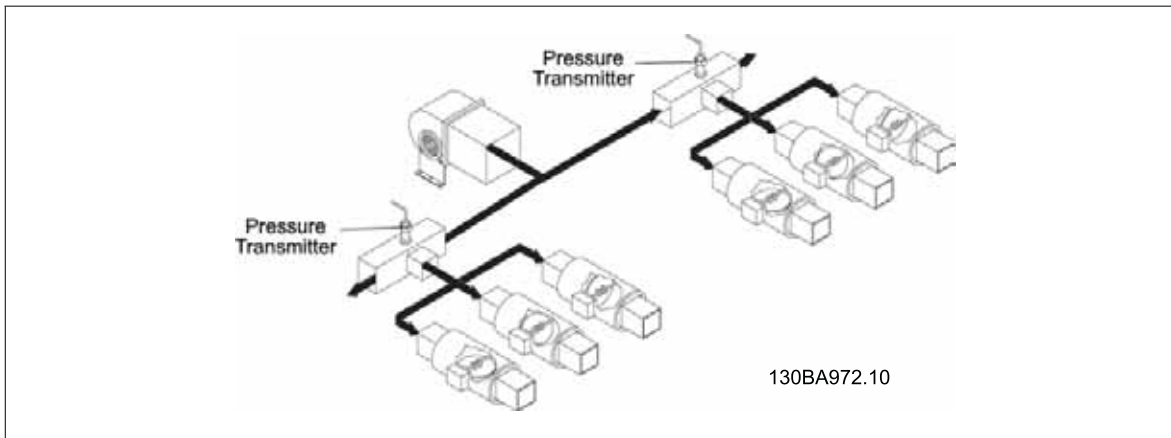


Illustration 2.4: Pressure Transmitter Placement

If the static pressure sensor is placed directly in the fan discharge (See table left above), the set-point must equal the design pressure at maximum flow conditions in the system. As VAV boxes reduce airflow, the static pressure at the fan discharge remains constant, even though the pressure loss in the duct has been reduced. Higher static pressure is supplied to the VAV boxes than necessary. While some energy is saved, the full energy savings potential is not realized. Over-pressurization, which occurs at less than full flow, wastes energy.

In VAV systems with complex runs where multiple branches split close to the fan (See illustration above) static pressure sensors should be located in each branch. The pressure sensor should be placed approximately $2/3^{\text{s}}$ downstream in the branch. Each sensor should have its own set-point. This avoids the assumption that branches and multi-sensor locations have identical requirements. The sensor with the lowest static pressure relative to its set-point should control the supply fan.

An advanced feature of the VLT® HVAC Drive is the ability to accept two or three input and set-point signals. A static pressure sensor can be mounted in each system branch. The PID controller chooses the lowest feedback signal compared to its set-point to control the speed of the fan motor when feedback function Multi Set-point Minimum is selected. If any one of the static pressure feedbacks is below its set-point, the PID controller will increase the speed of the fan motor. If all the feedbacks are above the static pressure set-points, the PID controller will decrease the speed of the fan motor.

Another application of the multi input PID controller is to use a static pressure transmitter to provide duct static high-limit control (see drawing below). High-limit control of the supply fan duct should be used to prevent damage to ducts, dampers, VAV boxes and air terminals.

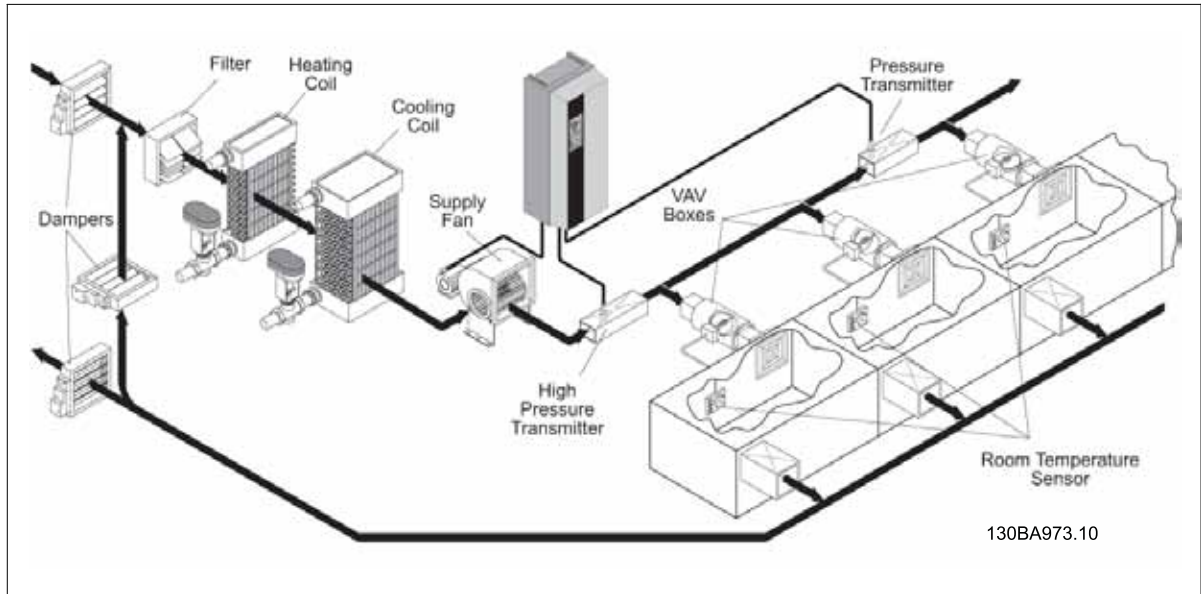


Illustration 2.5: Duct High-Limit Static Pressure Control

A static pressure high-limit control application is used when the fan system must continue to run if the duct is blocked or a fire or smoke damper is closed. The high-limit sensor is placed in the fan discharge. The system static pressure sensor controls fan motor speed, based upon actual static pressure as with a standard VAV control. If a blockage occurs, the duct static pressure sensor would detect low pressure. This would result in the fan increasing speed to maximum output pressure. The controlling static pressure high-limit sensor will reduce the fan speed to limit the output to the preset maximum duct static pressure to prevent damage to the ductwork or components.

2.3 Energy savings estimation

Savings from installing a VLT® HVAC Drive compared to the other methods of fan volume control can be estimated using the Danfoss VLT® Energy Box software. The program compares energy consumption for Variable Volume Systems using Discharge Dampers or Inlet Guide Vanes to energy consumption of the VLT® HVAC Drive and provides a simple payback calculation.

Typical input data is shown in the below illustration. A minimum of design data to plot the fan and system curve is required. If the fan surge (unstable region of fan operation) is known, it can be included on the graph. System operating hours are also entered.

To calculate the potential savings, a duty cycle or load profile is entered. The program has a default profile that can easily be changed. The duty cycle indicates the amount of flow the system requires to satisfy the building load. Profiles vary depending on the specific building and system operation.

2

Project: Fan 30 AF

System Name: Fan 30 AF

System Data:

- Design Head: 2.00 in wg
- Design Flow: 38,000.00 cfm
- Shaft Power: 34.8 HP
- Design Efficiency: 86.0 %
- Set Point Static Head: 2.00 in wg
- Removed Pressure Drop: 0.40 in wg

Motor and Drive Data:

- Motor Power: 50.0 HP
- Motor Efficiency: 90.0 %
- Drive Power: 50.0 HP
- Drive Efficiency: 97.0 %
- Drive Cost: \$ 3,654

Utility / Electricity Data:

- Average Cost per kWh: \$ 0.063
- Utility Incentive: 0 \$/HP
- Hours per Day: 16 hours
- Days per Week: 6.0 days
- Weeks per Year: 50 weeks

Fan and Control Curve Data

Graph showing In wg vs Flow (%). Curves include Control (red), Fan (blue), and Surge (black).

Duty Cycle

Bar chart showing Time (%) vs Flow (%). Total Operating Time: 5,400 Hrs.

Buttons: Go Back, Restore Default Values, Help, Update System, Cancel, Continue

130BA975.10

Illustration 2.6: Energy Box Input Data

After the fan and system data is entered, the program calculates the estimated energy consumption for the VLT® HVAC Drive and the comparison system.

The next illustration shows annual energy consumption for various air flows. If fan surge data was entered, the program determines if the fan would operate in the unstable region and indicates that system design limits are reached and adjusts energy calculations to reflect operation within the stable region of fan operation only.

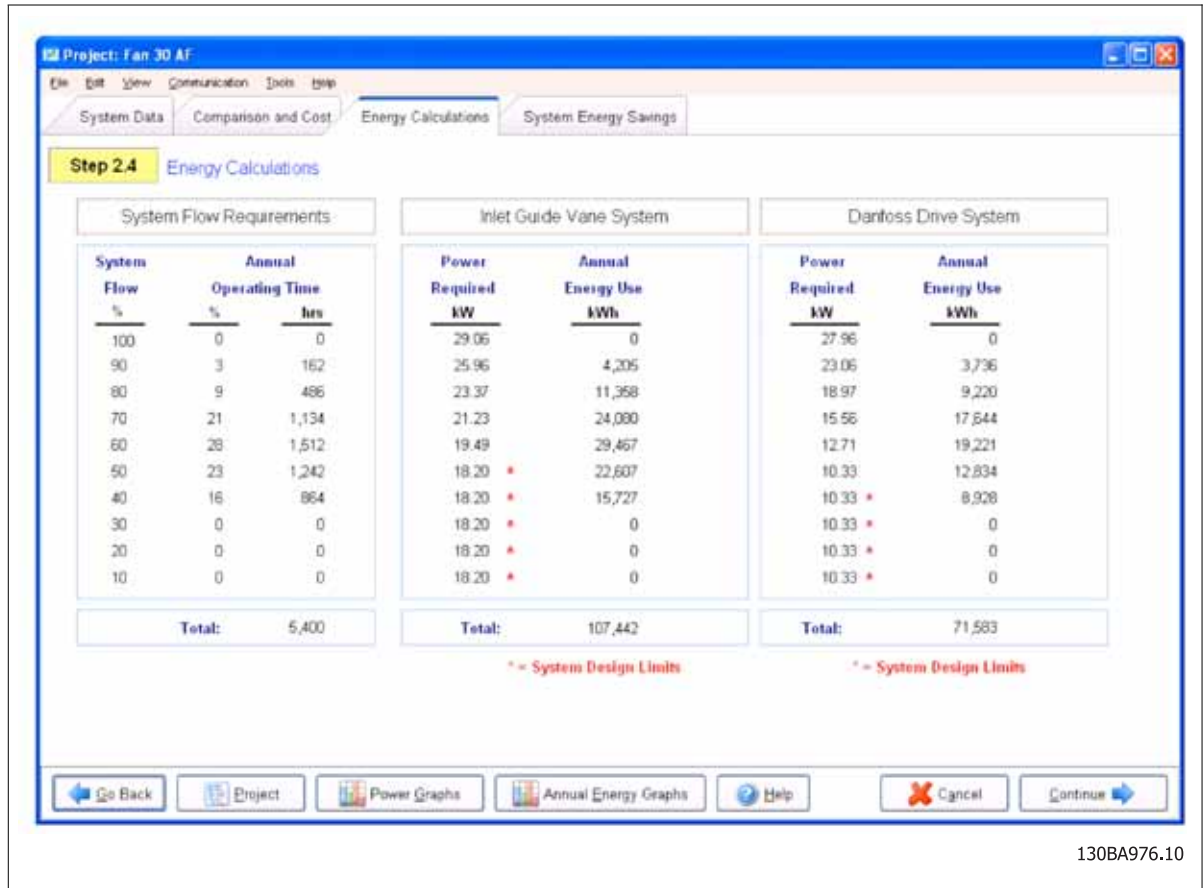


Illustration 2.7: Box Energy Consumption

The program also calculates the simple payback period for the drive including cost data for the drive, installation, wiring and other control components such as sensors.

The below illustration shows a payback of 1.89 years to replace an Inlet Guide Vane system with a VLT® HVAC Drive. The Energy Box Analysis and report can be printed, faxed or emailed.

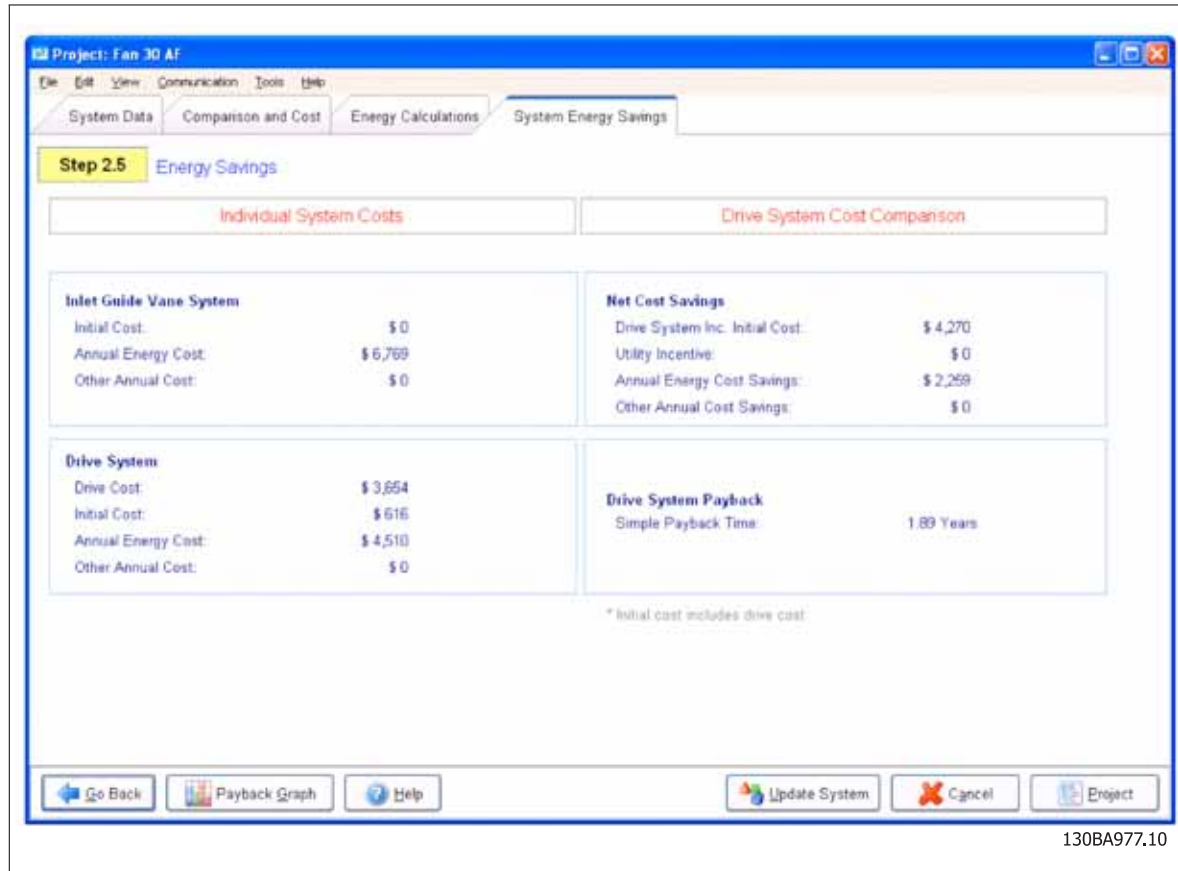


Illustration 2.8: Energy Box Financial Calculations

2.4 Drive features

The Danfoss VLT HVAC Drive is designed with features tailored for the unique control requirements of HVAC systems including Variable Air Volume systems. The following software features are incorporated, as standard, to optimize VAV performance.

2.4.1 Analog I/O option

The MCB 109 Analog I/O Option board extends the capabilities of the VLT HVAC Drive by adding programmable analog inputs and outputs. Up to three analog inputs can be configured for 0 – 10 V, Pt 1000 or Ni 1000 temperature sensor inputs. Three 0 – 10 V analog outputs are also available.

These I/O's features can be used with a stand alone digital controller, Building Management System (BMS) or with the internal PID controllers of the variable frequency drive. Use of the analog I/O option can eliminate the need for additional field points and reduce the total system cost.

The following illustration shows a VAV system control using the analog I/O option. The room sensor controls drive speed directly while the supply air temperature sensor maintains a constant supply air temperature through a BMS. The BMS communicates with the drive to sequence the analog outputs for control of the heating valve, mixed air dampers and cooling coil valve.

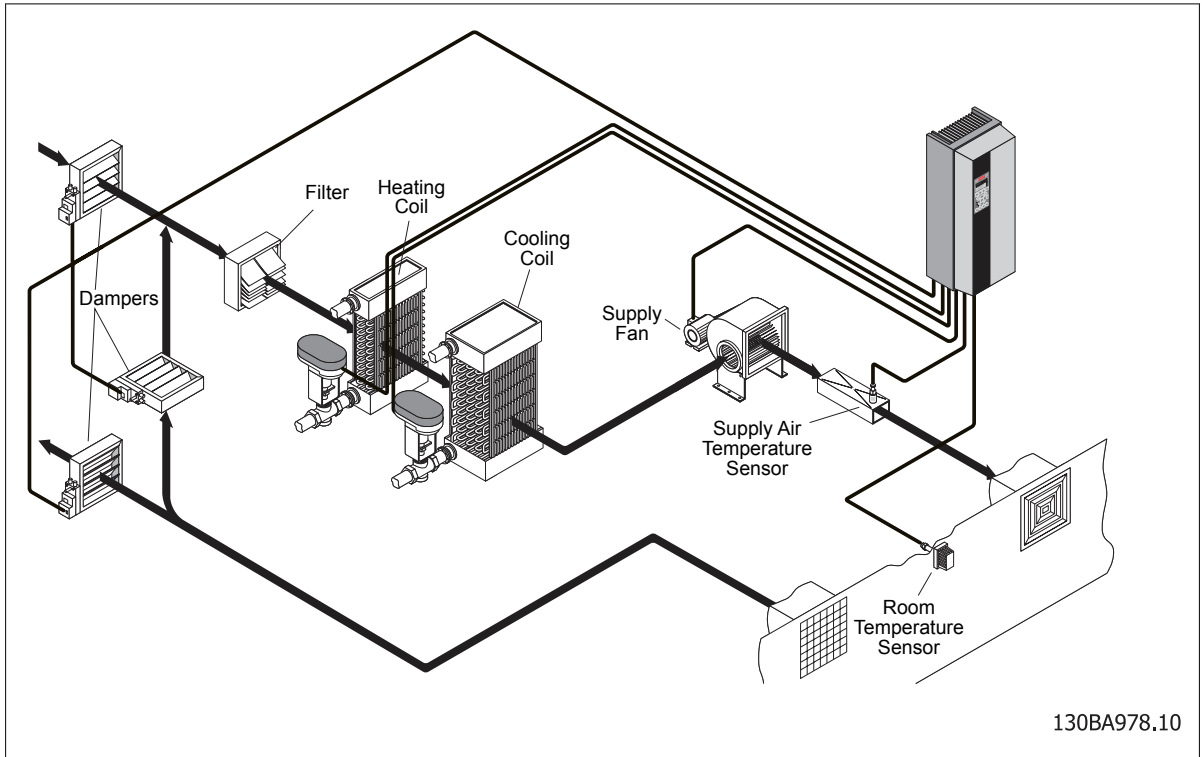


Illustration 2.9: VAV control with Analog I/O Option

Wiring of the sensors and actuators is shown below.

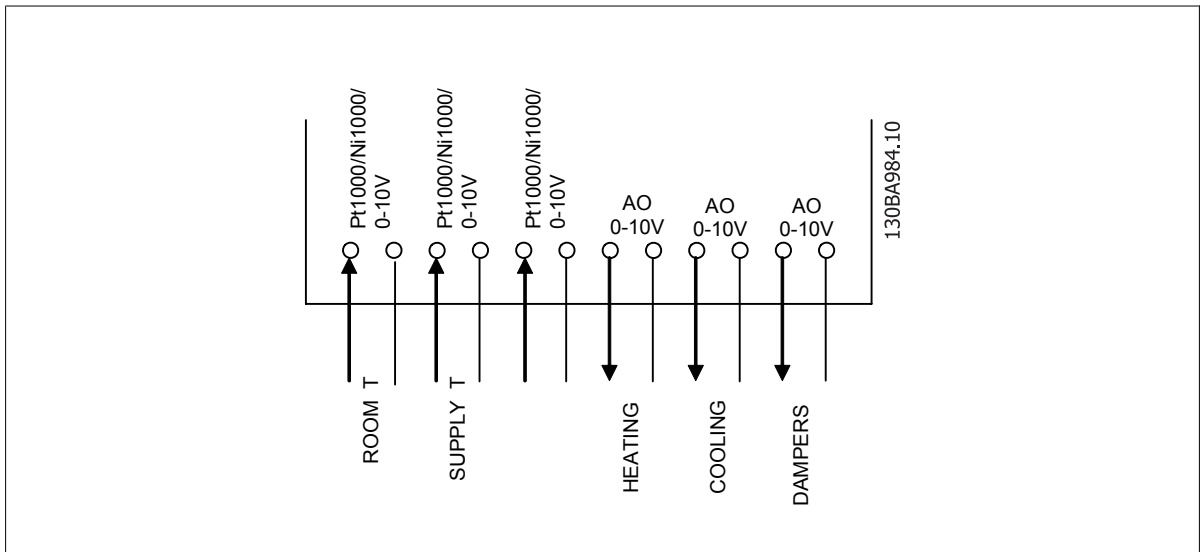


Illustration 2.10: Analog I/O Option Card Wiring

2.4.2 Extended PID controllers

The VLT® HVAC Drive has one PID controller that controls the drive's speed and three extended PID controllers that provide an output that can be used for the control of HVAC system damper or valve actuators. These controllers can accept a set-point and feedback signal from an external source (Building Automation System, digital controller, etc.). They also can be used with the MCB 101 General Purpose I/O or MCB 109 Analog I/O Option boards.

2.4.3 PID auto-tuning

The VLT® HVAC Drive PID controllers can be auto-tuned, simplifying the commissioning process and ensuring accurate control adjustment. During steady state operation, Auto-tuning introduces a step change in the output of the PID controller and the feedback signal is monitored. From the feedback response, the optimum values for PID control are calculated. In normal HVAC applications only the proportional gain and integral time are calculated.

2.4.4 Easy multiple programming

When a building has many AHU's, pumps and other variable frequency drive applications – set-up and programming is simplified in two ways. The PC Configuration Tool, MCT – 10 can be programmed for every drive and simply downloaded via the FC's USB port.

Second, all drive parameters can be uploaded from the variable frequency drive to the removable local control panel, LCP. One programmed panel can be used to quickly program other FCs by downloading settings from the keypad to the additional FCs. All keypads are interchangeable and easy to remove.

2.4.5 Energy log and trending

The VLT® HVAC Drive continuously accumulates the consumption of the actual power from the variable frequency drive to the motor. Data can be used in an Energy Log function allowing the user to analyze the energy consumption related to time. Data can be accumulated in two ways: a preset date and time for start and stop, or a predefined time period (such as the last 24 hours, seven days or month).

Trending is used to monitor how the variable changed over a period of time. The value of the trended variable is recorded in one of ten user-defined bins (data ranges). Common trending variables for VAV applications are motor power and output frequency.

The trending feature makes it possible to determine how much variation in flow or power occurs in the VAV system operation. Using this trending data with VLT Energy Box software determines the actual savings obtained for control of VAV systems with the VLT® HVAC Drive.

2.4.6 Serial communications

The VLT® HVAC Drive offers communication capabilities that are unmatched in variable frequency drives, reducing or eliminating the need for external devices.

Built-in serial communications options include: BACnet™, Modbus RTU, Johnson Controls Metasys® N2, and Siemens Apogee® FLN. Enhanced BACnet™ and LonWorks® are available as field-installed option cards that mount easily inside the VLT® HVAC Drive. Consult Danfoss for other serial communications options.

3 Single Zone Constant Air Volume ventilation systems

3.1 Introduction

The simplest air conditioning system is an air handling unit serving a single room or zone to control temperature. The single zone constant air volume (CAV) system changes the supply air temperature in response to the room sensor while maintaining a constant air flow. A well designed system maintains close temperature conditions in the room. A return fan may be needed, depending on the capacity of the system.

A single zone CAV system can be converted to a variable air volume system easily and economically by installing a variable frequency drive and making minor temperature control modifications. Lower system operating costs are obtained by using a variable frequency drive because of the fan affinity laws. When motor speed is decreased, the power required is reduced by the ratio of speed cubed. Additional system savings occur from heating or cooling a smaller volume of air.

3

3.2 Air volume control

3.2.1 Air volume control

Air Handling Units (AHU's) typically bring in outside air to mix with return air to maintain room conditions. The mixed air passes through a filter, across heating and/or cooling coils, and through the fan into ductwork for distribution to the room. The volume of air supplied is constant. A room temperature sensor and controller varies the flow of hot or chilled water through heating or cooling coils in the AHU maintaining the desired temperature.

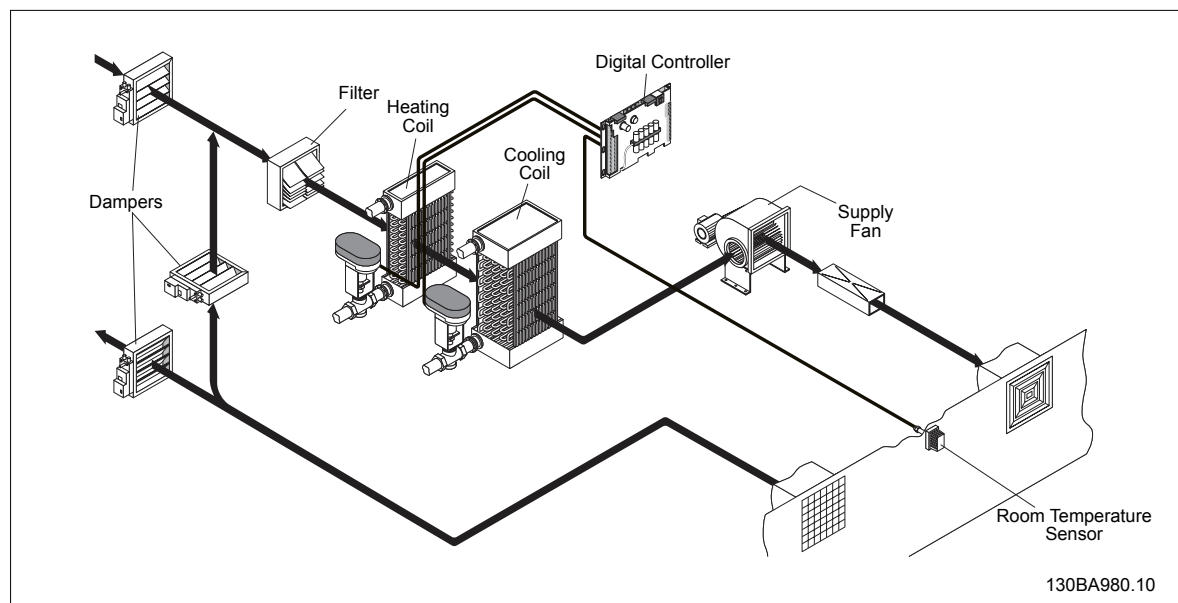


Illustration 3.1: Single Zone Constant Volume system

Installing a variable frequency drive and the addition of a supply air temperature sensor allows for simulation of a VAV system. Instead of varying the temperature of air, the volume of air can be changed to maintain room conditions. A variable frequency drive is installed to control the fan speed.

The room temperature sensor is connected directly to the variable frequency drive. As the room temperature changes, the fan speed and the volume of air delivered to the room changes. A second temperature sensor is installed in the supply air to maintain a constant temperature, just as with VAV control. The sensor is connected to a controller and varies the flow of hot or chilled water through the coils to maintain a constant supply air temperature.

3

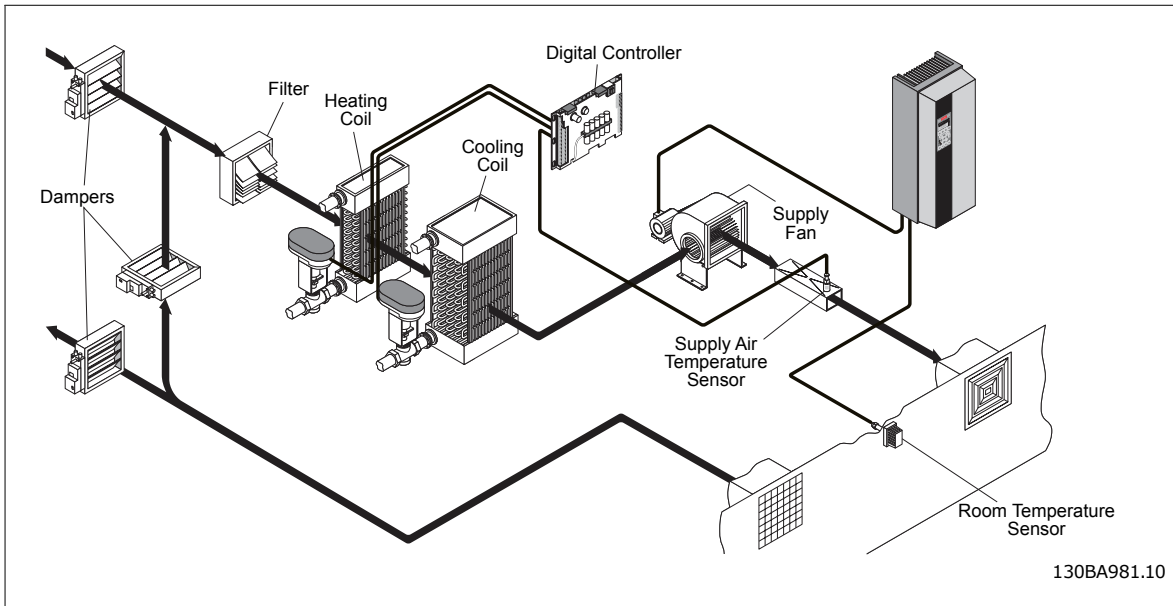


Illustration 3.2: Single Zone Variable Volume system with adjustable speed drive

The illustration below shows the power required of various methods available for variable air flow in a CAV system.

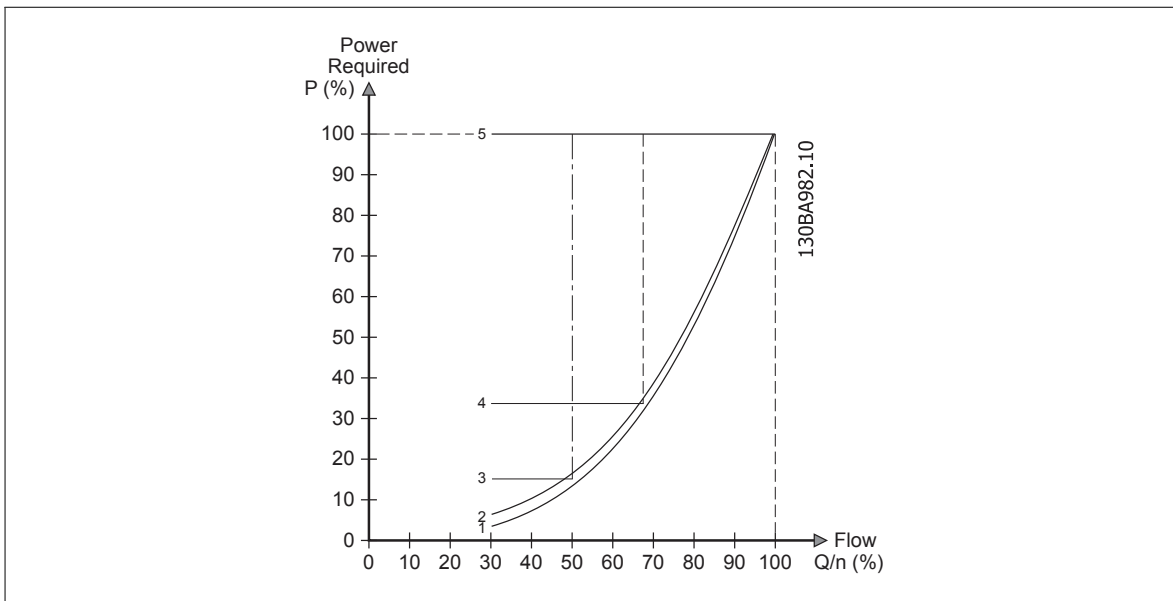


Illustration 3.3: Power requirements for Variable Speed CAV Control

- 1 Theoretical power requirement
- 2 Variable frequency drive
- 3 Two-speed motor control (4 pole / 8 pole)
- 4 Two-speed motor control (4 pole / 6 pole)
- 5 Constant speed operation

The illustration shows the energy saving potential of variable frequency drives over constant speed or two-speed motor operation. Power consumption closely follows the theoretical power requirement.

3.3 Variable frequency drive advantages

Variable frequency drives provide a number of features that add versatility and options to control of HVAC systems. Variable air volume (VAV) systems deliver air at a constant temperature while reducing or increasing air quantities to satisfy the changing space loads. The airflow can be varied based on temperature, but CO₂, or other air quality can be used to increase energy savings.

When controlling air quality using a CO₂ sensor, the drive regulates the air volume based upon the changing room conditions. For example, when people leave a controlled area, the amount of supply air needed is reduced. A sensor detects lower levels of CO₂ and the drive slows the supply fan's speed. When occupancy increases, the CO₂ level increases and the drive increases the fan speed to provide more supply air.

The MCB 109 Analog I/O Option board extends the capabilities of the VLT® HVAC Drive by adding programmable analog inputs and outputs. Up to three analog inputs can be configured for 0 – 10 v, Pt 1000 or Ni 1000 temperature sensor inputs. Three 0 – 10 v analog outputs are available.

These I/O's can be used with a stand alone digital controller, Building Management System (BMS) or with the drives integral PID controllers. Use of the Analog I/O option can eliminate the need for additional field points and reduce the total system cost.

The illustration below shows a CAV to VAV conversion using the Analog I/O option. Room and supply air temperature sensors are added to simulate VAV control. The room sensor controls drive speed directly while the supply air temperature sensor maintains a constant supply air temperature through a BMS. The BMS communicates with the drive to sequence the analog outputs for control of the heating valve, mixed air dampers and cooling coil valve.

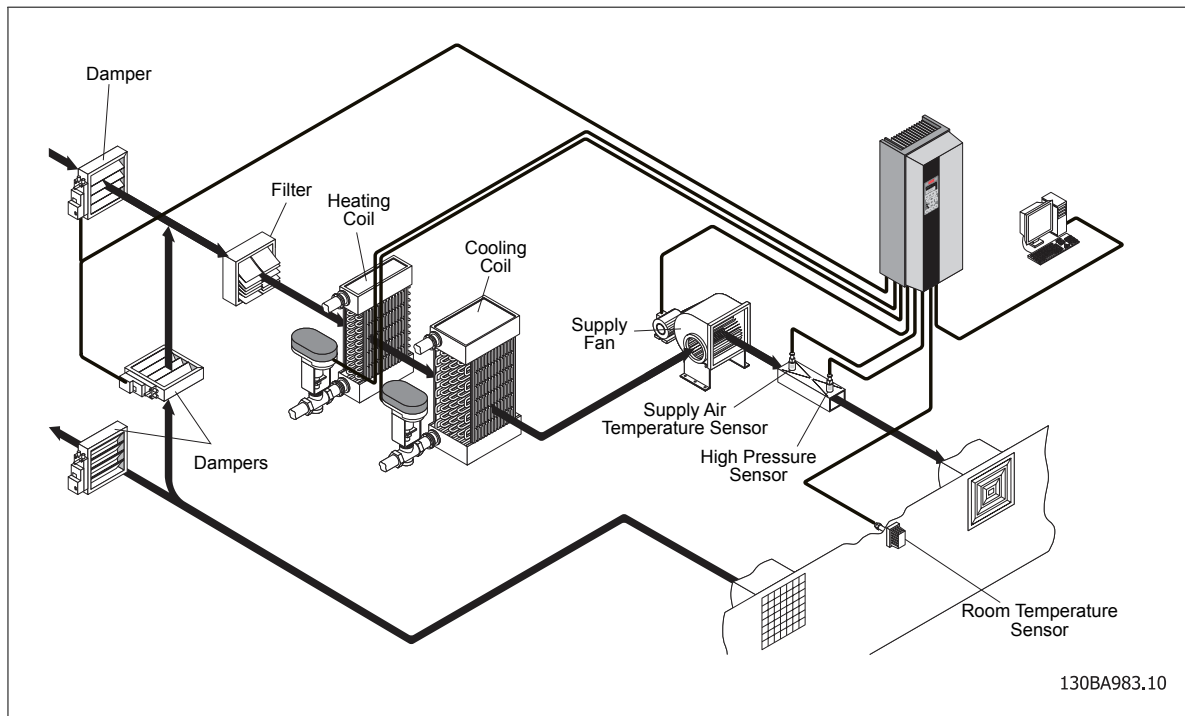


Illustration 3.4: CAV to VAV conversion with Analog I/O Option

Wiring of the sensors and actuators is shown in the illustration below.

3

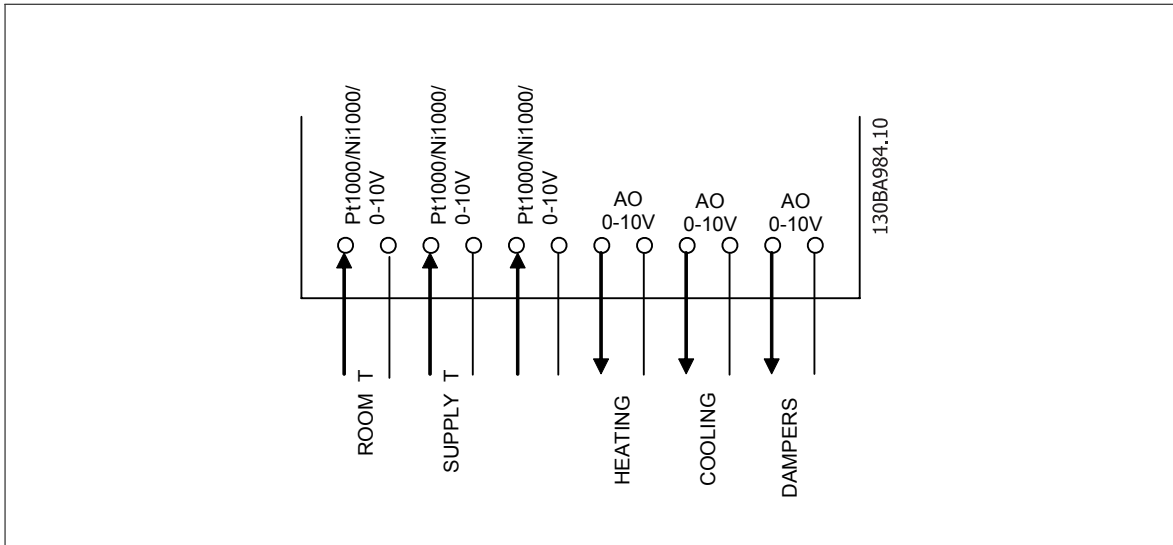


Illustration 3.5: Typical MCB 109 I/O Wiring

3.4 Energy savings

3.4.1 Energy savings estimation

Savings from installing a VLT HVAC Drive compared to the other methods of fan volume control can be estimated using the Danfoss VLT® Energy Box software. The program compares energy consumption for a Constant Volume System to energy consumption of a CAV to VAV System conversion using the VLT HVAC Drive and provides a simple payback calculation.

Typical input data is shown in the following illustration. A minimum of design data to plot the fan and system curve is required. If the fan surge (unstable region of fan operation) is known, it can be included on the graph. System operating hours are also entered.

To calculate the potential savings, a duty cycle or load profile is entered. The program has a default profile that can easily be changed. The duty cycle indicates the amount of flow the system requires to satisfy the building load. Profiles vary depending on the specific building and system operation.

3

Project: Fan 1 FR

System Name: Fan 1 FR Step 2.1

System Data:		Motor and Drive Data:		Utility / Electricity Data:	
Design Head:	1.92 in wg	Motor Power:	15.0 HP	Average Cost per kWh:	\$ 0.063
Design Flow:	57,300.36 cfm	Motor Efficiency:	90.0 %	Utility Incentive:	0 \$/HP
Shaft Power:	13.1 HP	Drive Power:	15.0 HP	Operation:	
Design Efficiency:	86.0 %	Drive Efficiency:	97.0 %	Hours per Day:	18 hours
Set Point Static Head:	0.44 in wg	Drive Cost:	\$ 1,236	Days per Week:	5.0 days
Removed Pressure Drop:	0.00 in wg			Weeks per Year:	48 weeks

Fan and Control Curve Data

Graph showing In wg vs Flow (%). The blue curve represents the Fan and the red curve represents the Control. The fan curve starts at approximately 2.0 in wg at 0% flow and decreases to 0 at 200% flow. The control curve starts at approximately 0.5 in wg at 0% flow and increases to approximately 2.0 in wg at 100% flow.

Duty Cycle

Bar chart showing Time (%) vs Flow (%). The x-axis ranges from 0 to 100% flow, and the y-axis ranges from 0 to 24 hours. The bars represent the time spent at various flow rates. The total operating time is 4,320 Hrs.

Total Operating Time: 4,320 Hrs Duty Cycle

Buttons: Go Back, Restore Default Values, Help, Update System, Cancel, Continue

130BA985.10

Illustration 3.6: Energy Box input data

After the fan and system data is entered, the program calculates the estimated energy consumption for the VLT HVAC Drive and the comparison system. The following illustration shows annual energy consumption for various air flows. If fan surge data was entered, the program determines if the fan would operate in the unstable region and indicates that system design limits are reached and adjusts energy calculations to reflect operation within the stable region of fan operation only.

3

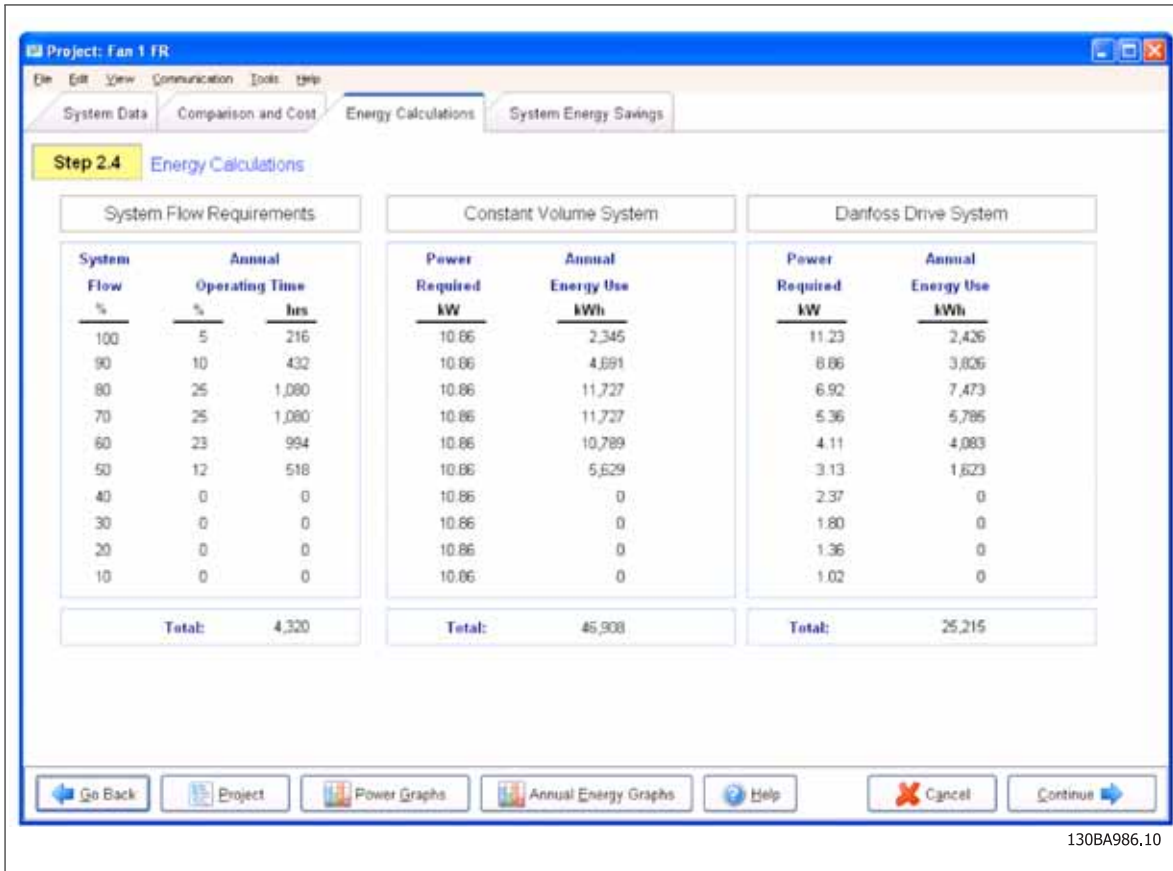


Illustration 3.7: Annual energy consumption

The program also calculates the simple payback period for the drive including cost data for the drive, installation, wiring and other control components such as sensors. The illustration below shows a payback of 1.36 years to upgrade an existing Constant Volume system with a new VLT HVAC Drive to a Variable Air Volume system. The Energy Box analysis and report can be printed, faxed or emailed.

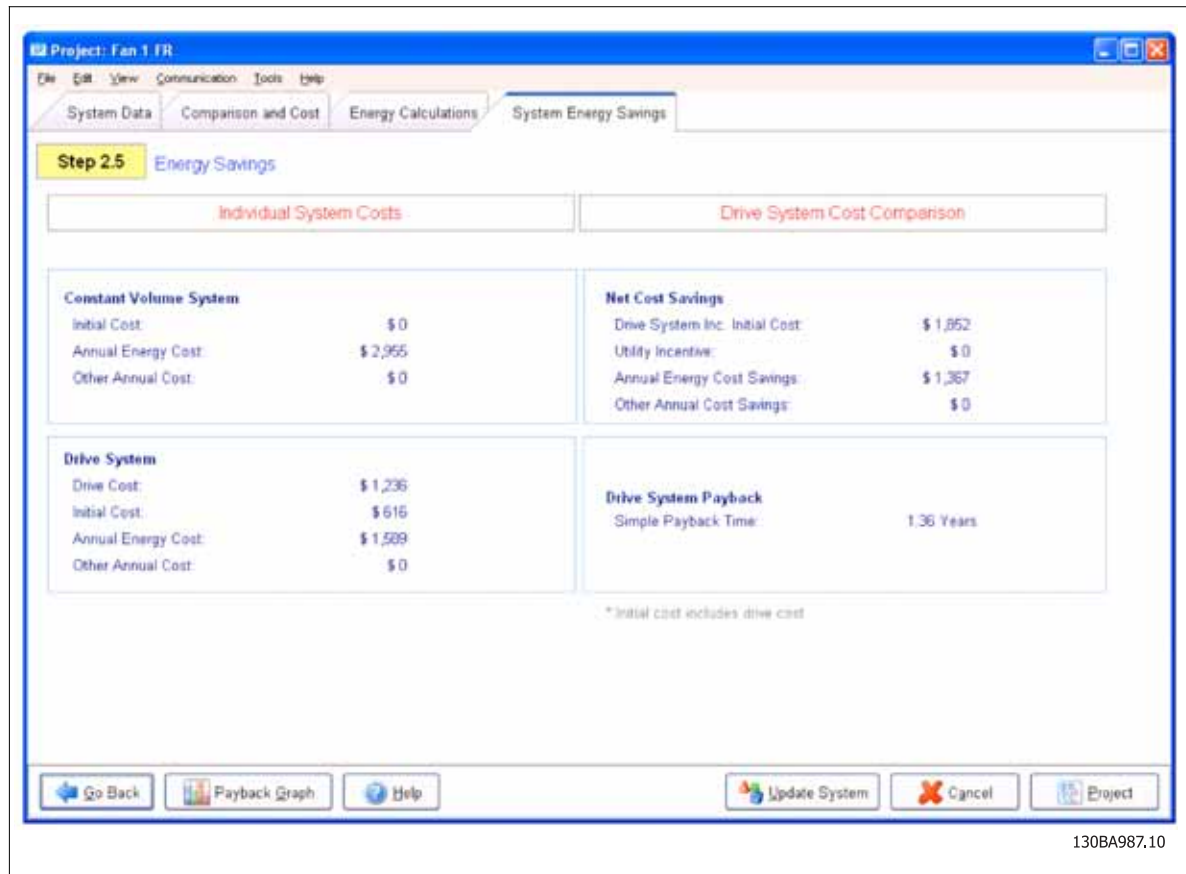


Illustration 3.8: Energy Box financial calculation

3.5 Drive features

3.5.1 Drive features

The Danfoss VLT® HVAC Drive is designed with features tailored for the unique control requirements of HVAC systems including Constant Air Volume system conversion. The following software features are incorporated, as standard, to optimize system performance.

3.5.2 Extended PID controllers

The VLT® HVAC Drive has one PID controller that controls the drive's speed and three extended PID controllers that provide an output that can be used for control of CAV system damper or valve actuators. These controllers can accept a set-point and feedback signal from an external source (Building Automation System, digital controller, etc.). They also can be used with the MCB 101 General Purpose I/O or MCB 109 Analog I/O Option boards.

3.5.3 PID auto-tuning

The VLT® HVAC Drive PID controllers can be auto-tuned, simplifying the commissioning process and ensuring accurate control adjustment. During steady state operation, Auto-tuning introduces a step change in the output of the PID controller and the feedback signal is monitored. From the feedback response, the optimum values for PID control are calculated. In normal HVAC applications only the proportional gain and integral time are calculated.

3.5.4 Easy multiple drive programming

When a building has many AHU's, pumps and other variable frequency drive applications, set-up and programming is simplified in two ways. VLT Motion Control Tool MCT 10 can be programmed for every drive and simply downloaded via the drive USB port.

Second, all drive parameters can be uploaded from the VLT® HVAC Drive to the removable local control panel. One programmed panel can be used to quickly program other drives by downloading settings from the keypad to the additional drives. All keypads are interchangeable and easy to remove.

3

3.5.5 Energy log and trending

The VLT® HVAC Drive continuously accumulates the consumption of the actual power from the variable frequency drive to the motor. Data can be used in an Energy Log function allowing the user to analyze the energy consumption related to time. Data can be accumulated in two ways: a preset date and time for start and stop, or a predefined time period (such as last 24 hours, seven days or month).

Trending is used to monitor how the variable changed over a period of time. The value of the trended variable is recorded in one of ten user-defined bins (data ranges). Common trending variables for CAV applications are motor power and output frequency.

The trending feature makes it possible to determine how much variation in flow or power occurs in the CAV to VAV system retrofit. Using this trending data with VLT® Energy Box software determines the actual savings obtained for control of CAV to VAV systems with the VLT HVAC Drive.

3.5.6 Serial communications

The VLT® HVAC Drive offers communication capabilities that are unmatched in variable frequency drives, reducing or eliminating the need for external devices.

Built-in serial communications options include: BACnet™, Modbus RTU, Johnson Controls Metasys® N2, and Siemens Apogee® FLN. Enhanced BACnet™ and LonWorks® are available as field-installed option cards that mount easily inside the VLT® HVAC Drive. Consult Danfoss for other serial communications options.

4 Cooling Tower Fan Control

4.1 Introduction

In large commercial buildings with central air conditioning provided by water cooled chillers, a cooling tower removes the heat absorbed by the chiller and rejects it to the atmosphere. In most climates, cooling towers provide the most energy efficient method of removing heat from the chillers condenser water.

A chiller provides cold water to the Air Handling Units (AHU's) throughout the building. The chilled water absorbs heat from the building and returns as warmer water to the chiller. A chiller condenser section is a heat exchanger which removes the heat absorbed by the chilled water.

A condenser pump moves the water from the chiller to a cooling tower where the heat is rejected to the atmosphere. Warm water pumped from the chiller's condenser section cascades through the cooling tower or is sprayed into the cooling tower fill area. This increases the water's surface area and allows more heat to be dissipated.

The thermal performance of a cooling tower depends primarily upon the entering air wet bulb temperature. The cooling tower rejects heat to the environment through direct heat exchange between the condenser water and outside air. Some of the condenser water evaporates, which enhances the cooling effect, allowing the return water temperature to be close to the ambient wet bulb temperature. The cooled water collects at the bottom of the tower in a basin. From there it is pumped back through the chillers condenser by the condenser water pump.

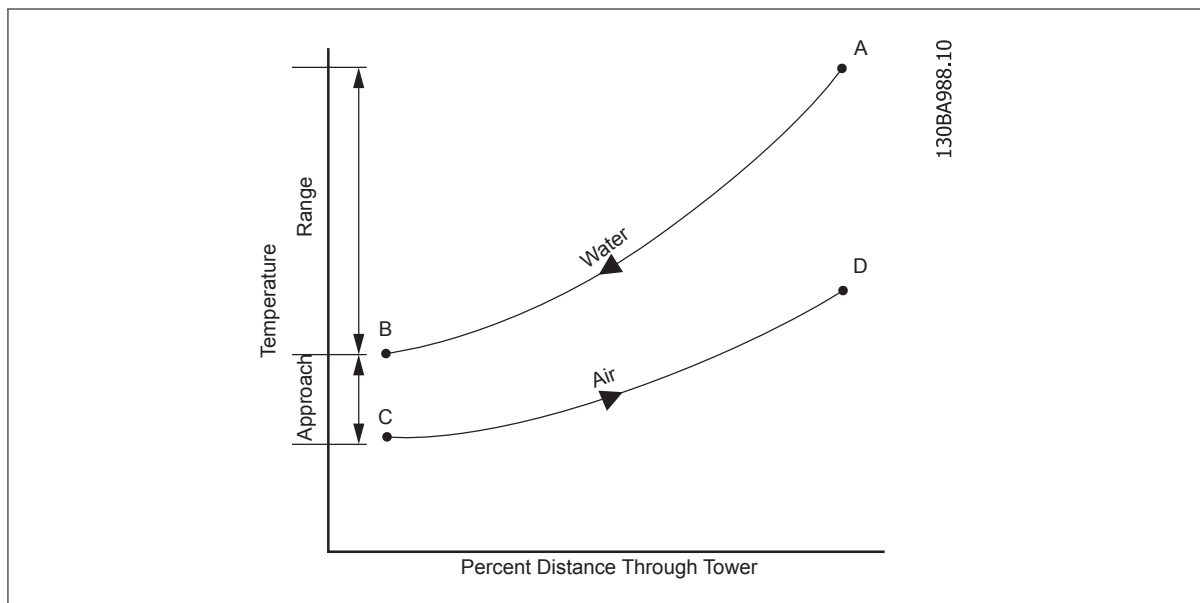


Illustration 4.1: Cooling Tower Temperature Relationships

The temperature difference between the condenser water entering and leaving the cooling tower is the range. The range is determined by the building heat load and water flow rate, not the size of the cooling tower. The difference between the leaving condenser water temperature and the entering air wet-bulb temperature is the approach of the cooling tower. The approach is a function of the cooling tower capacity (size), a larger cooling tower produces a closer approach (colder leaving water temperature) for a given load, water flow rate and entering air condition.

4.2 Fan Speed Control

4.2.1 Fan speed control

Cooling towers encounter substantial changes in outdoor wet-bulb temperature and building load during normal operation. Therefore some form of capacity control is required to maintain the desired condensing water temperature.

Fan cycling is the simplest method of capacity control. However, motor burnout from frequent cycling is a problem. Two-speed motors can double the number of steps of capacity control compared to fan cycling. This is useful on single-fan motor units, which would normally have only one step of fan capacity control. A two-speed motor requires a pole changing motor, suitable switch-gear, a 6-wire motor cable and power factor correction. A controller is necessary to switch speed. Frequent switching from one speed to another must be avoided. While they provide some energy savings, motor burnout from frequent cycling is still a problem and two-speed motors and starters are very costly.

Variable frequency drives provide infinite motor speed control to vary capacity and provide the most energy savings. The life span of the fan and FC assembly is extended compared to fan cycling with one or two-speed motors. A variable frequency drive eliminates the high starting currents and peaks created when two-speed motors are used along with the cost of a special starter and cable work. Stress on the motor, bearings and drives are also greatly reduced resulting in lower maintenance and installation costs.

4

The illustration below shows a basic cooling tower fan application. A variable frequency drive controls the exact fan speed required for cooling, by utilizing a temperature sensor in the cooling tower water basin or the condenser water return piping. A standard Platinum (PT 1000) or Nickel (Ni 1000) RTD temperature sensor is wired directly to the drive. Fan speed is varied to maintain a constant basin or return water temperature. Since the energy of a cooling tower fan varies by the cube of its speed, even small reductions in speed can produce significant energy savings.

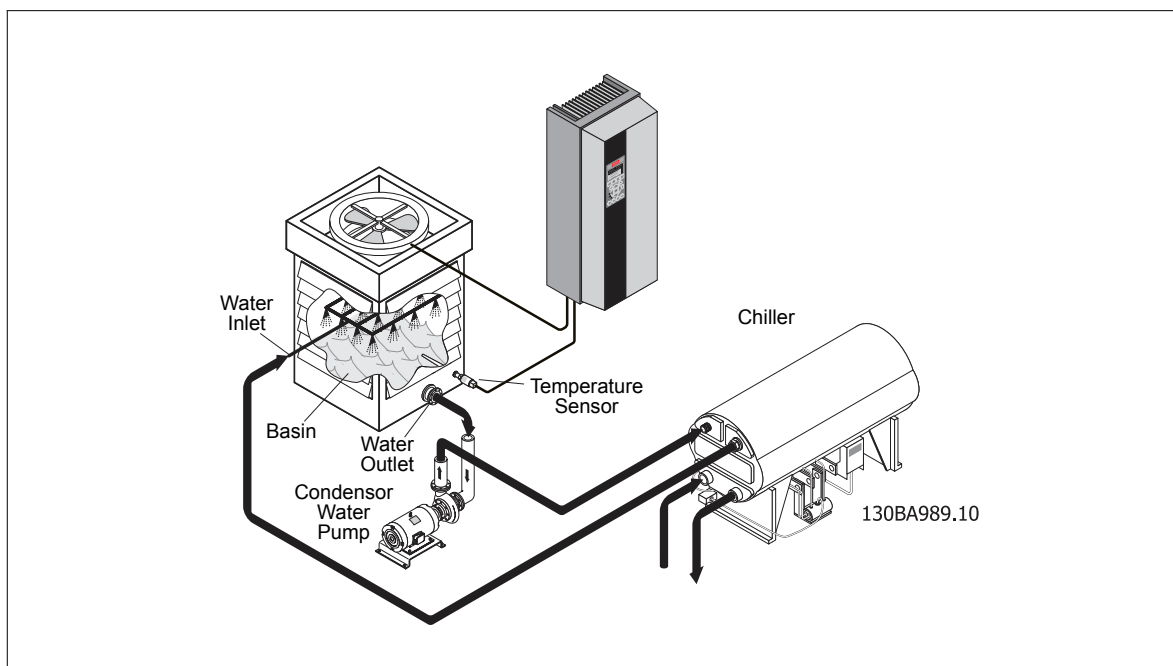


Illustration 4.2: Cooling Tower and Chiller Condenser System with variable frequency drive

The ideal temperature for condenser water return is different for each installation. The efficiency of a water cooled chiller varies with the temperature of the condenser water return – the cooler the return water, the more efficient the chiller, within design limits of the chiller. The chiller manufacturer should be consulted for the proper condenser water temperature setting. Energy consumption of the chiller at different condenser water return temperatures needs to be compared to the energy consumption of both the cooling tower fan and condenser pump to optimize the overall system efficiency.

Once the optimum water temperature has been determined, the variable frequency drive can maintain the temperature as the system loads and conditions change.

4.3 Energy Savings

4.3.1 Energy savings

Cooling tower performance is typically determined by the outdoor wet-bulb temperature, the temperature drop of the water flowing through the cooling tower (range), and the difference between leaving water and air wet-bulb temperatures (approach). For energy savings calculations, the range and approach for a tower is constant. Energy calculations estimate fan speed and power (kW) as a function of outdoor air wet-bulb temperature.

To calculate potential energy savings, a typical cooling tower load profile is shown in the illustration below. The load profile indicates the amount of air flow the system requires to satisfy the cooling loads during the time of operation. Profiles vary based on the specific system needs.

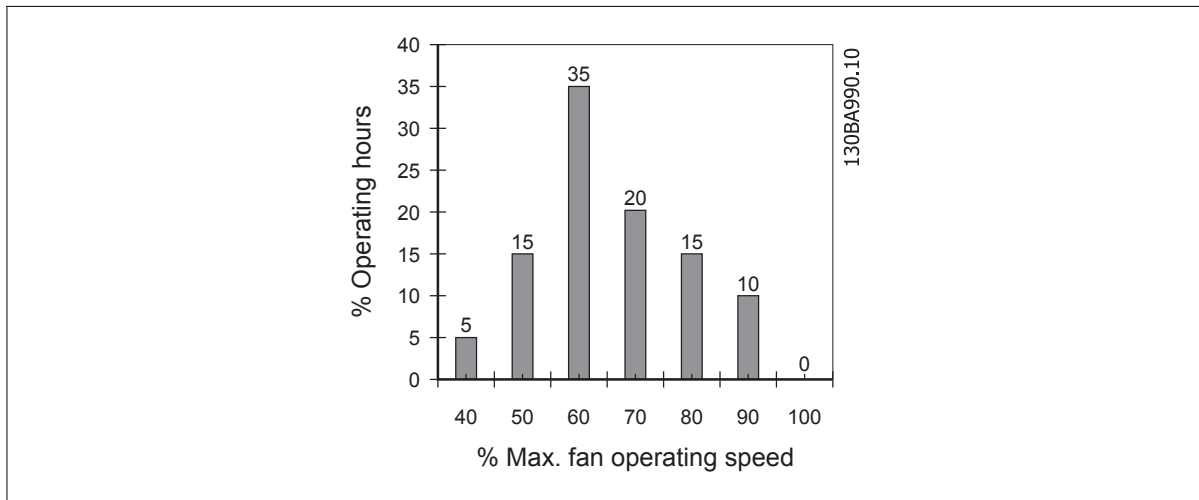


Illustration 4.3: Cooling tower operating hours and fan speed

In the energy calculation shown in the table below, a 40 HP fan motor is operated according to the load profile shown in the illustration above. The energy consumption for one year is calculated for a 2-speed cooling tower fan motor (half and full speed) compared to a variable frequency drive. The comparison shows energy savings of 44% with the variable frequency drive across all operation requirements.

Flow (%)	Hours (%)	Hours Run	Electrical power required (kW)		Energy consumption for fan motor (kWh)	
			2-speed motor	VLT HVAC	2-speed motor	VLT HVAC
40	5	225	3.75	2.67	844	601
50	15	675	3.75	4.83	2531	3260
60	35	1575	30	7.65	47250	12049
70	20	900	30	11.93	27000	10737
80	15	675	30	17.27	20250	11657
90	10	450	30	24.16	13500	10872
100	0	0	0	0	0	0
	100	4500			111375	49176

Table 4.1: Energy calculation for a 40 HP fan motor

4.4 Drive Features

4.4.1 Minimum frequency

Cooling towers should not be operated at speeds below a design minimum, usually between 25 and 40% of full motor speed. For cooling towers with gear speed reducers, low speed can cause noise or lubrication problems. The variable frequency drive can be set with a minimum output frequency to ensure fan speed operation without noise and for adequate lubrication for the tower fan gearbox. The tower manufacturer should be consulted for the proper minimum output frequency.

4.4.2 Frequency bypass

Undesirable resonant frequencies can cause mechanical vibration in the tower, possibly damaging mechanical components in the system. Sometimes the tower manufacturer can advise what speeds must be avoided but usually these frequencies must be determined in the field during commissioning. This is tedious and is often skipped. These frequencies can easily be avoided with the VLT® HVAC Drive by using Semi-Automatic Bypass setup. When using this feature, the FC slowly ramps up and down the entire frequency range. When a vibration band is identified the FC stores a bypass frequency range into the variable frequency drive. Up to four frequency ranges can be programmed. This allows the fan motor to step over speeds, which induce resonance, resulting in vibration free operation.

4.4.3 Sleep mode

The FC can cycle the fan on or off, by utilizing a feature called "sleep mode." This automatically stops the fan when the cooling tower basin temperature is at a low level for a pre-determined amount of time. When the temperature increases, the FC restarts the motor to reach the required output. This results in fewer fan motor operation hours and increased savings. Unlike a setback timer, the variable frequency drive is always available to run when the preset "wake-up" temperature is reached.

4.4.4 De-icing

Under below freezing conditions, cooling towers can be subjected to icing. When a building has high internal loads year round, chilled water must be supplied. The condenser water must be circulated when outdoor ambient temperature approaches or is below freezing. The tower can experience ice build-up at the inlet louvers and fill area due to temperature and atmospheric moisture. The variable frequency drive has the capability to de-ice the tower by reversing the airflow, which passes air over the warmer water in the basin and exhausts it through the fill area and inlets, melting the frost accumulation.

4.4.5 Motor preheat

When a motor has to be started in a cold or damp environment, such as in a cooling tower application, the variable frequency drive can trickle a small amount of DC current into the motor continuously to keep wiring dry and protect it from condensation in the tower and the effects of a cold start. This can extend the operational life of the motor.

4.4.6 Analogue I/O option

The MCB 109 Analog I/O Option board extends the capabilities of the VLT® HVAC Drive by adding programmable analog inputs and outputs. Up to three analog inputs can be configured for 0 – 10 V, Pt 1000 or Ni 1000 temperature sensor inputs. Three 0 – 10 V analog outputs are available. These I/O's can be used with a stand alone digital controller, Building Management System (BMS) or with the drive's integral PID controllers. Use of the Analog I/O option can eliminate the need for additional field points and reduce the total system cost.

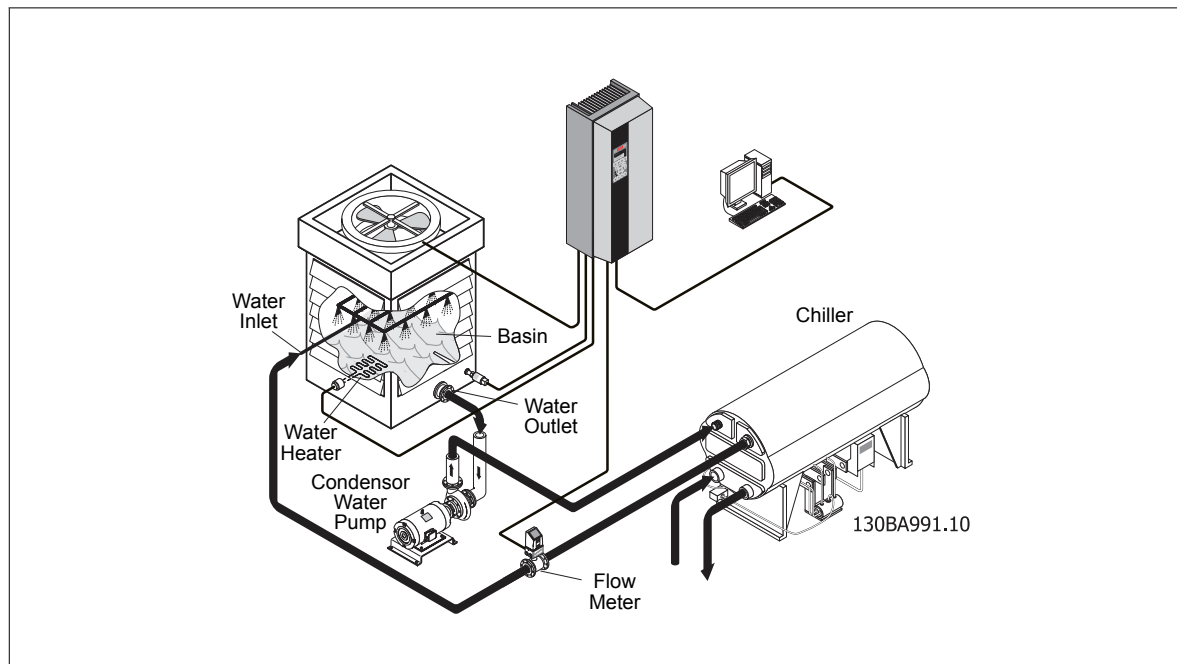


Illustration 4.4: Integrated Cooling Tower Control (Drawing needs to be revised)

The illustration above shows an integrated cooling tower control using MCB 109 Analog I/O Options. Outdoor and condenser water temperature sensors are added for cooling tower control. The condenser water sensor controls drive speed directly, while the outdoor air sensor provides tower on – off control through a BMS. The BMS communicates with the drive to run the cooling tower above certain outdoor temperatures. The basin electric water heater is controlled by the drive through one of the internal relays. A water flow meter can be added to provide a reading of water flow at the cooling tower and through the drive serial communication to the BMS. Wiring of the sensors and heaters is shown in the illustration below.

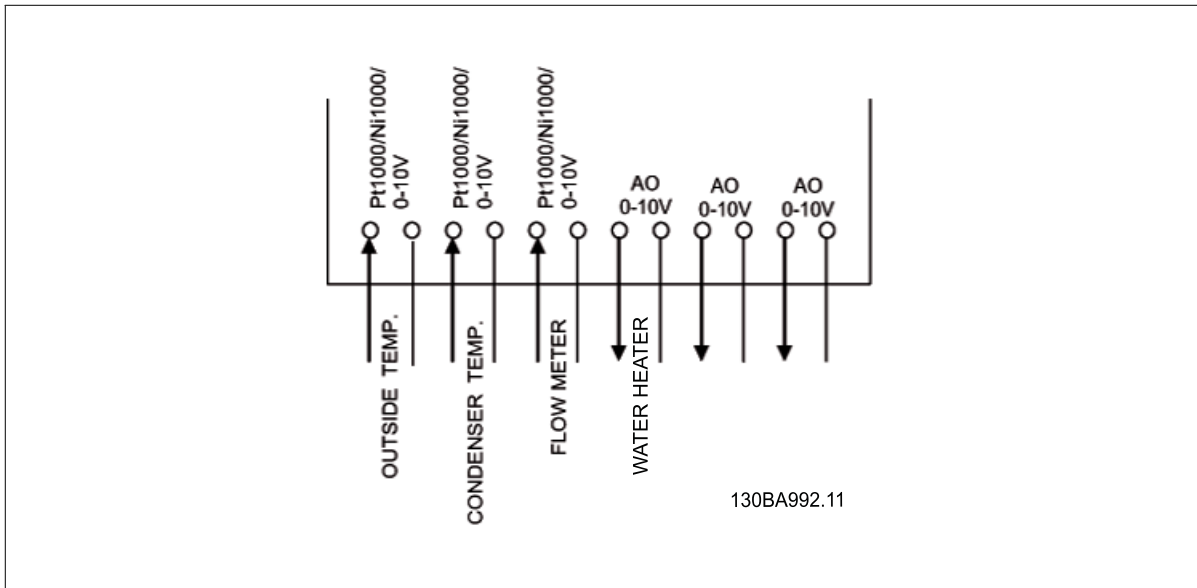


Illustration 4.5: Typical MCB 109 I/O wiring

4.4.7 Energy log and trending

The variable frequency drive continuously accumulates the consumption of the actual power from the variable frequency drive to the motor. Data can be used in an Energy Log function allowing the user to analyze the energy consumption related to time. Data can be accumulated in two ways: a preset date and time for start and stop or a predefined time period (such as last 24 hours, seven days or month). Trending is used to monitor how the variable changes over a period of time. The value of the trended variable is recorded in one of ten user-defined bins (data ranges).

Common trending variables for cooling tower applications are motor power and output frequency. The trending feature makes it possible to determine how much variation in power occurs in the cooling tower system operation. Using this trending data with VLT® Energy Box software determines the actual savings obtained for control of cooling tower systems with the VLT® HVAC Drive.

4.4.8 Serial communications

The VLT® HVAC Drive offers communication capabilities that are unmatched in variable frequency drives, reducing or eliminating the need for external devices.

Built-in serial communications options include: BACnet™, Modbus RTU, Johnson Controls Metasys® N2, and Siemens Apogee® FLN. Enhanced BACnet™ and LonWorks® are available as field-installed option cards that mount easily inside the VLT® HVAC Drive. Consult Danfoss for other serial communications options.



5

5 Condenser Water Pumping Systems

5.1 Introduction

In large commercial buildings, central air conditioning is provided by water cooled chillers. A cooling tower removes the heat absorbed by the chiller by evaporation and rejects it to the atmosphere. The cooled water is returned to the chiller to repeat the heat rejection cycle. In most climates, cooling towers provide the most energy efficient method of removing heat from the chiller's condenser water.

A chiller provides cold water to the Air Handling Units (AHU's) throughout the building. The chilled water absorbs heat from the building and returns as warmer water to the chiller. A chiller condenser section is a heat exchanger, which removes the heat absorbed by the chilled water.

A condenser pump moves the water from the chiller to a cooling tower, where the heat is rejected to the atmosphere. Warm water pumped from the chiller's condenser section cascades through the cooling tower or is sprayed into the cooling tower fill area. This increases the water surface area and allows more heat to be dissipated. The cooled water collects at the bottom of the tower in a basin. From there it is pumped back through the chillers condenser by the condenser water pump.

5

5.2 Pump Control

5.2.1 Condenser pump control

In traditional system design, the condenser water pump circulates the water continuously through the system at a constant flow. The temperature of the condenser water is controlled by the cooling tower fan control or a bypass valve. The lower the return condenser water temperature to the chiller, the lower the energy consumption of the chiller, within the design limits of the chiller.

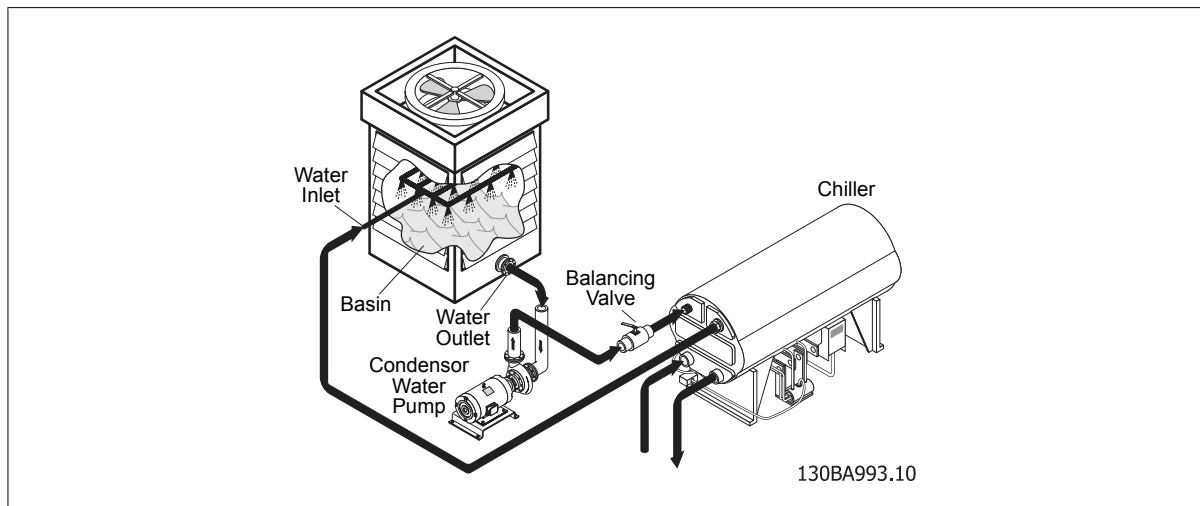


Illustration 5.1: Traditional Condenser Pump System

The condenser pump is usually oversized for a safety margin and to compensate for scaling in the piping and chiller tubes. Excess flow can erode the chiller's tubes, degrade system efficiency and increase maintenance expense. The system is balanced with a manual balancing valve to prevent too high a flow rate. By adding resistance to the system with the balancing valve, the rate of flow is reduced to the design flow rate of the condenser.

5

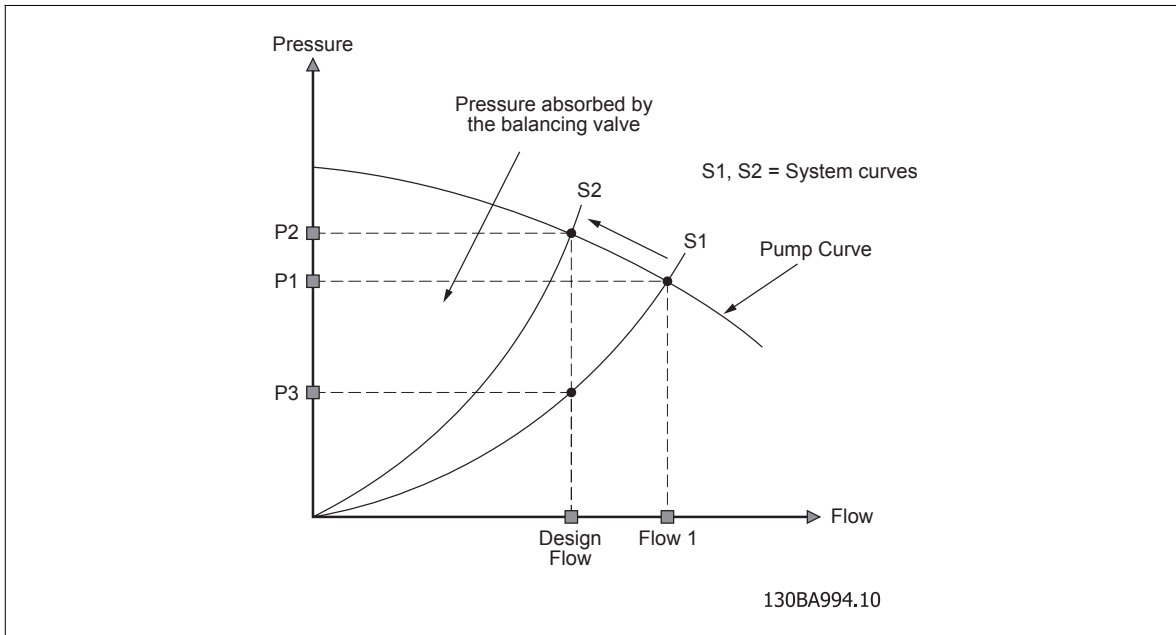


Illustration 5.2: Balancing Valve Pressure Loss

The illustration above shows the pressure that must be absorbed by a balancing valve in the condenser system to control flow. When the system is oversized, balancing the system changes water flow from the initial Flow 1 to the Design flow. By adjusting the valve, the pump pressure increases from P1 to P2. The pump discharge balancing valve absorbs a pressure drop equal to the pressure difference between P2 and P3.

Another method to adjust the condenser pump flow is to trim the pump impeller. The pump discharge balancing valve imposes a pressure drop equal to the pressure difference between P2 and P3 at design flow. The illustration below shows that use of a smaller impeller can reduce the pump capacity and pressure by substituting a new impeller with a smaller diameter or by trimming the existing pump impeller.

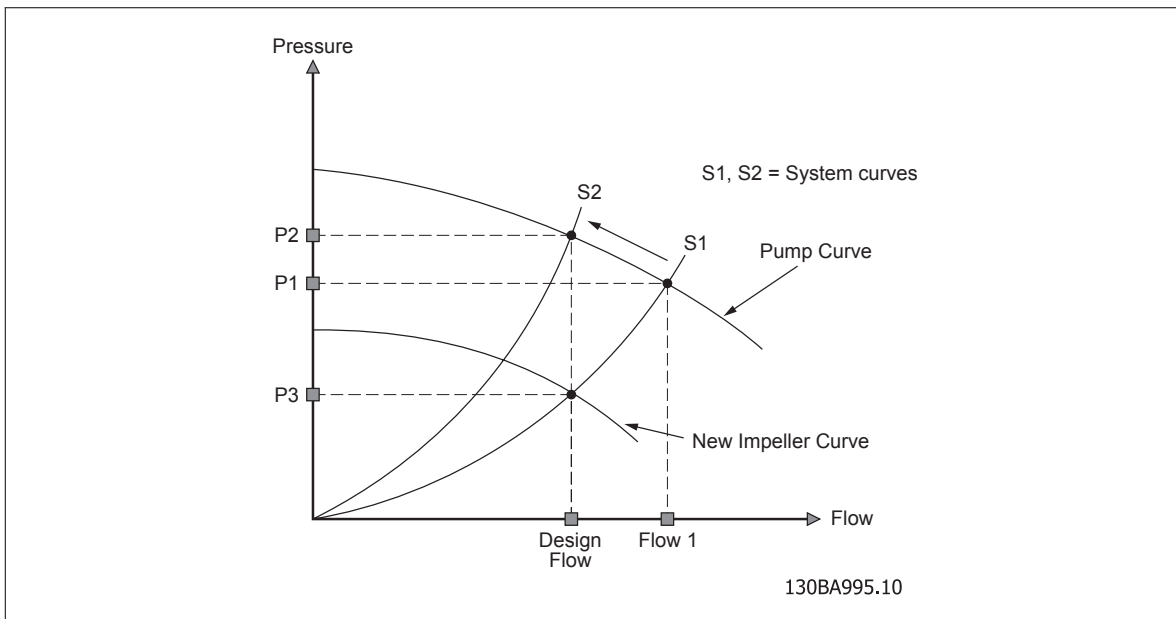


Illustration 5.3: Pump Impeller Trimming

Decreasing the diameter of the impeller reduces both the capacity and pressure of the pump as desired but has an impact on the pump's efficiency. The illustration below shows the effect of reducing the impeller size on pump efficiency. The change is fixed and permanent for a given change in impeller size.

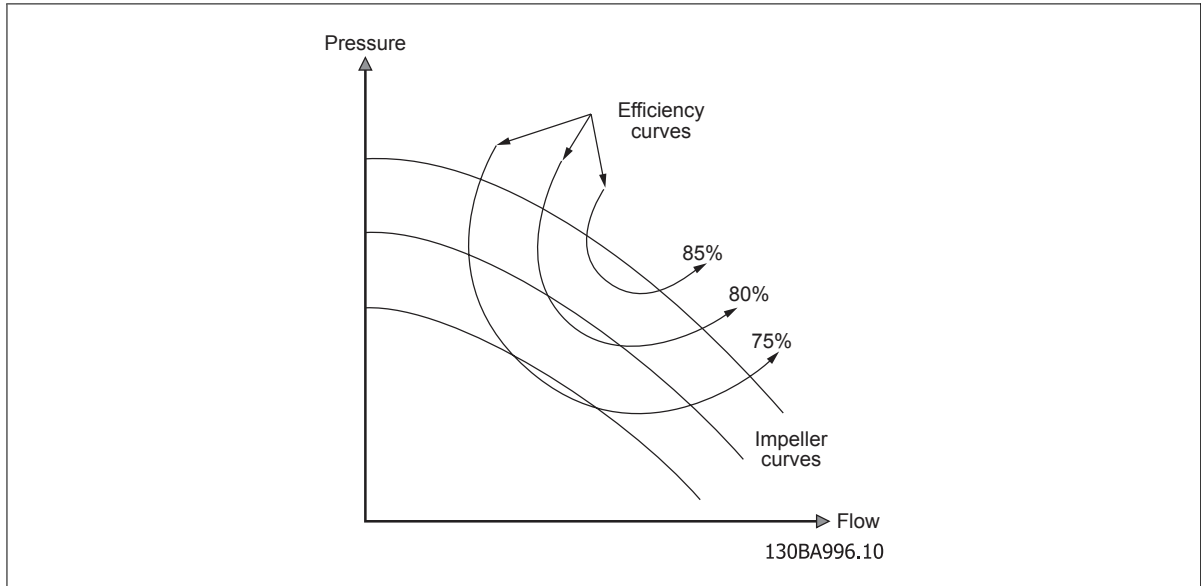


Illustration 5.4: Pump Efficiency Curves

5.3 Variable Frequency Drive Advantages

Based on the size of the system, the energy consumption of the condenser water loop can be substantial. A variable frequency drive controlling the condenser pump speed replaces the balancing valve or eliminates the need to trim the impeller. The result is greater energy efficiency and reduced maintenance and operating expense.

Typical control of a condenser pump is shown in the illustration below. Using a variable frequency drive to reduce pump speed and opening a balancing valve saves the energy that would have been absorbed by the valve. The output frequency is adjusted until the design flow rate is achieved. Savings with a variable frequency drive are based on the amount the balancing valve is closed.

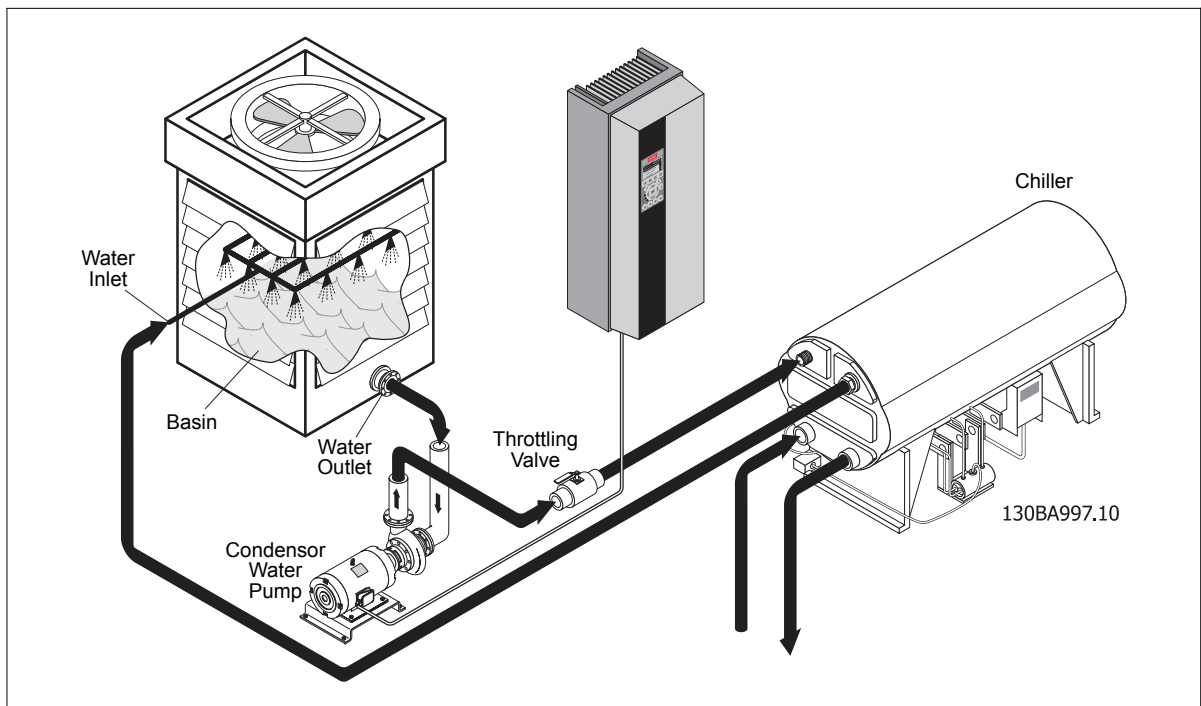


Illustration 5.5: Condenser Pump Control with Frequency Control

Using the variable frequency drive to decrease the pump speed has the same effect as trimming the pump impeller. By changing impeller diameter and maintaining a constant speed the efficiency is reduced because of the increased clearance between the pump casing and the periphery of the impeller. By changing speed and maintaining a constant impeller size, the pump efficiency remains the same but pressure, capacity and power are reduced. The illustration below shows that the pump efficiency remains constant as speed is reduced.

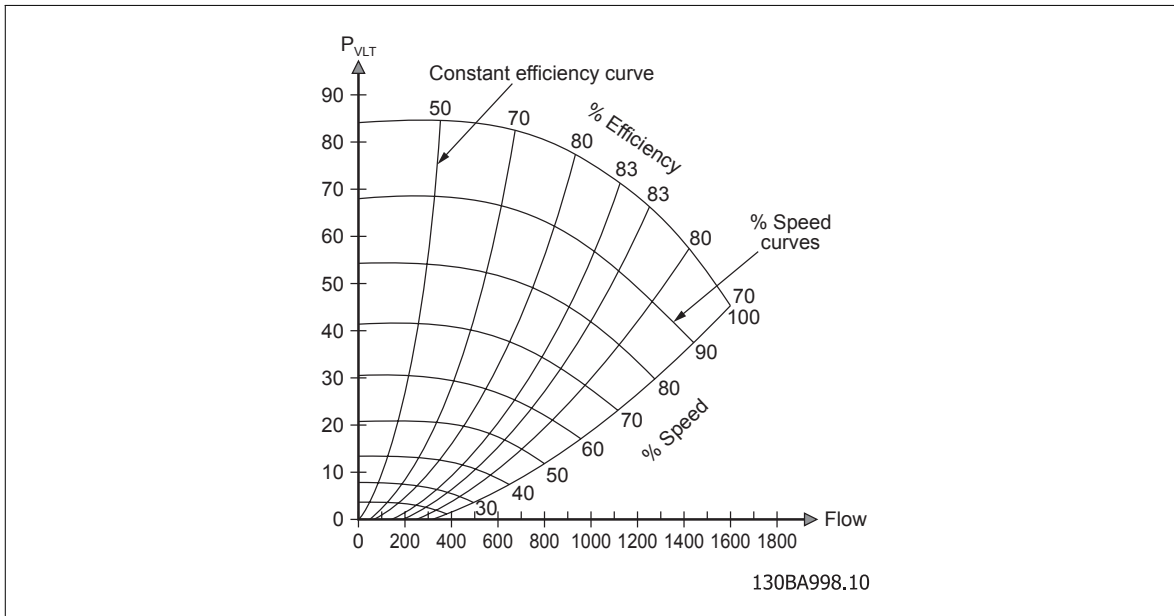


Illustration 5.6: Pump Efficiencies with Variable Speed

5.3.1 Retrofit chiller applications

Variable frequency drives can provide an optimized chiller flow rate without requiring new pumps, impeller reduction or balancing valves, which can reduce pump efficiency and add material and labor costs to the retrofit. Chiller retrofit applications have the potential for a change in the design flow rate of the condenser water. With decreased flow requirements, the variable frequency drive can easily reduce the pump motor speed.

Consult the chiller manufacturer for condenser water flow requirements before varying the flow rate of the condenser water pump.

5.4 Energy Savings

5.4.1 Energy savings estimation

Savings from installing a VLT® HVAC Drive compared to the other methods of pump volume control can be estimated using the Danfoss VLT® Energy Box software. The program compares energy consumption for a condenser pump running at full speed to the pump running at reduced speed using the VLT® HVAC Drive and provides a simple payback calculation.

A minimum of design data to plot the pump and system curve is required. If a balancing valve is partially close, the pressure drop it imposes on the system is included in the data. System operating hours are also entered.

To calculate the potential savings, a duty cycle or load profile is entered. The duty cycle indicates the amount of reduced flow the condenser system requires to satisfy the required chiller flow. Duty cycles vary depending on the amount of system over-sizing.

Typical input data is shown in the illustration below. It is estimated that the condenser pump flow can be reduced to 76% using a variable frequency drive and opening the balancing valve. After the pump and system data is entered, the program calculates the estimated energy consumption for the VLT® HVAC Drive and the comparison system.

The screenshot shows the 'Project: Condenser Pump' software interface. It includes a menu bar (File, Edit, View, Communication, Tools, Help) and tabs for System Data, Comparison and Cost, Energy Calculations, and System Energy Savings. The 'System Data' tab is active, showing a 'System Name' of 'Condenser Pump' and a 'Step 2.1' indicator.

System Data:

- Design Head: 98.40 ft wg
- Design Flow: 2,932.00 GPM
- Shaft Power: 100.0 HP
- Design Efficiency: 82.0 %
- Set Point Static Head: 32.80 ft wg
- Removed Pressure Drop: 3.20 ft wg

Motor and Drive Data:

- Motor Power: 100.0 HP
- Motor Efficiency: 85.0 %
- Drive Power: 100.0 HP
- Drive Efficiency: 98.0 %
- Drive Cost: \$ 5,796

Utility / Electricity Data:

- Average Cost per kWh: \$ 0.063
- Utility Incentive: 0 \$/HP

Operation:

- Hours per Day: 24 hours
- Days per Week: 7.0 days
- Weeks per Year: 38 weeks

Two graphs are displayed:

- Pump and Control Curve Data:** A line graph showing Head (ft wg) vs. Flow (%). The 'Control' curve (red) starts at approximately 30 ft wg at 0% flow and rises to about 100 ft wg at 100% flow. The 'Pump' curve (blue) starts at approximately 110 ft wg at 0% flow and decreases to about 0 ft wg at 100% flow.
- Duty Cycle:** A bar chart showing Time (%) vs. Flow (%). A single bar at 100% flow indicates 100% time.

Buttons at the bottom include: Go Back, Restore Default Values, Help, Update System, Cancel, and Continue. A 'Total Operating Time: 6,384 Hrs' is also displayed.

5

Illustration 5.7: Energy Box Input Data

130BA999.10

The illustration next page shows annual energy consumption for the condenser pump with constant volume and the Danfoss Drive System. A significant reduction in energy is achieved by removing the pressure drop and reducing pump motor speed.

5

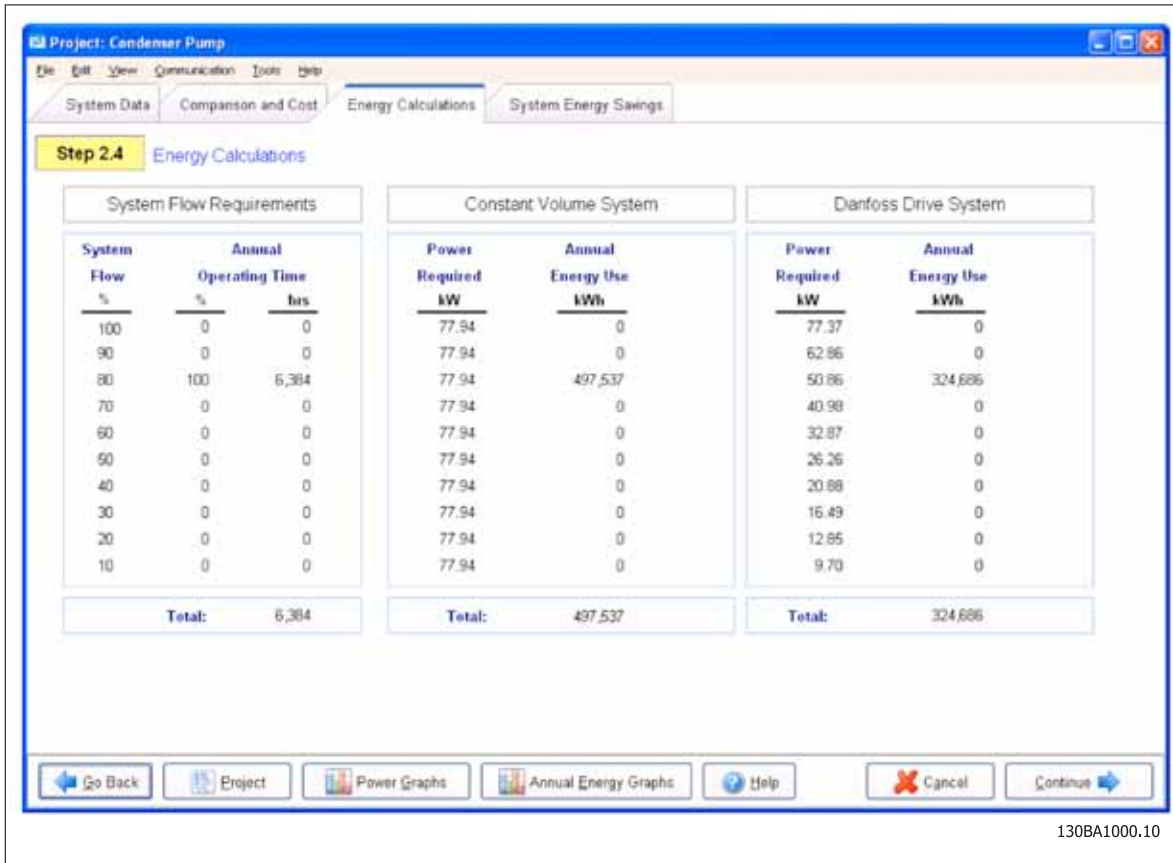


Illustration 5.8: Annual Energy Consumption

The program also calculates the simple payback period for the variable frequency drive including cost for the drive installation, wiring and other control components that may be needed. Below illustration shows a payback of 0.84 years to upgrade an existing condenser water pump system. The Energy Box Analysis and report can be printed, faxed or emailed.

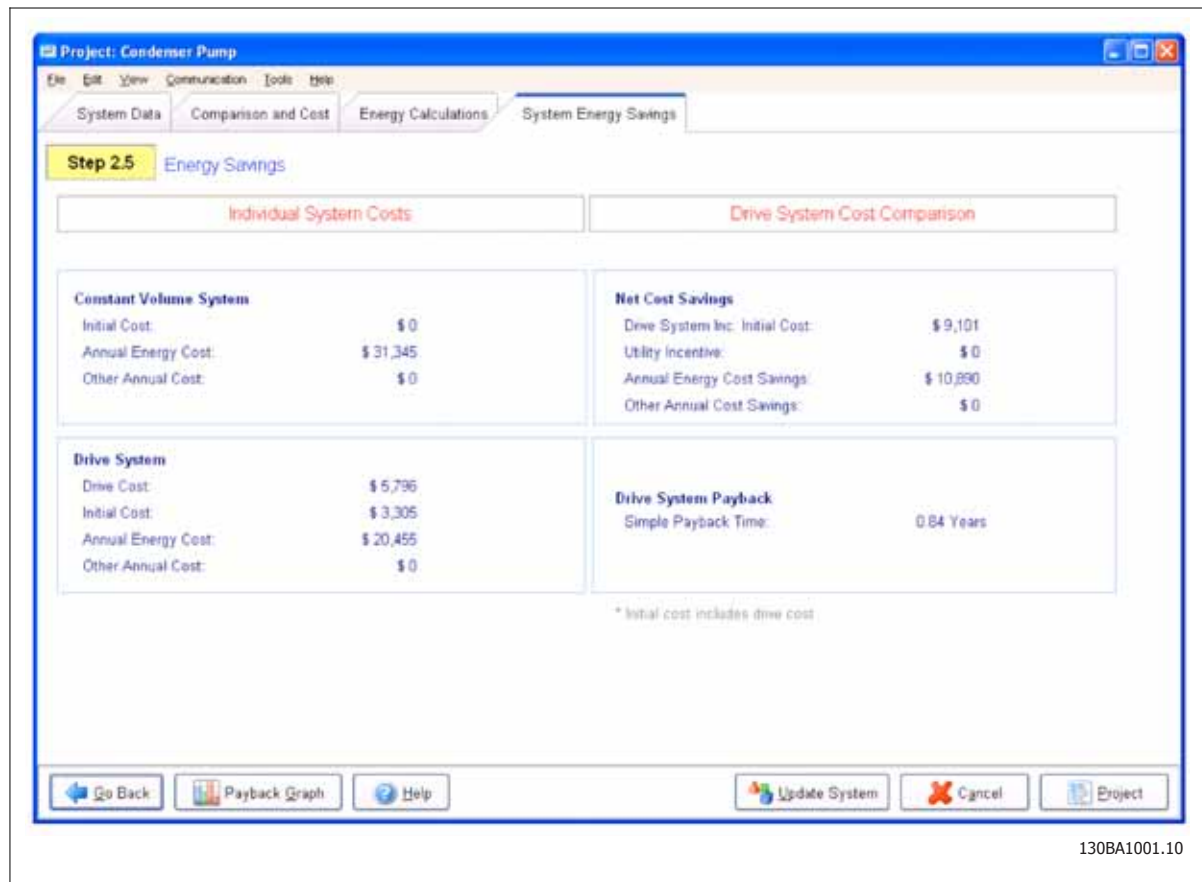


Illustration 5.9: Energy Box Financial Calculation

5.5 Drive Features

The Danfoss VLT® HVAC Drive is designed with features tailored for the unique control requirements of HVAC systems including condenser pump control. The following software features are incorporated, as standard, to optimize system performance.

5.5.1 No-flow

This feature is useful for detecting conditions where a pump is producing no-flow but is running. A no-flow condition can cause pump damage if not detected and corrected. No-Flow detection does not require the use of external differential pressure switches or flow meters and associated wiring.

No-flow Detection is based on the measurement of power at specific motor speeds. The variable frequency drive monitors actual power and motor frequency and compares these with the calculated power at specific speeds. If the power measured at a specific frequency is greater than the calculated power stored in the drive, the pump is producing flow. If the power measured at a specific frequency is less than the calculated power stored in the drive, a warning or alarm is generated to notify the operator of the condition.

5.5.2 Dry pump

This feature is useful for detecting a condition when the pump is running but no water is in the system. A dry pump condition can cause pump damage if not detected and corrected. Dry pump detection does not require the use of external differential pressure switches or flow meters and associated wiring.

If there is no water in the system, the pump will not produce pressure. The variable frequency drive will go to maximum speed to try to produce pressure. Because there is no water, the load on the motor will be low and power consumption will be low. If the variable frequency drive is running at the maximum speed and the system power consumption is low, a warning or alarm is generated to notify the operator of the condition.

5.5.3 End of curve

This feature is used to detect leakage in a pipe system or the loss of pressure in the system. End of Curve detection does not require the use of external pressure sensors or flow meters and associated wiring.

End of curve occurs if a pump is delivering a large volume of water but cannot maintain the set static head. When there is a water leak in the pipe system, the pump will not produce full pressure. The variable frequency drive speed increases to maximum speed to attempt to produce the full pressure. If the variable frequency drive is running at the maximum speed and the system pressure is low, a warning or alarm is generated to notify the operator of the condition.

5

5.5.4 Energy log and trending

The variable frequency drive continuously accumulates the consumption of the actual power from the variable frequency drive to the motor. Data can be used in an Energy Log function allowing the user to analyze the energy consumption related to time. Data can be accumulated in two ways: a preset date and time for start and stop or a predefined time period (such as the last 24 hours, seven days or month).

Trending is used to monitor how the variable changes over a period of time. The value of the trended variable is recorded in one of ten user-defined bins (data ranges). Common Trending variables for condenser pump applications are motor power and output frequency.

The trending feature makes it possible to determine how much power reduction occurs for the condenser pump system operation. Using these trending data with VLT® Energy Box software determines the actual savings obtained for control of condenser pumps with the VLT® HVAC Drive.

5.5.5 Serial communications

The VLT® HVAC Drive offers communication capabilities that are unmatched in variable frequency drives, reducing or eliminating the need for external devices.

Built-in serial communications options include: BACnet™, Modbus RTU, Johnson Controls Metasys®N2, and Siemens Apogee®FLN. Enhanced BACnet™ and LonWorks® are available as field-installed option cards that mount easily inside the VLT®HVAC Drive. Consult Danfoss for other serial communications options.

6 Primary Pumps in a Primary/Secondary Chilled Water Pumping System

6.1 Introduction

Primary/secondary systems are one of the most common types of chilled water systems used in commercial buildings. Factors such as simplicity and experience have made them a choice of building owners and operators for over 50 years.

The primary/secondary pumping system separates the primary production loop from the secondary distribution loop. In the primary loop, pumps are used to maintain a constant flow. This allows the chillers and the primary chilled water loop to maintain a constant design flow while allowing the secondary system to vary the flow based on the building cooling load demand. A de-coupler pipe, also called a bypass, separates the primary and secondary loops.

In traditional chilled water systems, the primary loop consists of constant speed pumps sized to produce the design flow rate of the chillers at a discharge pressure sufficient to circulate the water through the chillers and the primary loop. The primary loop is as small as possible to minimize the resistance of the loop and the energy consumption of the constant speed primary pumps.

6.2 Primary Loop Control

6.2.1 Primary loop pump control

The flow through chillers is kept relatively constant to minimize problems. When the chiller evaporator section flow rate decreases, such as when the building cooling demand drops, the water in the evaporator section can become over-chilled. When this happens, the chiller will attempt to decrease its cooling capacity. If the flow rate drops too low or too quickly, the chiller cannot shed (reduce) its load properly. A low evaporator temperature safety will trip off the chiller, requiring a manual reset to restart the chiller. This situation can be common, especially with two or more chillers installed in parallel.

A typical primary/secondary system is shown in the illustration below. The primary pumps are usually oversized to provide a safety margin in the design and to accommodate scaling in the piping and chiller tubes. To obtain proper flow in the primary loops, a balancing valve on the discharge of the primary pumps is adjusted. By adjusting the balancing valve and creating a pressure drop to reduce flow, the proper design flow rate is established.

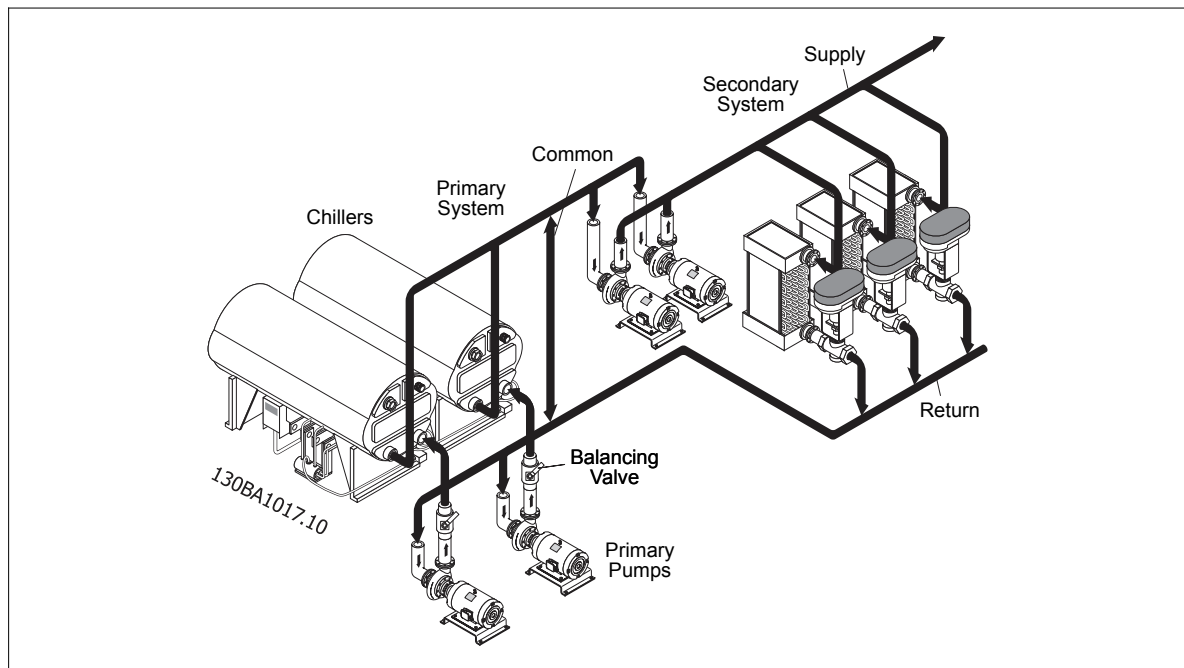


Illustration 6.1: Traditional Primary/Secondary Pumping System Design

The illustration below shows the pressure or static head that must be absorbed by a balancing valve to control the flow. By adjusting the valve, the pump pressure increases from P1 to P2 and the water flow changes from Flow 1 to the design flow. The pressure drop between P2 and P3 is absorbed by the balancing valve.

6

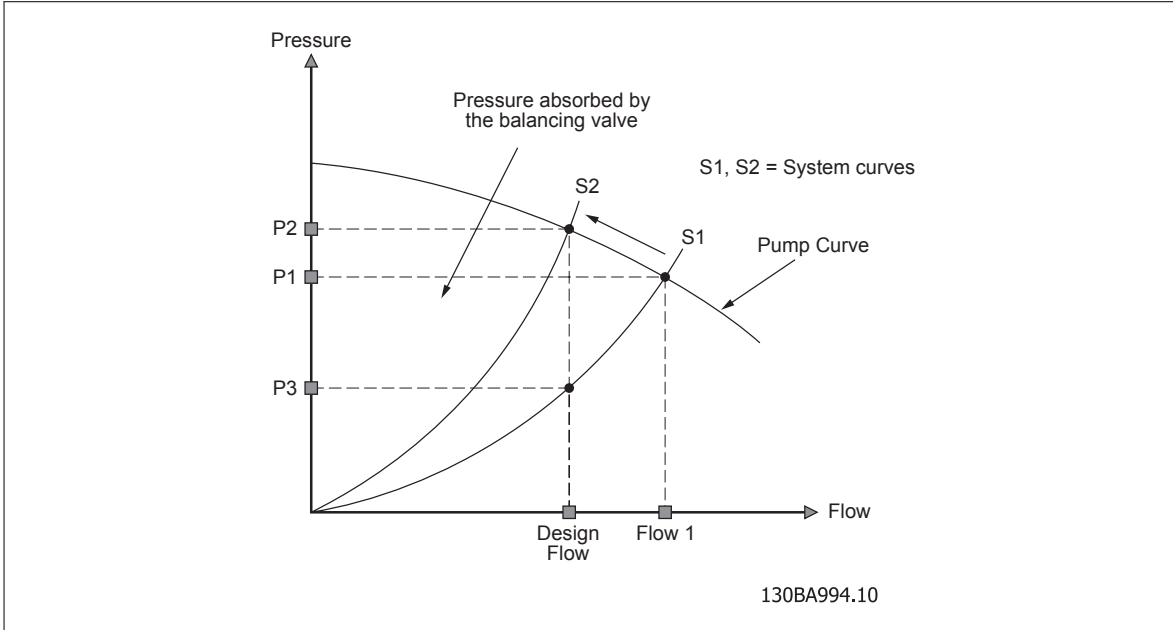


Illustration 6.2: Balancing Valve Pressure Loss

Another method to adjust the primary pump flow is to trim the pump impeller. The pump discharge balancing valve imposes a pressure drop equal to the pressure difference between P2 and P3 at design flow. The illustration below shows that use of a smaller impeller can reduce the pump capacity by substituting a new impeller with a smaller diameter or by trimming the existing pump impeller.

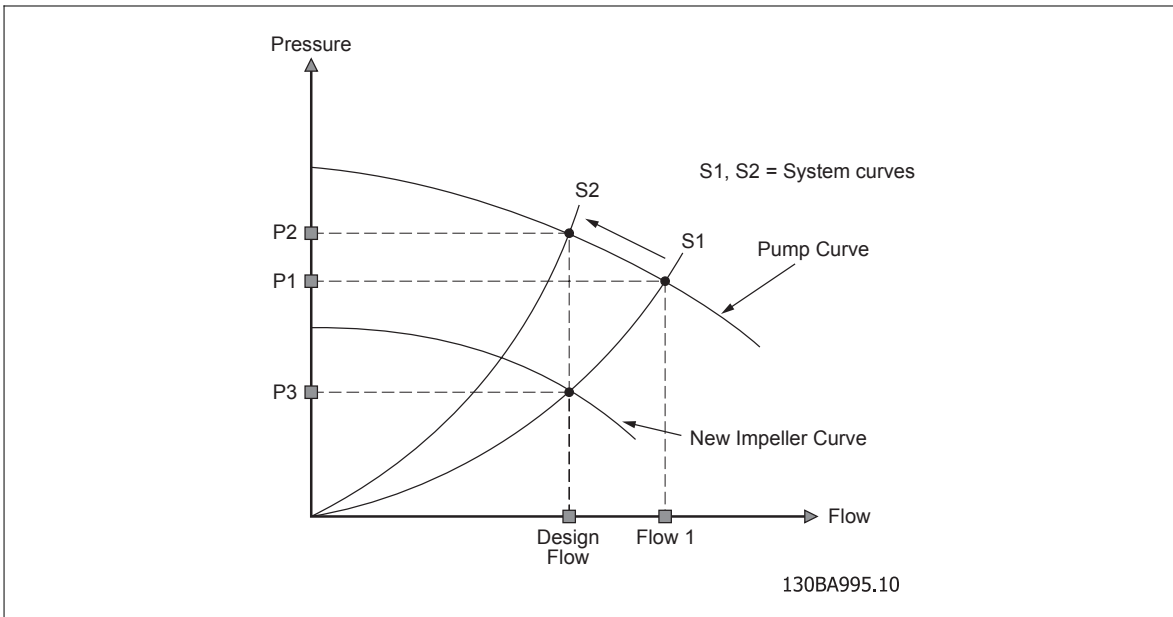


Illustration 6.3: Pump Impeller Trimming

Decreasing the diameter of the impeller reduces both the capacity and pressure of the pump as desired but has an impact on the pump's efficiency. The illustration below shows the effect of reducing the impeller size on pump efficiency. The change is fixed and permanent for a given change in impeller size.

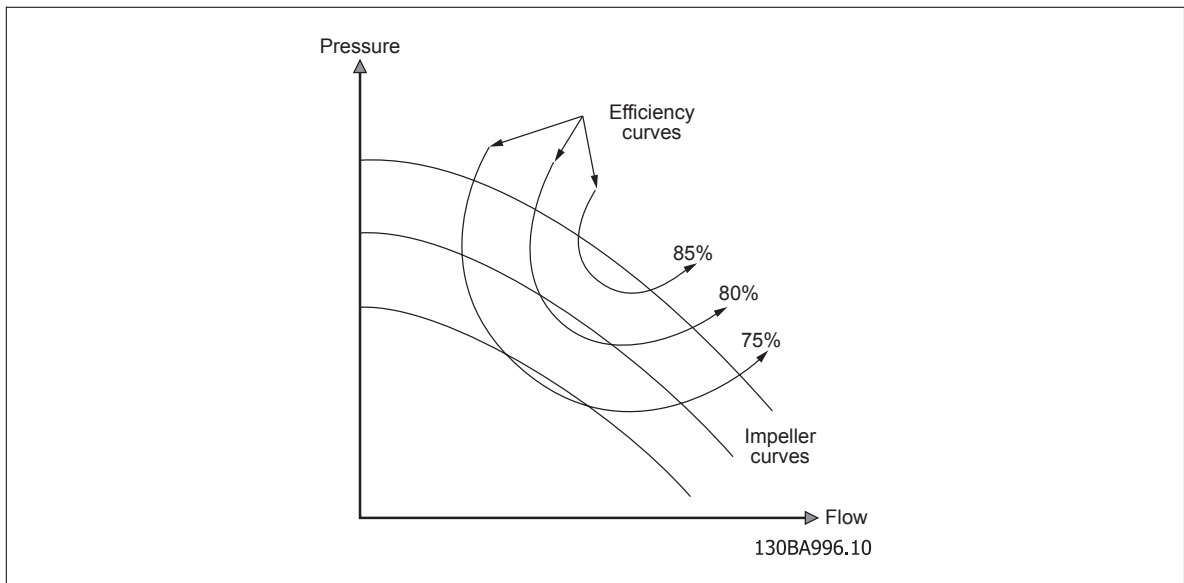


Illustration 6.4: Pump Efficiency Curves

6.2.2 Variable frequency drive primary loop control

Based on the size of the system, the energy consumption of the primary water loop can be substantial. A variable frequency drive controlling the primary pump replaces the balancing valve or eliminates the need to trim the impeller. The result is greater energy efficiency and reduced maintenance and operating expense.

Two variable frequency drive control methods are common. One method, shown in the illustration below, uses a feedback signal from a flow meter. Because the desired constant-flow rate is known, a flow meter installed in the discharge of each chiller measures the pump output. The flow meter signal is used as an analog input to the variable frequency drive to maintain the appropriate flow rate. The variable frequency drive automatically compensates for scale buildup and changing resistance in the primary piping loop as chillers and pumps are staged on and off.

6

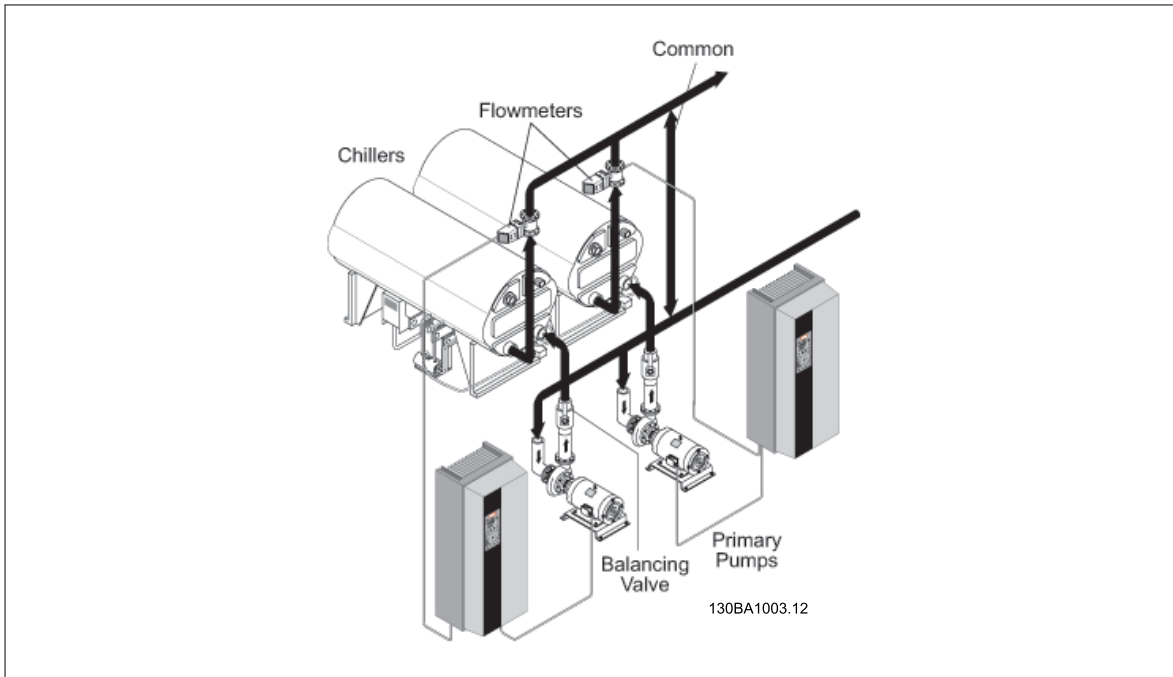


Illustration 6.5: Variable frequency drives for Primary Loop Control

Local speed control is the other and more common method. The operator can simply adjust the output frequency of the FC manually until the design flow rate is achieved. The pump operates at this constant speed when the chiller is staged on.

The variable frequency drives can control primary water pumps without the need to close a balancing valve in the system or reducing impeller size. Using a variable frequency drive to reduce pump speed and opening a balancing valve saves the energy that would have been absorbed by the valve. The FC output frequency is adjusted until the design flow rate is achieved. Savings with a variable frequency drive are based on the amount the balancing valve is closed.

Using the variable frequency drive to decrease the pump speed has the same effect as trimming the pump impeller. By changing impeller diameter and maintaining a constant speed the efficiency is reduced because of the increased clearance between the pump casing and the periphery of the impeller. By changing speed and maintaining a constant impeller size, the pump efficiency remains the same but pressure, capacity and power are reduced. The illustration below shows that the pump efficiency remains constant as speed is reduced.

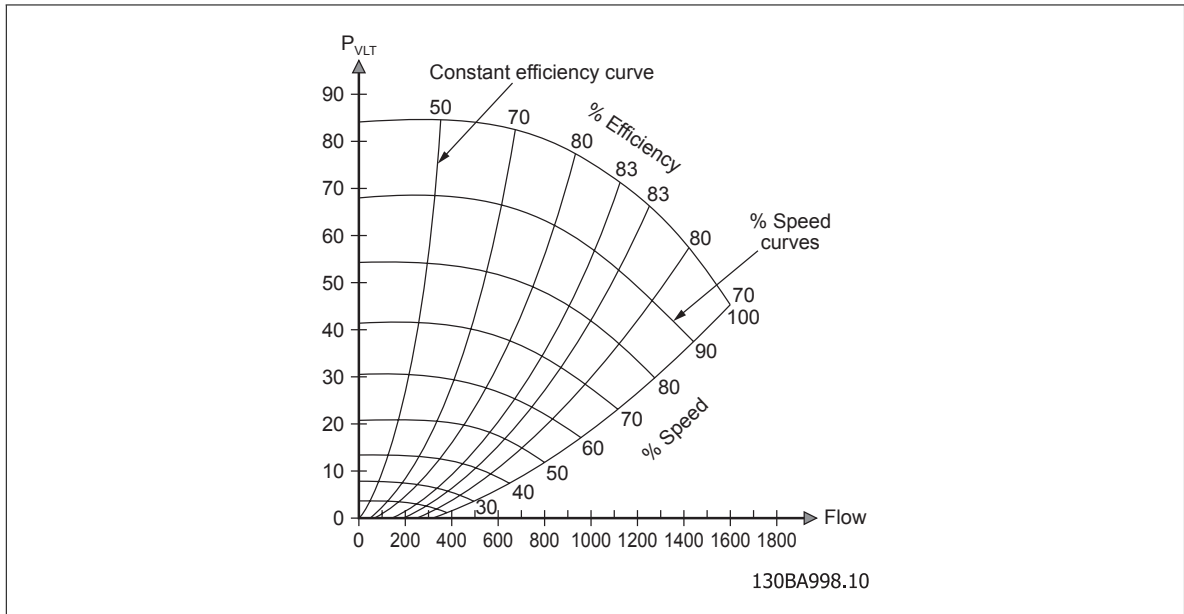


Illustration 6.6: Pump Efficiencies with Variable Speed

6.3 Energy Savings

6.3.1 Energy savings estimation

Savings from installing a VLT® HVAC Drive compared to the other methods of pump volume control can be estimated using the Danfoss VLT® Energy Box software. The program compares energy consumption for a primary pump running at full speed to the pump running at reduced speed using the VLT® HVAC Drive and provides a simple payback calculation.

A minimum of design data to plot the pump and system curve is required. If a balancing valve is partially closed, the pressure drop it imposes on the system is included in the data. System operating hours are also entered.

To calculate the potential savings, a duty cycle or load profile is entered. The duty cycle indicates the amount of reduced flow the primary chilled water system requires to satisfy the required chiller flow. Duty cycles vary depending on the amount of system oversizing.

Typical input data is shown in the illustration below. It is estimated that the primary pump flow can be reduced to 90% by using a variable frequency drive and opening the balancing valve. After the pump and system data is entered, the program calculates the estimated energy consumption for the VLT® HVAC Drive and the comparison system.

6

The screenshot shows the 'Project: Primary Chiller Pump' software interface. It includes a menu bar (File, Edit, View, Communication, Tools, Help) and tabs for System Data, Comparison and Cost, Energy Calculations, and System Energy Savings. The 'System Data' tab is active, showing 'Step 2.1'.

System Data:

- Design Head: 96.70 ft wg
- Design Flow: 169.33 GPM
- Shaft Power: 28.1 HP
- Design Efficiency: 86.0 %
- Set Point Static Head: 9.84 ft wg
- Removed Pressure Drop: 13.12 ft wg

Motor and Drive Data:

- Motor Power: 30.0 HP
- Motor Efficiency: 93.0 %
- Drive Power: 30.0 HP
- Drive Efficiency: 96.0 %
- Drive Cost: \$ 2,374

Utility / Electricity Data:

- Average Cost per kWh: \$ 0.063
- Utility Incentive: 0 \$/HP

Operation:

- Hours per Day: 24 hours
- Days per Week: 7.0 days
- Weeks per Year: 38 weeks

Pump and Control Curve Data: A graph showing Head (ft wg) vs Flow (%). The Pump curve (blue) starts at 110 ft wg at 0% flow and decreases to 0 ft wg at 200% flow. The Control curve (red) starts at 0 ft wg at 0% flow and increases to 110 ft wg at 100% flow.

Duty Cycle: A graph showing Time (%) vs Flow (%). The duty cycle is a single vertical bar at 100% flow, indicating 100% of the time is spent at that flow rate.

Total Operating Time: 6,384 Hrs

Buttons: Go Back, Restore Default Values, Help, Update System, Cancel, Continue

130BA1004.10

Illustration 6.7: Energy Box Input Data

The illustration below shows annual energy consumption for the primary pump with constant volume and the Danfoss Drive System. A significant reduction in energy is achieved by removing the pressure drop and reducing pump motor speed.

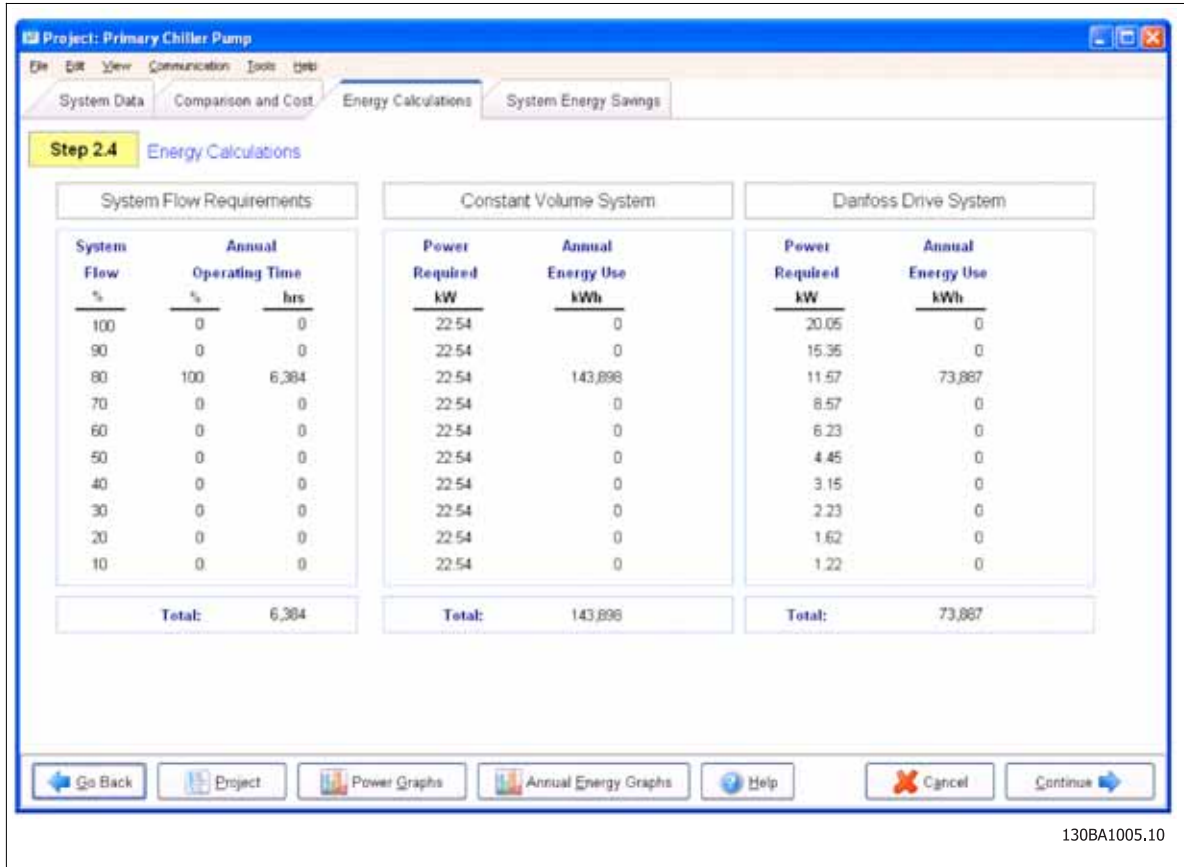


Illustration 6.8: Annual Energy Consumption

The program also calculates the simple payback period for the variable frequency drive including cost for the drive, installation, wiring and other control components that may be needed. The illustration below shows a payback of 0.79 years to upgrade an existing primary pump system. The Energy Box Analysis and report can be printed, faxed or emailed.

6

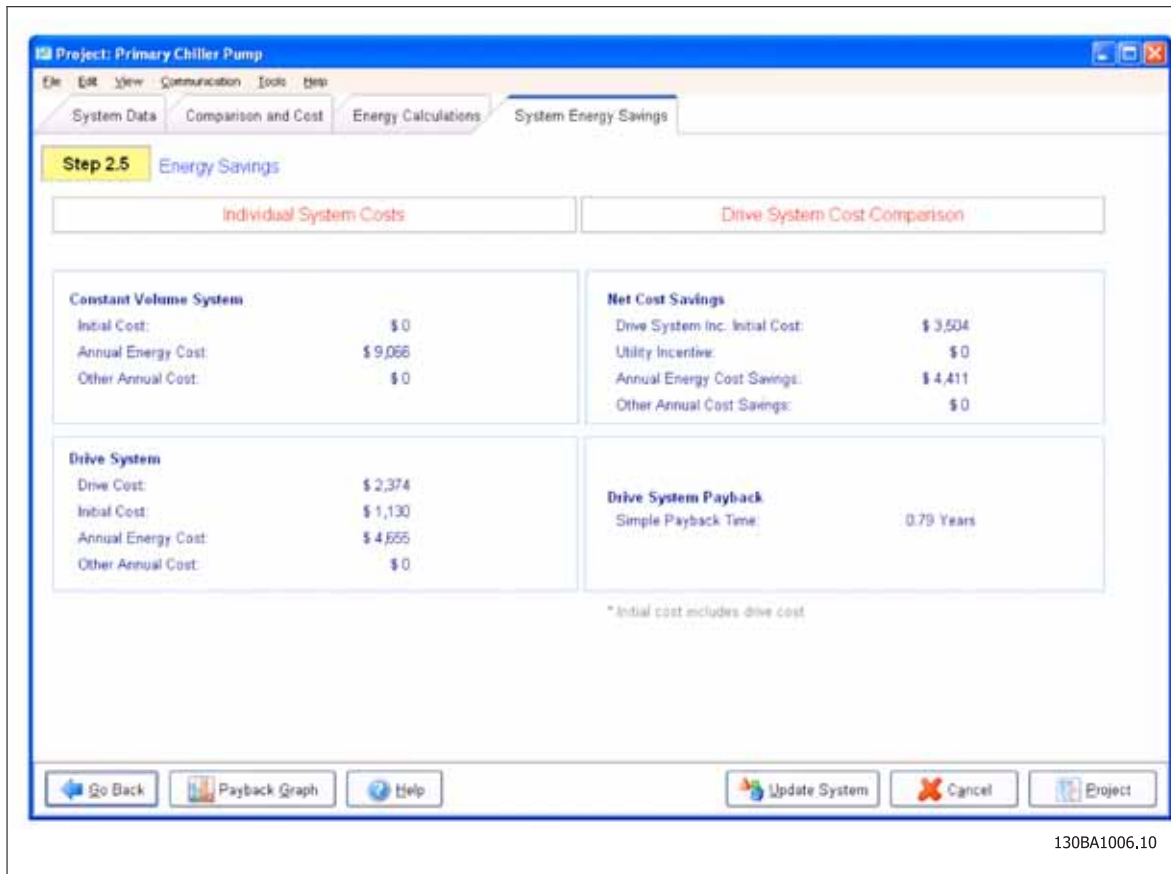


Illustration 6.9: Energy Box Financial Calculation

6.4 Drive Features

The Danfoss VLT® HVAC Drive is designed with features tailored for the unique control requirements of HVAC systems, including primary pump control. The following software features are incorporated as standard, to optimize system performance.

6.4.1 No-flow

This feature is useful for detecting conditions where a pump is producing no-flow but is running. A no-flow condition can cause pump damage if not detected and corrected. No-Flow detection does not require the use of external differential pressure switches or flow meters and associated wiring.

No-flow Detection is based on the measurement of power at specific motor speeds. The variable frequency drive monitors actual power and motor frequency and compares these with the calculated power at specific speeds. If the power measured at a specific frequency is greater than the calculated power stored in the drive, the pump is producing flow. If the power measured at a specific frequency is less than the calculated power stored in the drive, a warning or alarm is generated to notify the operator of the condition.

6.4.2 Dry pump

This feature is useful for detecting a condition when the pump is running but no water is in the system. A dry pump condition can cause pump damage if not detected and corrected. Dry pump detection does not require the use of external differential pressure switches or flow meters and associated wiring.

If there is no water in the system, the pump will not produce pressure. The variable frequency drive will go to maximum speed to try to produce pressure. Because there is no water, the load on the motor will be low and power consumption will be low. If the variable frequency drive is running at the maximum speed and the system power consumption is low, a warning or alarm is generated to notify the operator of the condition.

6.4.3 End of curve

This feature is used to detect leakage in a pipe system or the loss of pressure in the system. End of Curve detection does not require the use of external pressure sensors or flow meters and associated wiring.

End of curve occurs if a pump is delivering a large volume of water but cannot maintain the set static head. When there is a water leak in the pipe system, the pump will not produce full pressure. The variable frequency drive speed increases to maximum speed to attempt to produce the full pressure. If the variable frequency drive is running at the maximum speed and the system pressure is low, a warning or alarm is generated to notify the operator of the condition.

6.4.4 Energy log and trending

The variable frequency drive continuously accumulates the consumption of the actual power from the variable frequency drive to the motor. Data can be used in an Energy Log function allowing the user to analyze the energy consumption related to time. Data can be accumulated in two ways: a preset date and time for start and stop or a predefined time period (such as last 24 hours, seven days or month).

Trending is used to monitor how the variable changes over a period of time. The value of the trended variable is recorded in one of ten user-defined bins (data ranges). Common trending variables for primary pump applications are motor power and output frequency.

The trending feature makes it possible to determine how much power reduction occurs for the primary pump system operation. Using this trending data with VLT® Energy Box software determines the actual savings obtained for control of primary pumps with the VLT® HVAC Drive.

6.4.5 Serial communications

The VLT® HVAC Drive offers communication capabilities that are unmatched in variable frequency drives, reducing or eliminating the need for external devices.

Built-in serial communications options include: BACnet™, Modbus RTU, Johnson Controls Metasys® N2, and Siemens Apogee® FLN. Enhanced BACnet™ and LonWorks® are available as field-installed option cards that mount easily inside the VLT® HVAC Drive. Consult Danfoss for other serial communications options.



7

7 Secondary Pumps in a Primary/Secondary Chilled Water Pumping System

7.1 Introduction

Primary/secondary systems are one of the most common types of chilled water systems used in commercial buildings. Factors such as simplicity and experience have made them a choice of building owners and operators for over 50 years.

The primary/secondary pumping system separates the primary production loop from the secondary distribution loop. In the primary loop, pumps are used to maintain a constant flow. This allows the chillers and the primary chilled water loop to maintain a constant design flow while allowing the secondary system to vary the flow based on the building cooling load demand. A de-coupler pipe, also called a bypass, separates the primary and secondary loops.

Larger secondary pumps circulate the water throughout the rest of the system. Since the secondary pumps are isolated from the primary loop by the de-coupler pipe, the pumps have no minimum flow constraints and can use two-way valves to control the cooling coils.

7.2 Loop Pump Control

7.2.1 Secondary loop pump control

The illustration below shows a conventional primary/secondary system. The flow through each chiller is constant and set by the constant flow of a primary pump. The secondary pumps circulate water through the secondary water loop to meet the building load requirements. This flow is variable and is controlled by the opening and closing of two-way valves on the cooling coils.

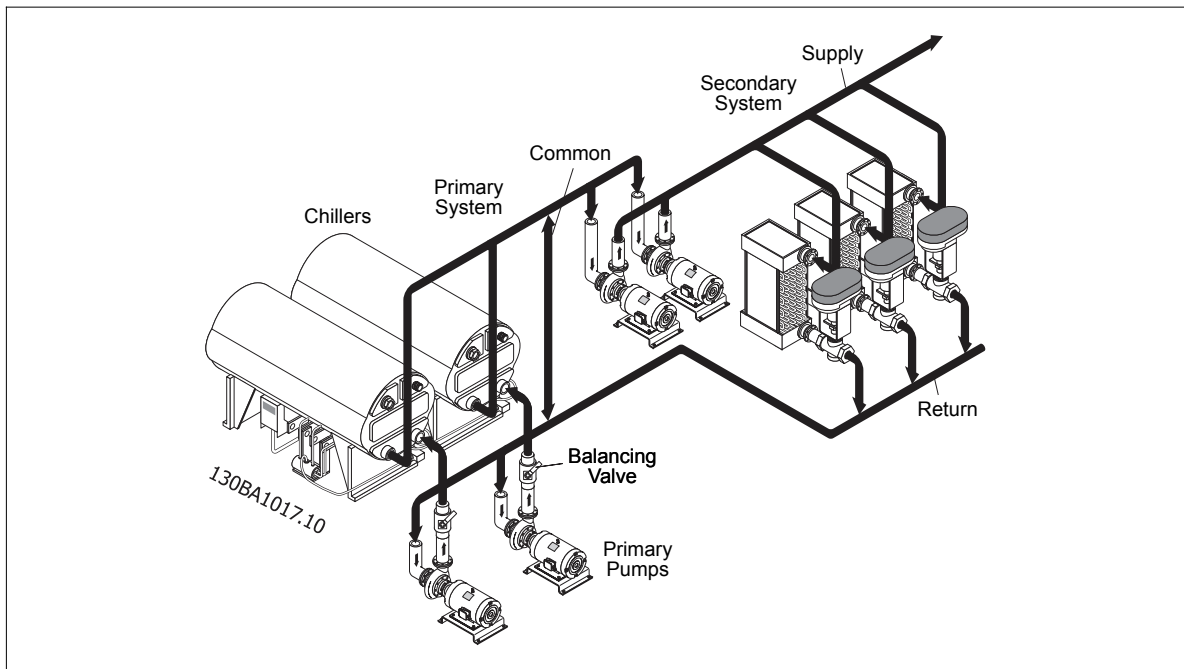


Illustration 7.1: Primary/Secondary Pumping System

The illustration below shows the system flow requirements decrease from Flow 1 to Flow 2 as the cooling coil two-way valves modulate from the full open position to a closed position. The system curve is the discharge pressure that the secondary pumps must produce to overcome system resistance in delivering water to the cooling coils. System resistance is due to the restrictions caused by piping, fittings, valves and coils. The system curve can change position from curve S1 to curve S2 if the system resistance increases, requiring more pressure to achieve a given flow. This increase in resistance occurs as the two-way valves at the cooling coils stroke toward a closed position in response to a decrease in cooling requirements in the conditioned spaces.

As the valves close to reduce flow, the resistance increases and the pump must produce a higher pressure (system head) to overcome this resistance. A constant speed pump with two-way valves must follow the pump curve from the design pressure to the pressure P1 as the control valves decrease the flow. This means that, as the flow decreases, the pumps increase discharge pressure even though the system requires a lower discharge pressure.

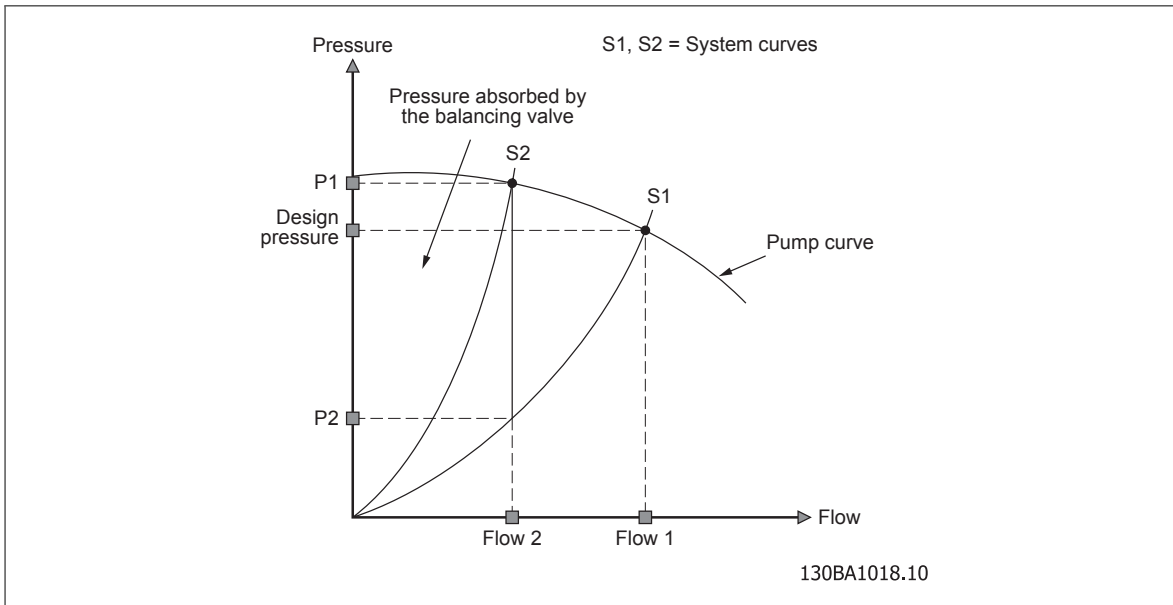


Illustration 7.2: Pressure Absorbed by Two-way Valve

The difference between pressure P1 and P2 is the pressure drop that the two-way valves must absorb. The pressure absorbed varies with the flow. This pressure can become greater than the valve is designed to operate against, forcing the valve to remain open. This can over-cool the conditioned zones closest to the pump, while insufficiently cooling the more distant zones, and can lead to a low ΔT condition for the chiller evaporator. This results in wasted energy and inadequate system performance.

7.2.2 Variable speed secondary loop pump control

Significant energy savings and increased control potential are realized by adding variable frequency drives to the secondary system. The pumps are controlled to vary speed in accordance with the system requirements. Following the system curve instead of "riding the pump curve" results in optimum energy savings and eliminates the over-pressurization of the cooling coil two-way control valves.

The secondary pumps maintain a differential pressure at a specific point in the system. In the illustration below, this point is the pressure difference across the most significant distant load. The pressure difference is the coil, piping and control valve pressure drop at design flow.

As the building cooling loads are satisfied, the coil two-way control valves move toward the closed position, this increases the differential pressure measured across the cooling coil, valve and piping. As the differential pressure starts to rise, the variable frequency drive slows the pump to maintain the differential pressure set-point value. The variable frequency drive set-point value is the sum of the pressure drop across the cooling coil, coil piping and two-way control valve under design flow conditions.

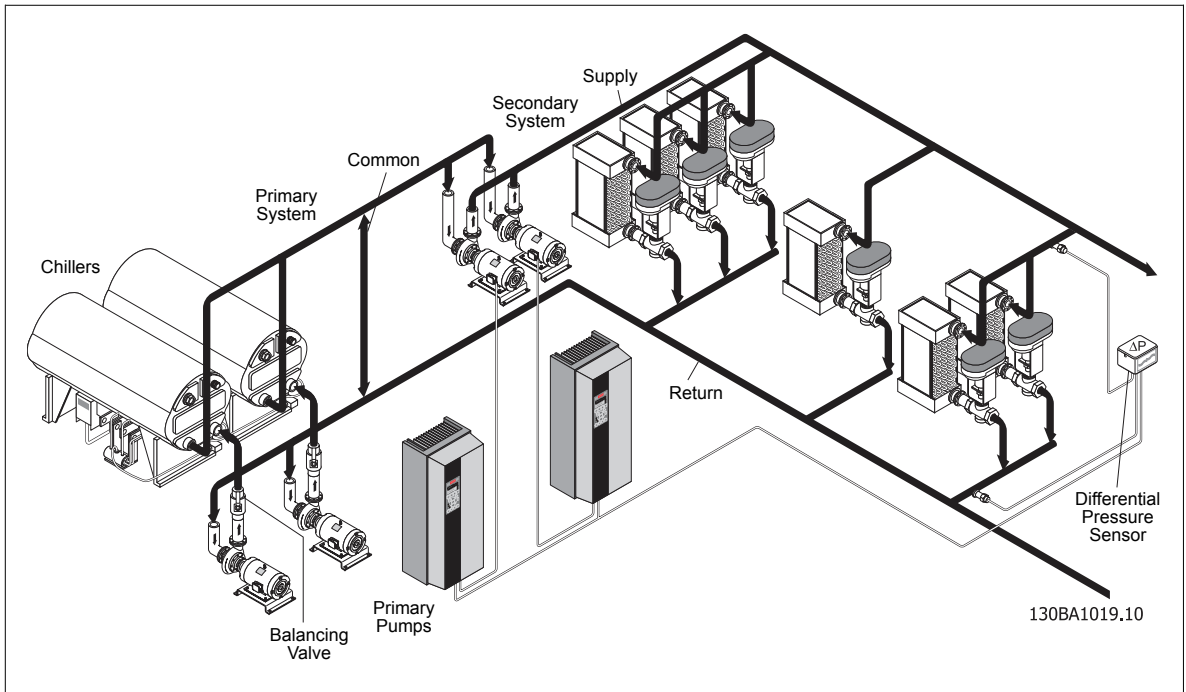


Illustration 7.3: Secondary Pumping System with Variable Frequency Drives

Although the same cooling coil differential head is maintained across the most significant distant load, the overall system pressure is reduced. The illustration below shows the variable frequency drive and variable speed secondary pump response to the modulation or control curve. The control curve shows the actual operation points of the pump with variable speed control and represents the required secondary pump discharge pressure to maintain the set-point at the load, as the friction loss in the piping decreases with flow. The lower the set-point, the greater the potential savings, as shown in tables on sensor location on the next page.

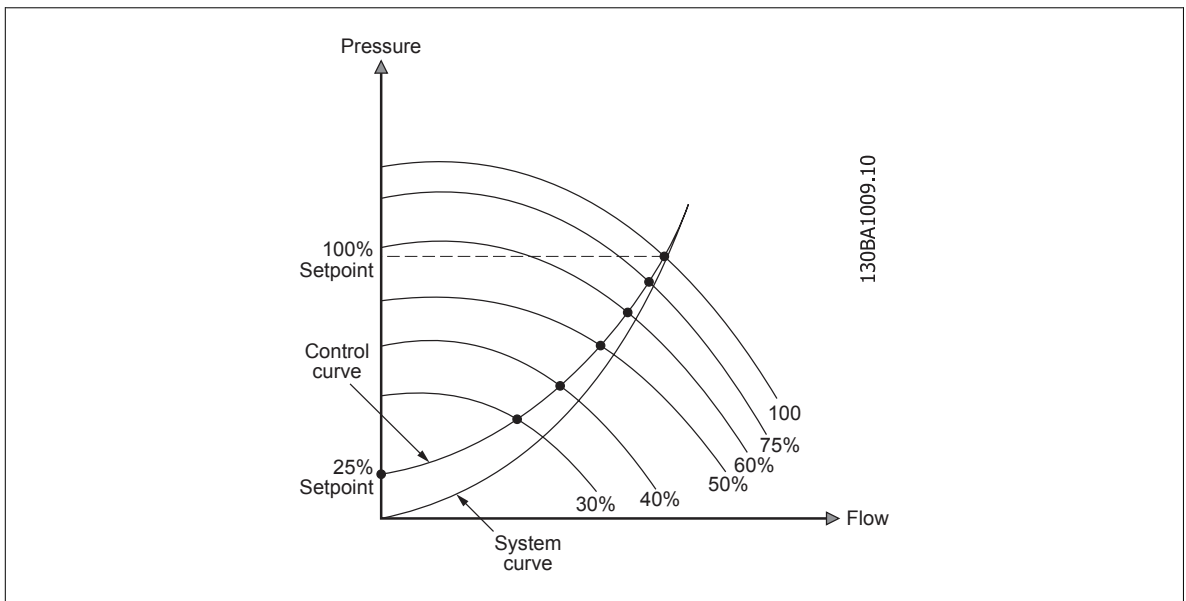


Illustration 7.4: Variable Speed Pump Curves

7.3 Sensors

7.3.1 Sensor type and placement

While the energy savings of a properly installed variable frequency drive is significant, the importance of pressure sensor type and location is critical for proper control of the pump and to achieve maximum energy savings.

For secondary pumping systems, a differential pressure sensor should be used. The sensor detects the pressure difference across the cooling coil, two-way valve and piping. It is important to place the sensor to measure the furthest most significant load. This allows the variable frequency drive PID controller to take advantage of the decreased resistance of the piping network, known as the variable head loss, as flow is reduced. With this sensor placement, the set-point requirement is the static pressure drop across the cooling coil and control valve. If this value is not known, an estimate of 25% of design static head is sometimes used.

Some installations have incorrectly located the differential pressure sensor in the supply and return headers at the pump, usually in an effort to reduce installation costs. Illustrations on sensor location below show the significant impact that sensor placement has on energy savings. The table below shows the sensor located across the pump supply and return headers. The set-point is the design static head. The power reduction is shown as the slight motor speed savings from maintaining a constant design static head.

7

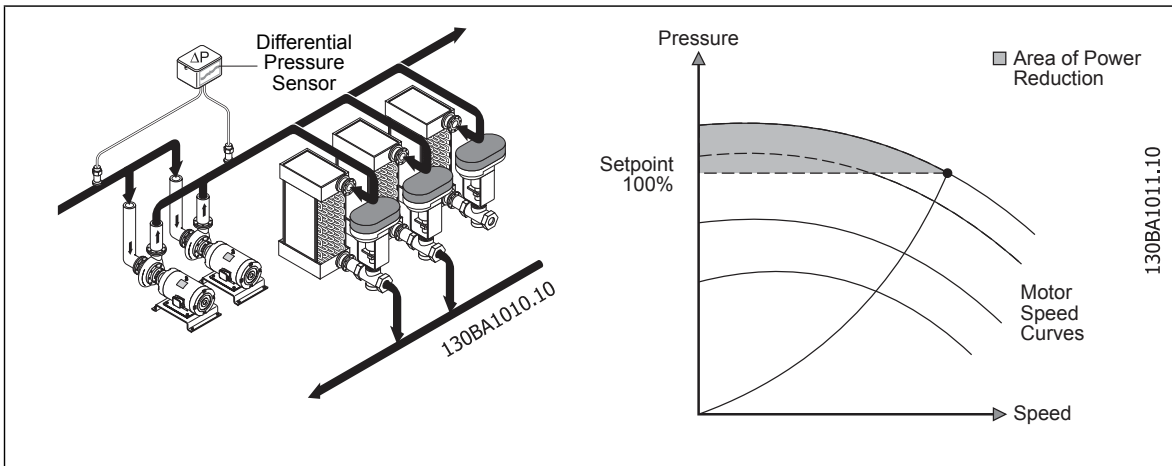


Table 7.1: Sensor Location with 100% Set-point (Across Pump)

The table below shows the differential pressure sensor located correctly across the most significant distant load with a set-point (reference) of 25% of design static head. The power reduction is shown as the motor speed savings from following the control curve.

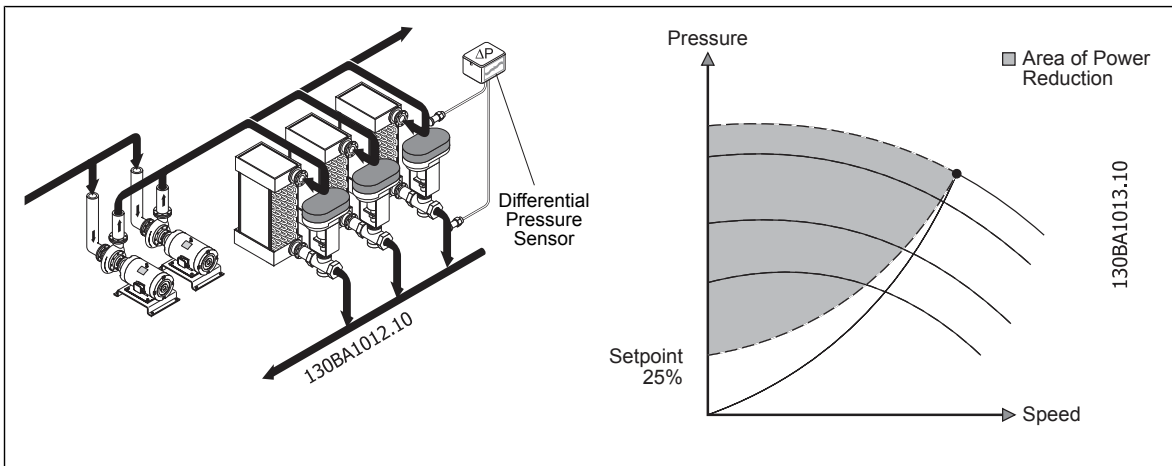


Table 7.2: Sensor Location with 25% Set-point (Across Load)

7.4 Energy Savings

7.4.1 Energy savings estimation

Savings from installing a VLT HVAC Drive compared to the other methods of pump volume control can be estimated using the Danfoss VLT® Energy Box software. The program compares energy consumption for a secondary pump system with throttling valves running at full speed to the pump running at reduced speed using the VLT® HVAC Drive and provides a simple payback calculation.

A minimum of design data to plot the pump and system curve is required. If a balancing valve is partially closed, the pressure drop it imposes on the system is included in the data. System operating hours are also entered.

To calculate the potential savings, a duty cycle or load profile is entered. The duty cycle indicates the amount of flow the system requires to satisfy the building load. Duty cycles vary depending on the specific building and system operation. The program has a default profile that can easily be changed.

Typical input data is shown in the illustration below. After the pump and system data are entered, the program calculates the estimated energy consumption for the VLT® HVAC Drive and the comparison system.

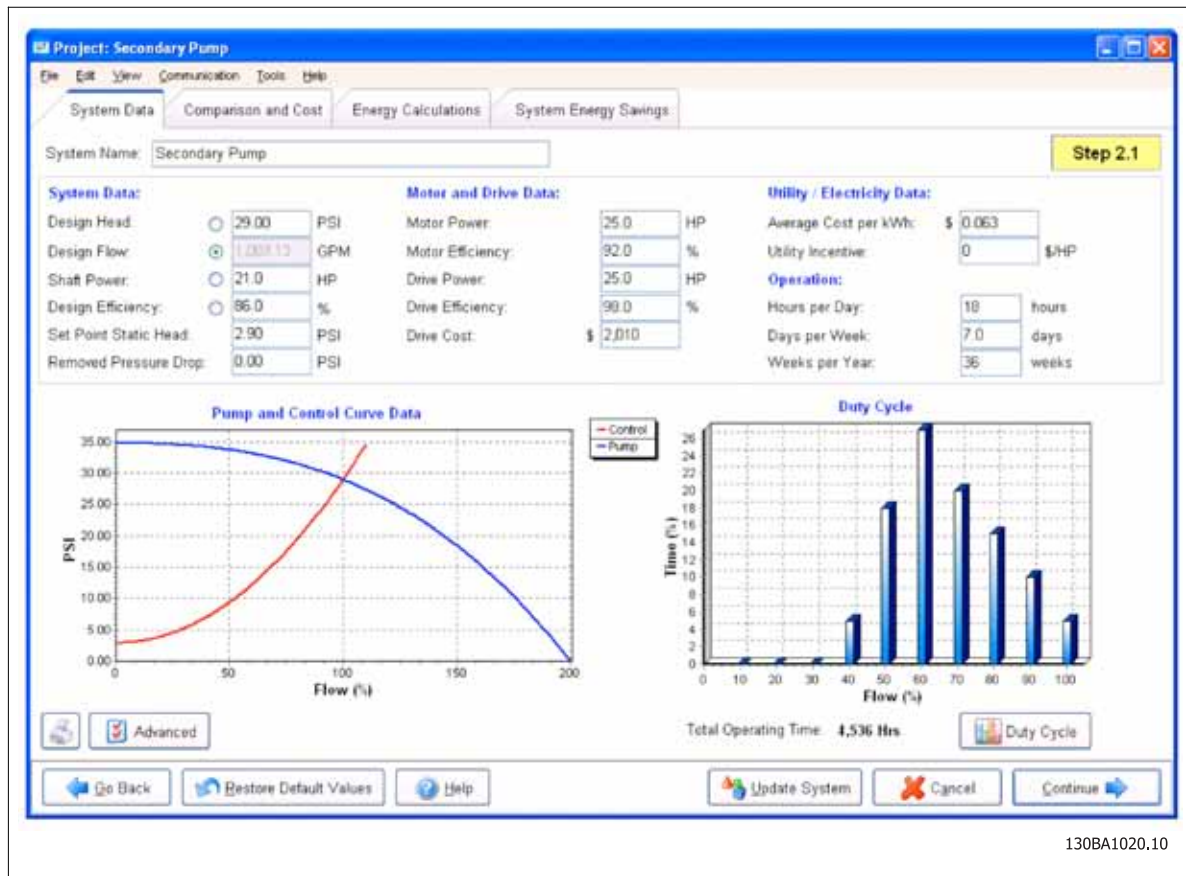


Illustration 7.5: Energy Box Input Data

7

The illustration below shows annual energy consumption for a secondary pump with throttling valve compared to a variable speed secondary pump with the Danfoss Drive System. Significant energy savings are achieved by using a VLT® HVAC Drive with a primary/secondary system.

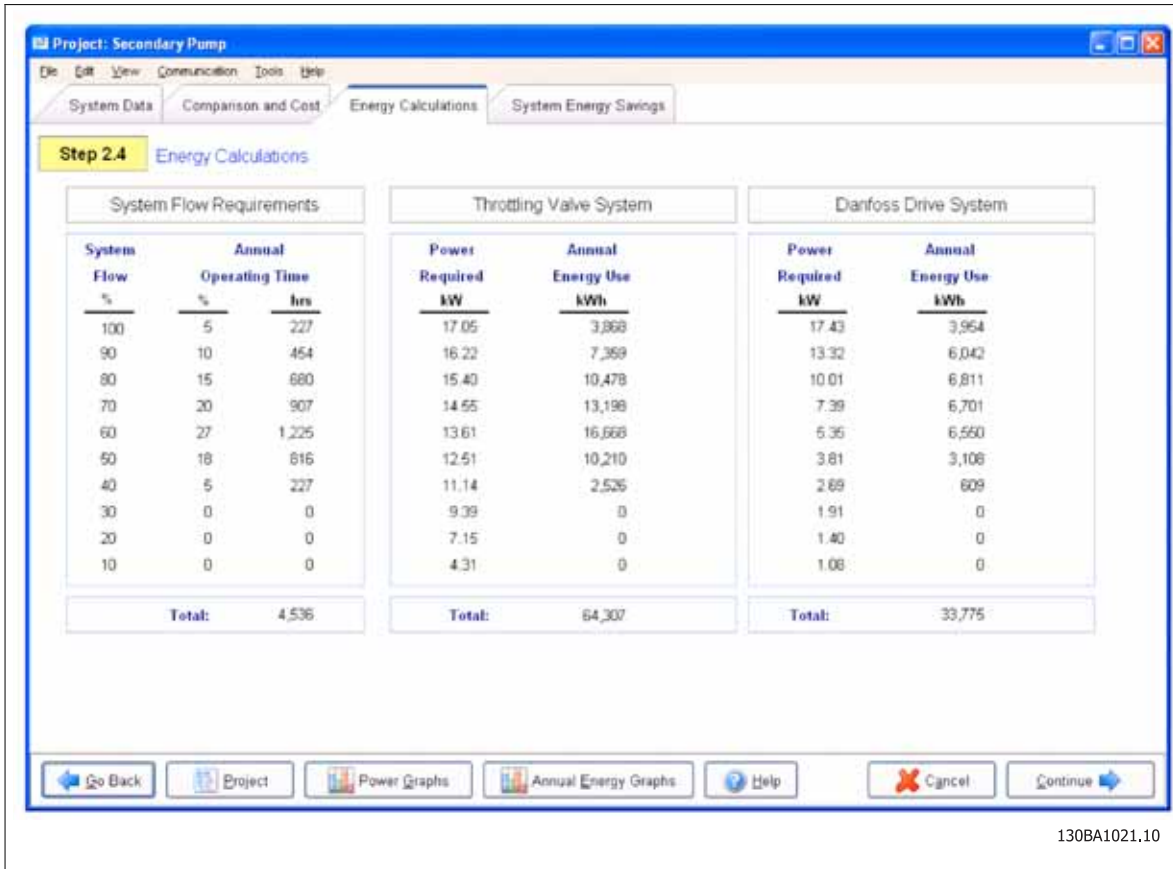
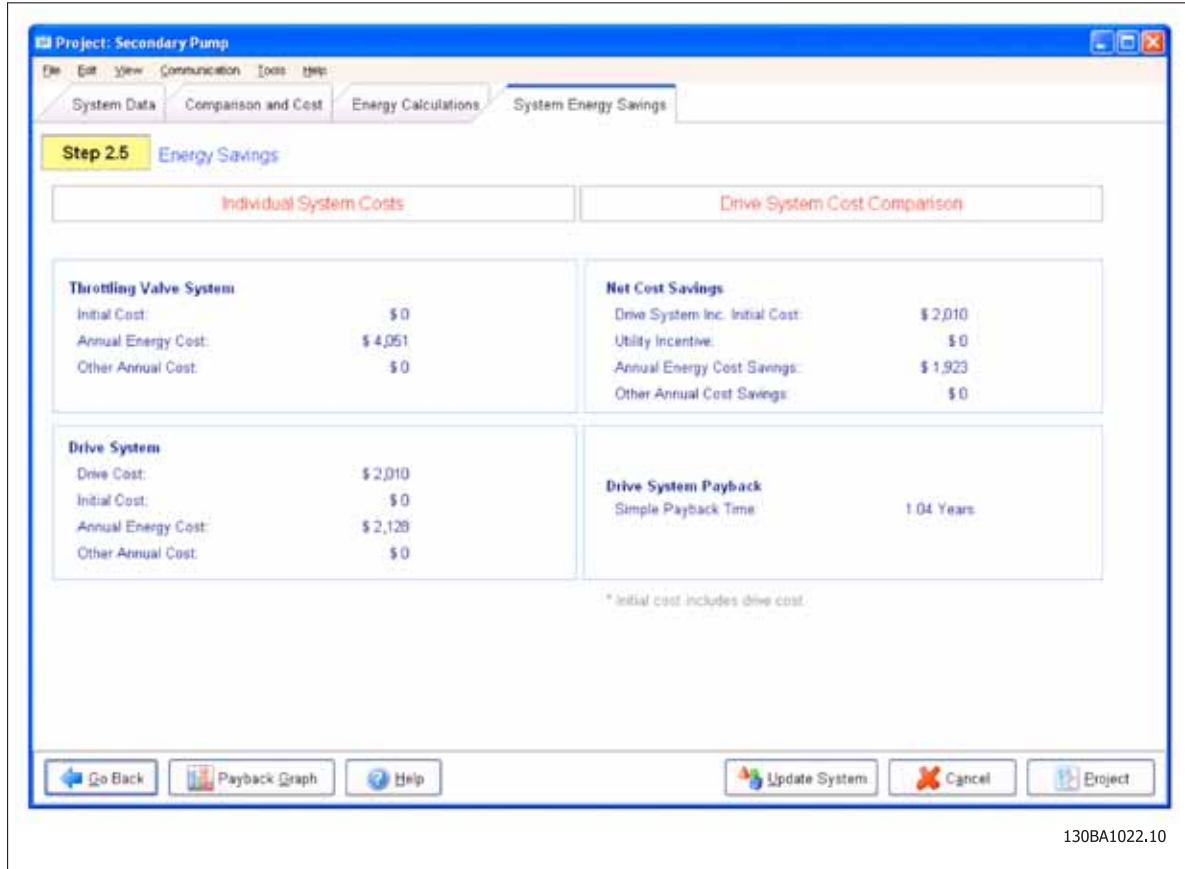


Illustration 7.6: Annual Energy Consumption

The program also calculates the simple payback period for the variable frequency drive including cost data for the drive, installation, wiring and other control components such as sensors. The illustration below shows a payback of 1.04 years to use a VLT® HVAC Drive for a secondary pump in a primary/secondary system. The Energy Box Analysis and report can be printed, faxed or emailed.



Individual System Costs		Drive System Cost Comparison	
Throttling Valve System			
Initial Cost:	\$ 0	Net Cost Savings	
Annual Energy Cost:	\$ 4,051	Drive System Inc. Initial Cost:	\$ 2,010
Other Annual Cost:	\$ 0	Utility Incentive:	\$ 0
		Annual Energy Cost Savings:	\$ 1,923
		Other Annual Cost Savings:	\$ 0
Drive System			
Drive Cost:	\$ 2,010	Drive System Payback	
Initial Cost:	\$ 0	Simple Payback Time:	1.04 Years
Annual Energy Cost:	\$ 2,128		
Other Annual Cost:	\$ 0		

* Initial cost includes drive cost.

Illustration 7.7: Energy Box Financial Calculation

7.5 Drive Features

The Danfoss VLT® HVAC Drive is designed with features tailored for the unique control requirements of HVAC systems including Primary/Secondary water systems. The following software features are incorporated, as standard, as the most effective means of controlling secondary loop pumps for maximum system efficiency, reliability and increased energy and cost savings.

7.5.1 Multi-zone control

The variable frequency drive accommodates up to three feedback signals for three different sensors. This allows regulating a system with multiple sensors when the most significant distant load is not known. The variable frequency drive makes control decisions by comparing the signals to optimize system performance.

In some installations, there are major differences in system variable head losses from one location to another, or the set-points can be significantly different, such as different size cooling coils. In controlling dissimilar loads, it is possible to place a differential pressure transmitter in up to three parallel piping runs and control to the "worst case" condition.

7.5.2 PID auto-tuning

The variable frequency drive PID controllers can be auto-tuned, simplifying the commissioning process and ensuring accurate control adjustment. During steady state operation, Auto-tuning introduces a step change in the output of the PID controller and the feedback signal is monitored. From the feedback response, the optimum values for PID control are calculated. In normal HVAC applications, only the Proportional Gain and Integral Time are calculated.

7.5.3 No-flow

This feature is useful for detecting conditions where a pump is producing no-flow but is running. A no-flow condition can cause pump damage if not detected and corrected. No-Flow detection does not require the use of external differential pressure switches or flow meters and associated wiring.

No-flow Detection is based on the measurement of power at specific motor speeds. The variable frequency drive monitors actual power and motor frequency and compares these with the calculated power at specific speeds. If the power measured at a specific frequency is greater than the calculated power stored in the drive, the pump is producing flow. If the power measured at a specific frequency is less than the calculated power stored in the drive, a warning or alarm is generated to notify the operator of the condition.

7.5.4 Dry pump

7

This feature is useful for detecting a condition when the pump is running but no water is in the system. A dry pump condition can cause pump damage if not detected and corrected. Dry pump detection does not require the use of external differential pressure switches or flow meters and associated wiring.

If there is no water in the system, the pump will not produce pressure. The variable frequency drive will go to maximum speed to try to produce pressure. Because there is no water, the load on the motor will be low and power consumption will be low. If the variable frequency drive is running at the maximum speed and the system power consumption is low, a warning or alarm is generated to notify the operator of the condition.

7.5.5 End of curve

This feature is used to detect leakage in a pipe system or the loss of pressure in the system. End of Curve detection does not require the use of external pressure sensors or flow meters and associated wiring.

End of curve occurs if a pump is delivering a large volume of water but cannot maintain the set static head. When there is a water leak in the pipe system, the pump will not produce full pressure. The variable frequency drive speed increases to maximum speed to attempt to produce the full pressure. If the variable frequency drive is running at the maximum speed and the system pressure is low, a warning or alarm is generated to notify the operator of the condition.

7.5.6 Energy log and trending

The variable frequency drive continuously accumulates the consumption of the actual power from the variable frequency drive to the motor. Data can be used in an Energy Log function allowing the user to analyze the energy consumption related to time. Data can be accumulated in two ways: a preset date and time for start and stop or a predefined time period (such as the last 24 hours, seven days or month).

Trending is used to monitor how the variable changed over a period of time. The value of the trended variable is recorded in one of ten user-defined bins (data ranges). Common trending variables for secondary pump applications are motor power and output frequency.

The trending feature makes it possible to determine how much variation in flow or power for the secondary pump occurs in the system operation. Using this trending data with VLT® Energy Box software determines the actual savings obtained for control of secondary pump systems with the VLT® HVAC Drive.

7.5.7 Serial communications

The VLT® HVAC Drive offers communication capabilities that are unmatched in variable frequency drives, reducing or eliminating the need for external devices.

Built-in serial communications options include: BACnet™, Modbus RTU, Johnson Controls Metasys® N2, and Siemens Apogee® FLN. Enhanced BACnet™ and LonWorks® are available as field-installed option cards that mount easily inside the VLT® HVAC Drive. Consult Danfoss for other serial communications options.

8 Variable Pumping Systems

8.1 Introduction

There is an increased interest in chilled water systems with variable primary flow. These systems use fewer pumps and piping connections than primary/secondary systems, which results in a smaller mechanical equipment room. Some of the initial cost savings for pumps, piping and reduced electrical wiring is partially offset by additional costs for flow metering and bypass flow valve control.

A variable primary flow system eliminates the small primary pumps used in primary/secondary systems. The pressure drops previously satisfied by the primary pumps are satisfied by the larger, more efficient distribution pumps, similar to secondary pumps in a primary/secondary system.

8.2 Variable Speed Pump

8.2.1 Variable primary flow loop control

With newer chillers, manufacturers specify maximum and minimum limits for evaporator water flow. The maximum limit avoids tube erosion. The minimum limit ensures good heat transfer and stable control.

The variable primary flow system in the illustration below uses the variable flow pumps to circulate water through the chilled water loop to meet the building load requirements. A de-coupler, used in primary/secondary systems, is replaced by a bypass line with a modulating flow valve. As long as the flow is above the minimum required by the chiller, the bypass line remains closed and the flow through the chiller varies with the building requirement. When the minimum chiller flow is reached, the bypass control valve is modulated so that the minimum flow required by the chiller manufacturer is maintained.

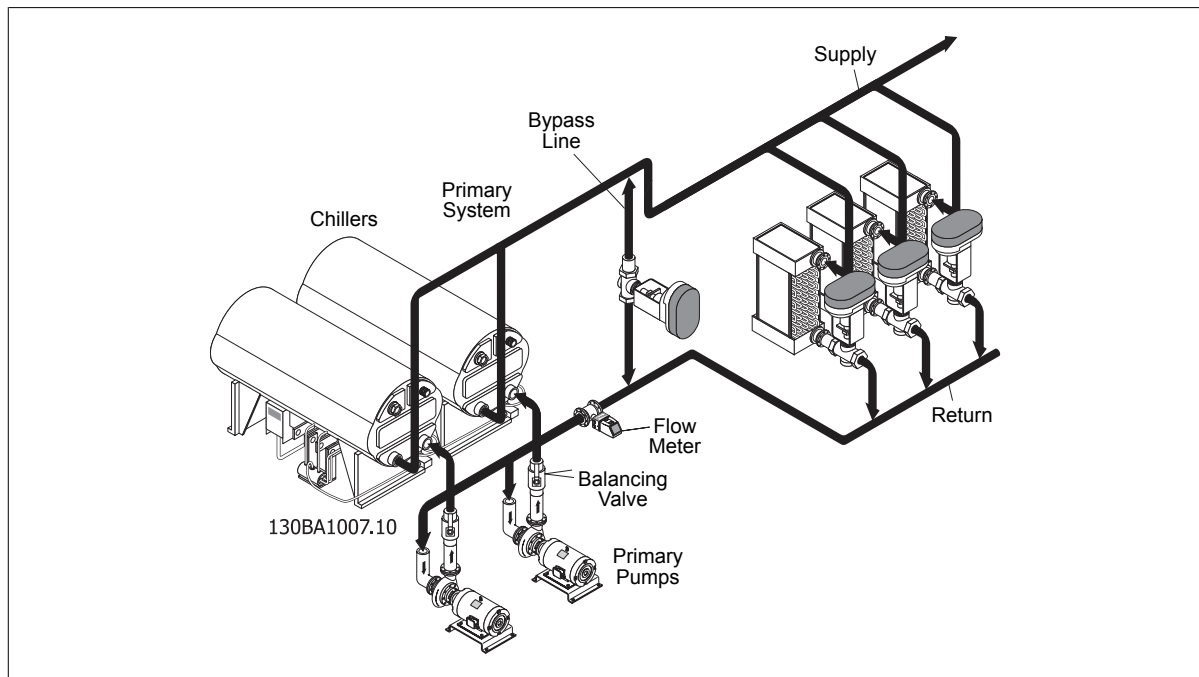


Illustration 8.1: Variable Primary Flow System

The bypass should be located near the pumps to minimize flow and pressure drop through the distribution system and reduce pump energy requirements. Delivering the appropriate bypass flow requires proper line sizing and control valve selection. When there is a low demand for chilled water by coils, the system flow rate may be below the minimum flow rate required by the chillers. This is sensed by a flow meter. A PI controller then modulates the bypass control valve as required to maintain minimum chiller flow. Instead of a flow meter, differential pressure across the chillers can be measured and correlated to flow based on the chiller flow versus pressure drop-data provided by the chiller manufacturer.

The success of a variable primary flow system depends on the quality of the flow-measuring device that controls the bypass valve. If a flow meter is used, a magnetic flow meter should be used. While more expensive than other meter types, they are extremely accurate, less susceptible to error and nearly maintenance free. For a differential pressure sensor, the range should closely match the pressure drop across the chiller evaporator section.

8.2.2 Variable speed pump control

Like a secondary pump in a primary/secondary system, the pumps in a variable primary flow system maintain a differential pressure at a specific point in the system. In the illustration below this point is the pressure drop across the most significant distant load. The pressure difference is the coil, piping and control valve pressure drop at design flow.

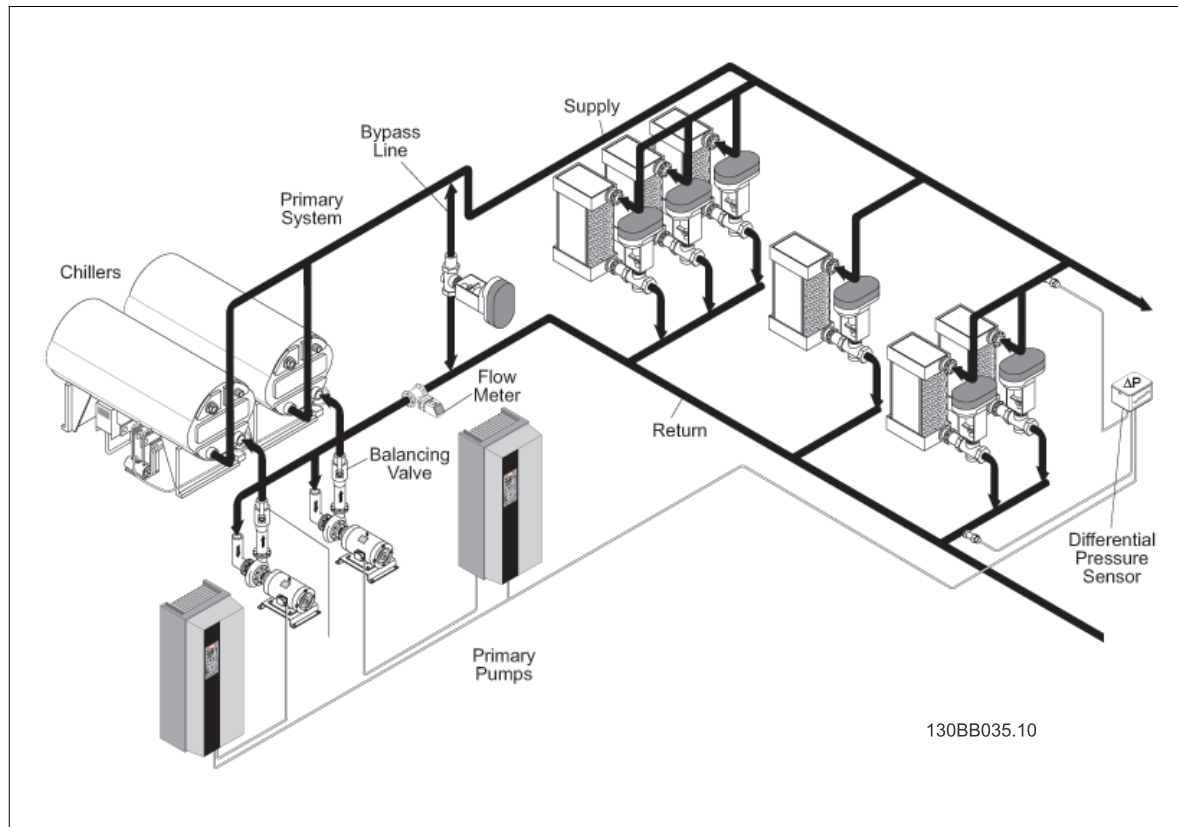


Illustration 8.2: Variable Primary Flow System with variable frequency drives

When less flow is required, the differential pressure sensor (DP) adjusts the speed of pump variable frequency drive. As the cooling loads are satisfied, the two-way control valves move toward the closed position. This increases the differential pressure measured across the cooling coil and valve. As this differential pressure starts to rise, the variable frequency drive slows the pump to maintain the DP set-point value.

Although the same cooling coil differential head is maintained across the individual air handling unit coils and valves, the overall system pressure and control valve DP is reduced. In the illustration next page, the control curve shows the actual operation points of the pump with variable speed control. The set-point is the amount of pressure that must be maintained to satisfy system requirements. The control curve represents the required primary pump discharge pressure to maintain the set-point, at the load, as the friction loss in the piping decreases with flow. The lower the set-point, the greater the potential savings as shown below.

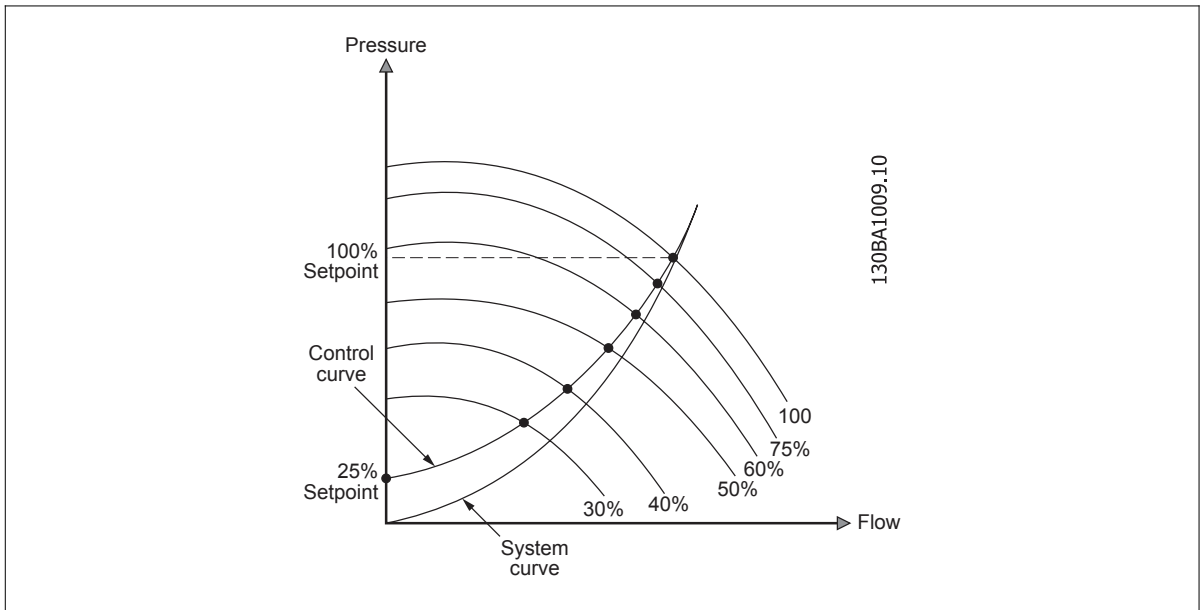


Illustration 8.3: Variable Speed Pump Curves

8.3 Sensors

8.3.1 Sensor type and placement

While the energy savings of a properly installed variable frequency drive is significant, the importance of pressure sensor type and location is critical for proper control of the pump and to achieve the most energy savings.

For variable primary flow pumping systems, a differential pressure sensor should be used. It is important for the sensor to measure the furthest, most significant load. This allows the variable frequency drive PID controller to take advantage of the decreased resistance of the piping network, known as the variable head loss, as flow is reduced. With this sensor placement, the set-point requirement is the static pressure drop across the cooling coil and two-way control valve. If this value is not known, an estimate of 25% of design static head is sometimes used.

Some installations have incorrectly located the differential pressure sensor in the supply and return headers at the pump, usually to reduce installation costs. Illustrations below show the significant impact that sensor placement has on energy savings. The table below shows the sensor located across the pump supply and return headers. The set-point (reference) is the design static head. The power reduction is shown as the slight motor speed savings from maintaining a constant design static head.

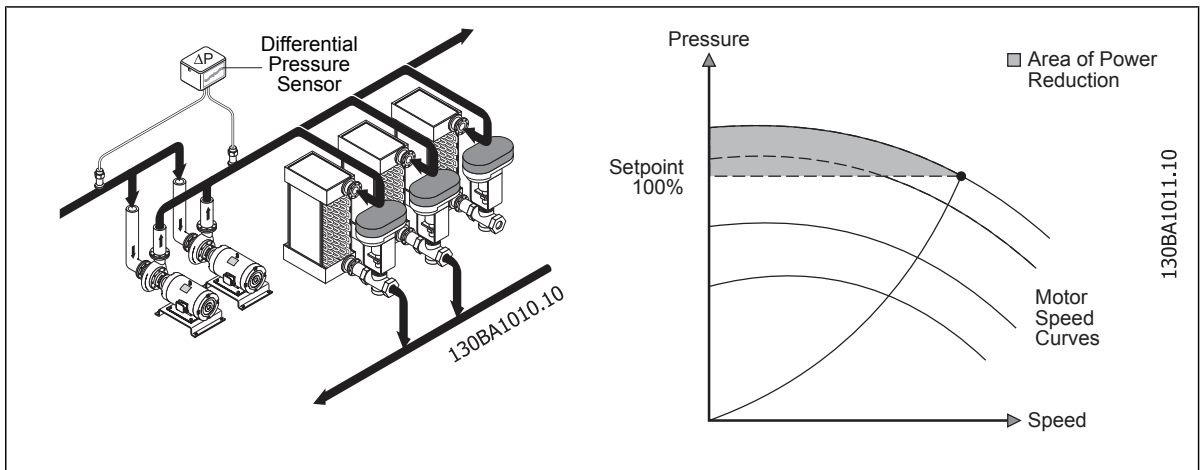


Table 8.1: Sensor Location with 100% Set-point (Across Pump)

The table below shows the differential pressure located correctly across the furthest significant load with a set-point (reference) of 25% of design static head. The power reduction is shown as the motor speed savings from following the control curve.

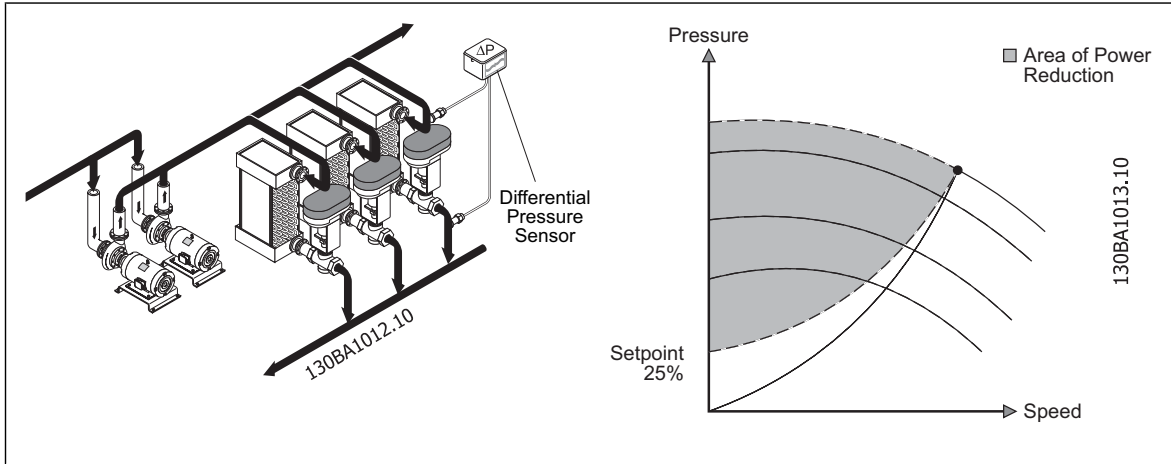


Table 8.2: Sensor Location with 25% Set-point (Across Load)

8.4 Energy Savings Potential

8.4.1 Energy Savings Estimation

Savings from installing a VLT® HVAC Drive compared to the other methods of pump volume control can be estimated using the Danfoss VLT® Energy Box software. The program compares energy consumption for a primary pump running at full speed to the pump running at variable speed using the VLT® HVAC Drive and provides a simple payback calculation.

A minimum of design data to plot the pump and system curve is required. If a balancing valve is partially close, the pressure drop it imposes on the system is included in the data. System operating hours are also entered.

To calculate the potential savings, a duty cycle or load profile is entered. The program has a default profile that can easily be changed. The duty cycle indicates the amount of flow the system requires to satisfy the building load. Duty cycles vary depending on the specific building and system operation.

Typical input data is shown in the illustration below. After the pump and system data is entered, the program calculates the estimated energy consumption for the VLT® HVAC Drive and the comparison system.

Project: Primary Pump 6x8x9

System Name: Primary Pump 6x8x9 Step 2.1

System Data:		Motor and Drive Data:		Utility / Electricity Data:	
Design Head:	29.00 PSI	Motor Power:	25.0 HP	Average Cost per kWh:	\$ 0.063
Design Flow:	1,064.04 GPM	Motor Efficiency:	92.0 %	Utility Incentive:	0 \$/HP
Shaft Power:	20.9 HP	Drive Power:	25.0 HP	Operation:	
Design Efficiency:	86.0 %	Drive Efficiency:	98.0 %	Hours per Day:	18 hours
Set Point Static Head:	2.90 PSI	Drive Cost:	\$ 2,010	Days per Week:	7.0 days
Removed Pressure Drop:	0.00 PSI			Weeks per Year:	45 weeks

Pump and Control Curve Data

The graph shows Pressure (PSI) on the y-axis (0 to 35) and Flow (%) on the x-axis (0 to 200). A blue curve represents the Pump head, and a red curve represents the Control head. They intersect at approximately 110% flow and 28 PSI.

Duty Cycle

The bar chart shows Time (%) on the y-axis (0 to 26) and Flow (%) on the x-axis (0 to 100). The bars represent the percentage of time the pump operates at various flow rates. The highest operating time is at 60% flow, reaching approximately 26%.

Total Operating Time: 5,670 Hrs

Buttons: Go Back, Restore Default Values, Help, Update System, Cancel, Continue

130BA1014.10

Illustration 8.4: Energy Box Input Data

The illustration below shows annual energy consumption for a primary pump with throttling valve compared to a variable primary flow pump with the Danfoss Drive System. Significant energy savings are achieved by using a VLT® HVAC Drive with a Variable Primary Flow system.

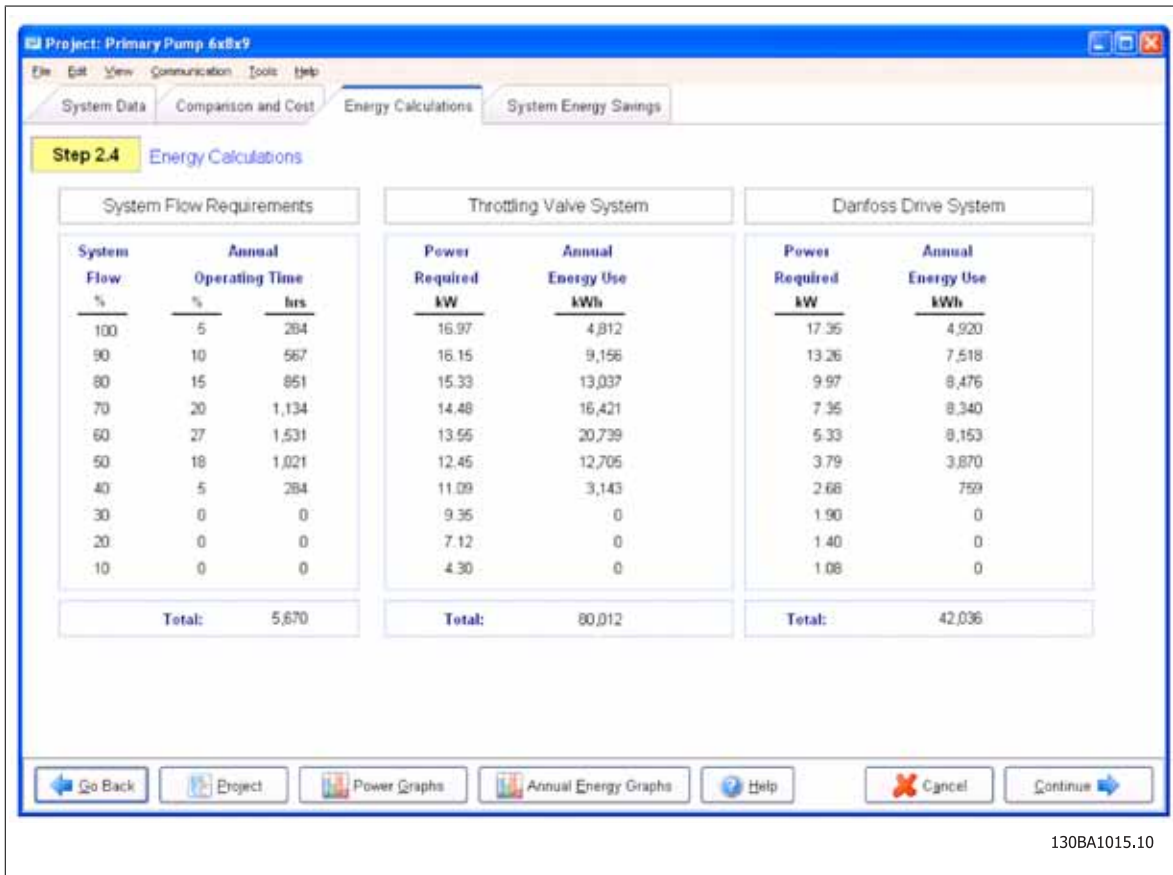


Illustration 8.5: Annual Energy Consumption

The program also calculates the simple payback period for the variable frequency drive including cost data for the drive, installation, wiring and other control components such as sensors. The illustration below shows a payback of 0.84 years to use a VLT® HVAC Drive with a Variable Primary Flow system. The Energy Box Analysis and report can be printed, faxed or emailed

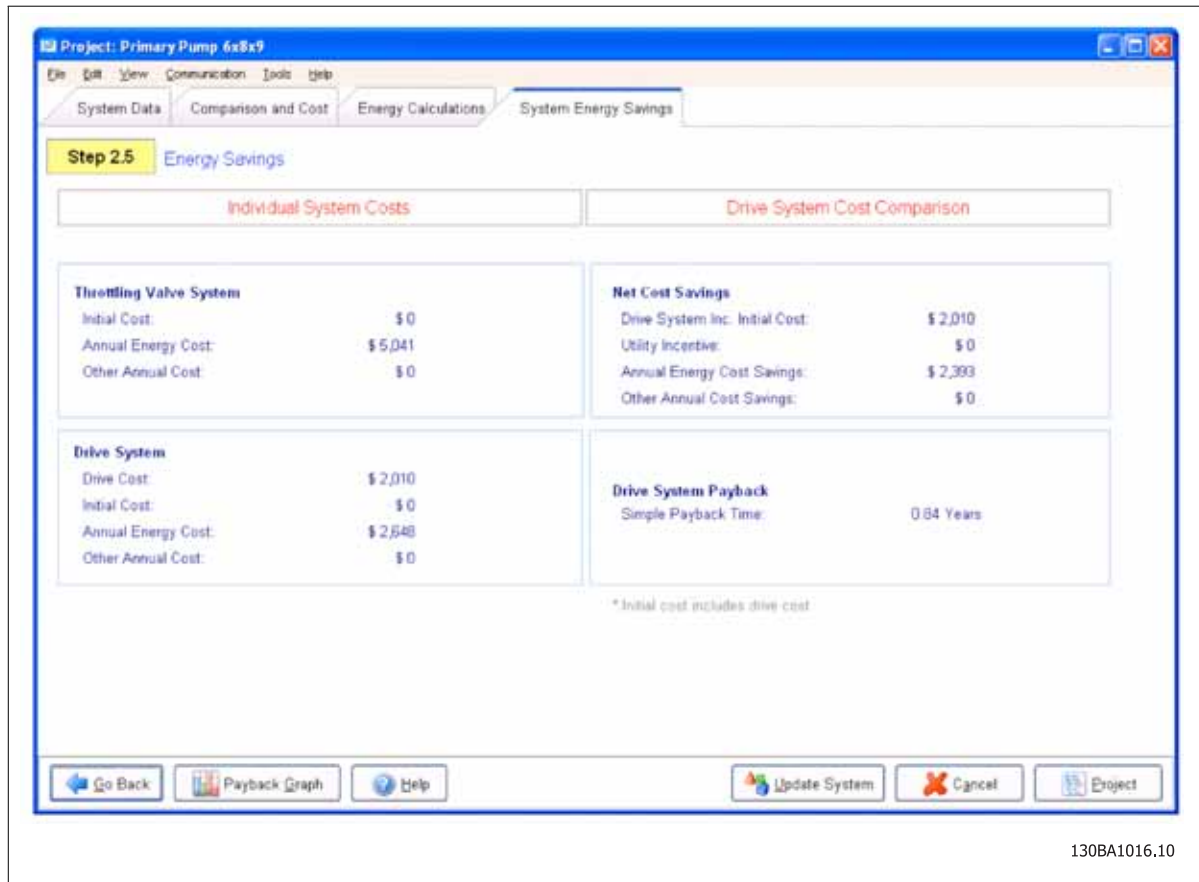


Illustration 8.6: Energy Box Financial Calculation

8.5 Drive features

The Danfoss VLT® HVAC Drive is designed with features tailored for the unique control requirements of HVAC systems including Variable Primary Flow systems. The following software features are incorporated, as standard, to optimize performance.

8.5.1 HVAC intelligent control

The VLT® HVAC Drive includes as standard a PID controller, two voltage or current analog inputs and one programmable analog output. This built-in combination of flexible I/O features and PID control result in the capability to fully implement variable primary flow control without the need for additional control components.

A differential pressure sensor is connected to the variable frequency drive to provide primary pump control based on the flow at the most distant load in the system. A flow meter or second differential pressure sensor is connected to the variable frequency drive and the internal PID controller modulates the bypass line control valve to maintain minimum flow through the chillers.

8.5.2 PID auto-tuning

The variable frequency drive PID controllers can be auto-tuned, simplifying the commissioning process and ensuring accurate control adjustment. During steady state operation, Auto-tuning introduces a step change in the output of the PID controller and the feedback signal is monitored. From the feedback response, the optimum values for PID control are calculated. In normal HVAC applications only the proportional gain and integral time are calculated.

8.5.3 No-flow

This feature is useful for detecting conditions where a pump is producing no-flow but is running. A no-flow condition can cause pump damage if not detected and corrected. No-Flow detection does not require the use of external differential pressure switches or flow meters and associated wiring.

No-flow Detection is based on the measurement of power at specific motor speeds. The variable frequency drive monitors actual power and motor frequency and compares these with the calculated power at specific speeds. If the power measured at a specific frequency is greater than the calculated power stored in the drive, the pump is producing flow. If the power measured at a specific frequency is less than the calculated power stored in the drive, a warning or alarm is generated to notify the operator of the condition.

8.5.4 Dry pump

This feature is useful for detecting a condition when the pump is running but no water is in the system. A dry pump condition can cause pump damage if not detected and corrected. Dry pump detection does not require the use of external differential pressure switches or flow meters and associated wiring.

If there is no water in the system, the pump will not produce pressure. The variable frequency drive will go to maximum speed to try to produce pressure. Because there is no water, the load on the motor will be low and power consumption will be low. If the variable frequency drive is running at the maximum speed and the system power consumption is low, a warning or alarm is generated to notify the operator of the condition.

8.5.5 End of curve

This feature is used to detect leakage in a pipe system or the loss of pressure in the system. End of Curve detection does not require the use of external pressure sensors or flow meters and associated wiring.

End of curve occurs if a pump is delivering a large volume of water but cannot maintain the set static head. When there is a water leak in the pipe system, the pump will not produce full pressure. The variable frequency drive speed increases to maximum speed to attempt to produce the full pressure. If the variable frequency drive is running at the maximum speed and the system pressure is low, a warning or alarm is generated to notify the operator of the condition.

8.5.6 Energy log and trending

The variable frequency drive continuously accumulates the consumption of the actual power from the variable frequency drive to the motor. Data can be used in an Energy Log function allowing the user to analyze the energy consumption related to time. Data can be accumulated in two ways: a preset date and time for start and stop or a predefined time period (such as the last 24 hours, seven days or month).

Trending is used to monitor how the variable changed over a period of time. The value of the trended variable is recorded in one of ten user-defined bins (data ranges). Common trending variables for variable flow applications are motor power and output frequency.

The trending feature makes it possible to determine how much variation in flow or power occurs in the variable primary flow system operation. Using this trending data with VLT® Energy Box software determines the actual savings obtained for control of variable primary flow systems with the VLT® HVAC Drive.

8.5.7 Serial communications

The VLT® HVAC Drive offers communication capabilities that are unmatched in variable frequency drives, reducing or eliminating the need for external devices.

Built-in serial communications options include: BACnet™, Modbus RTU, Johnson Controls Metasys® N2, and Siemens Apogee® FLN. Enhanced BACnet™ and LonWorks® are available as field-installed option cards that mount easily inside the VLT® HVAC Drive. Consult Danfoss for other serial communications options.

9 Booster Pumping Systems

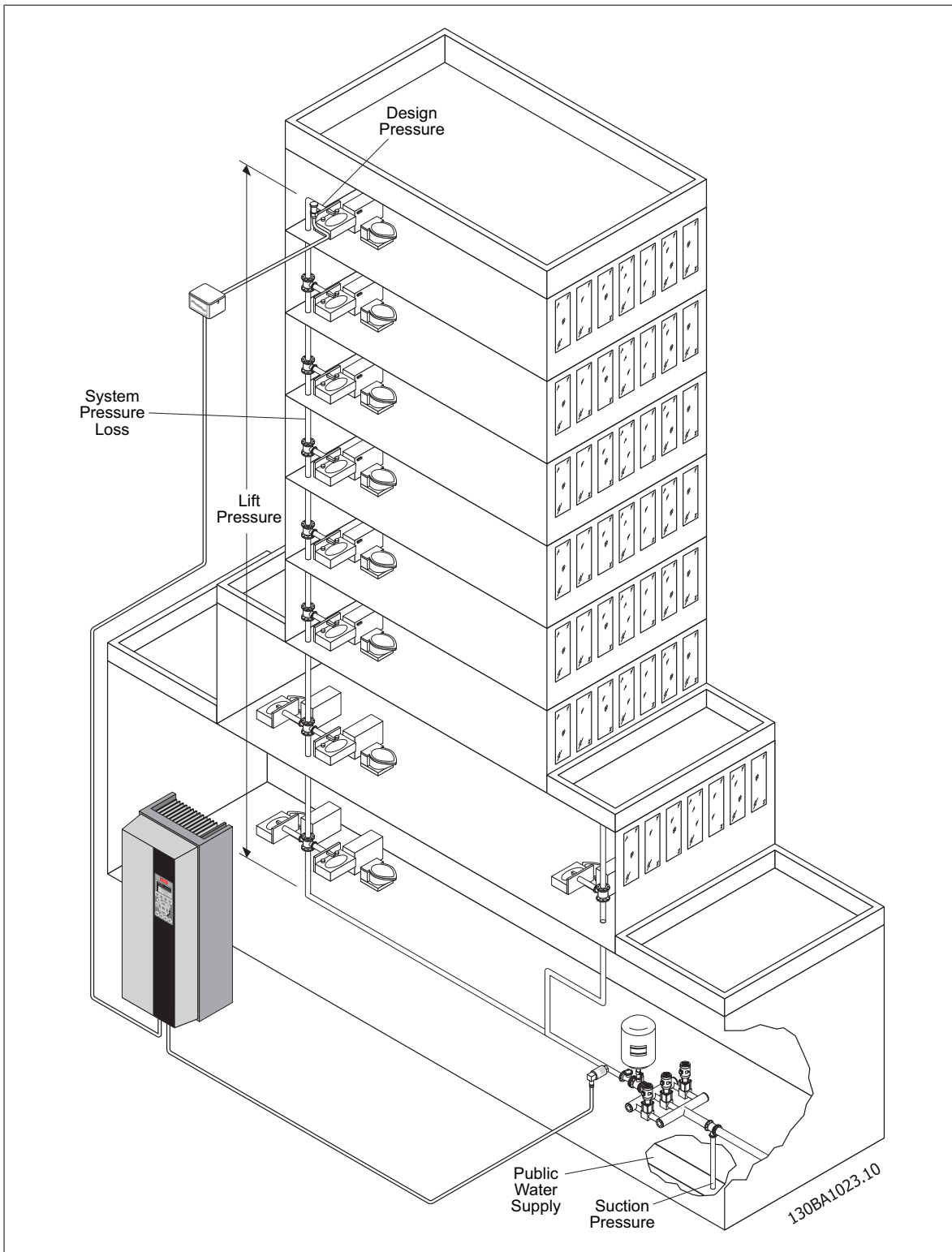
9.1 Pressure Booster Pumping Systems

9.1.1 Introduction

Pressure booster pumping systems are installed in commercial buildings to maintain a constant pressure in the domestic water supply. A typical multi-storey commercial office building, hotel, hospital or other high rise building requires constant pressure for drinking water, lavatories, sinks or other water fixtures to operate properly.

Domestic water pressure boosting packaged systems have been developed to meet the varying demands of buildings. Typically these have been oversized to meet peak building demands. Varying flow rates occur throughout the day in buildings. For example mornings in a hotel would result in a peak flow usage as many people get ready for work or conferences at the same time. During the evening this building could have a minimum flow usage while most people are sleeping. The flow rate that fixtures in the entire building are using would vary greatly but each fixture would require a constant pressure for proper operation.

In high rise buildings, every floor translates into a pressure loss from the city or municipal water supply. Friction and fitting losses, design operating pressure and suction pressure are also a factor in system design. The illustration next page shows a typical booster pump installation in a building.



9

Illustration 9.1: Typical Building Pressure Booster System

A booster pump system is sized to overcome the Total Pressure (P_{Total}) at a given flow rate. This pressure is determined as follows:

$$P_{Total} = P_{Design} + P_{Lift} + P_{System} - P_{Suction}$$

P_{Design} is the pressure required at the highest point in the system

P_{Lift} is the vertical distance from the pump to the highest point in the system

P_{System} are the system piping and fittings pressure losses at full flow

$P_{Suction}$ is the pump suction pressure

9.2 Booster Pump Control

9.2.1 Constant speed booster pump control

Modern booster pump systems are factory assembled packages and include multiple pumps, pressure reducing valve, pressure sensor, control panel and all required piping fittings to connect the package to supply and return headers. A storage tank is usually an option that can be mounted next to the packaged system. A typical system is shown in the illustration below.

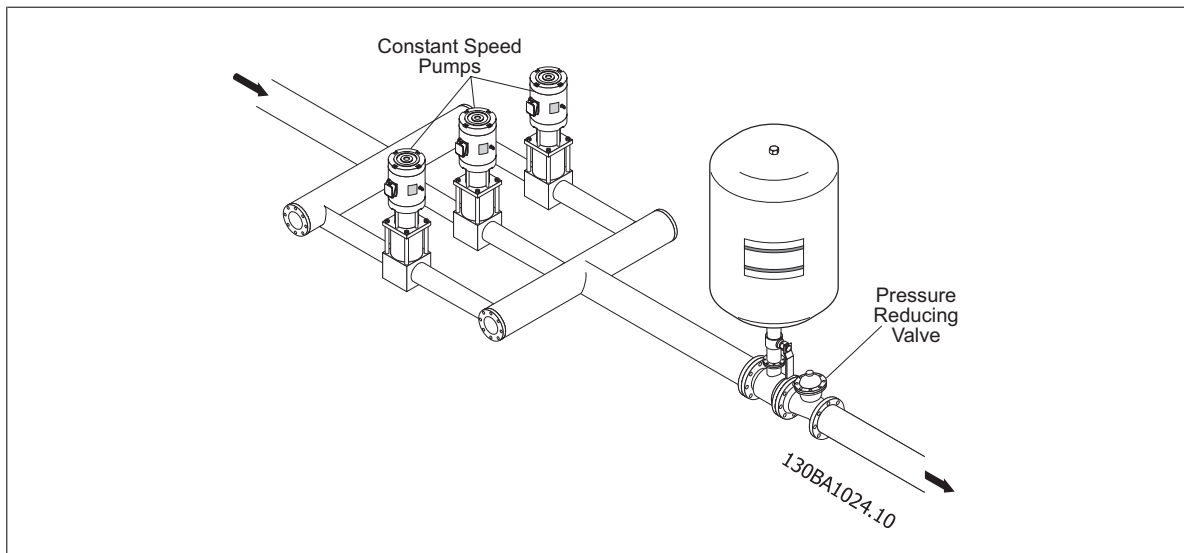


Illustration 9.2: Pressure Booster System

Delivering design water pressure to the building ensures that the system will satisfy the building demand, regardless of load. A constant speed pressure booster system utilizes centrifugal pumps with a pressure reducing valve (PRV) on the discharge to maintain constant supply water pressure to the system.

The PRV is used as a means of pressure control by modulating open and closed to maintain a constant discharge pressure. Because proper pressure must be maintained in the system, the control curve is basically a flat line. The illustration next page shows a typical control curve for a constant speed pump using a PRV. The control curve consists of two components first is the variable pressure loss through the pump, piping and fittings. The second component is the pressure drop across the PRV. At lower flows the PRV absorbs the excess head produced by the pump as the control curve rides back and forth on the pump curve. This absorbed head represents wasted pump energy.

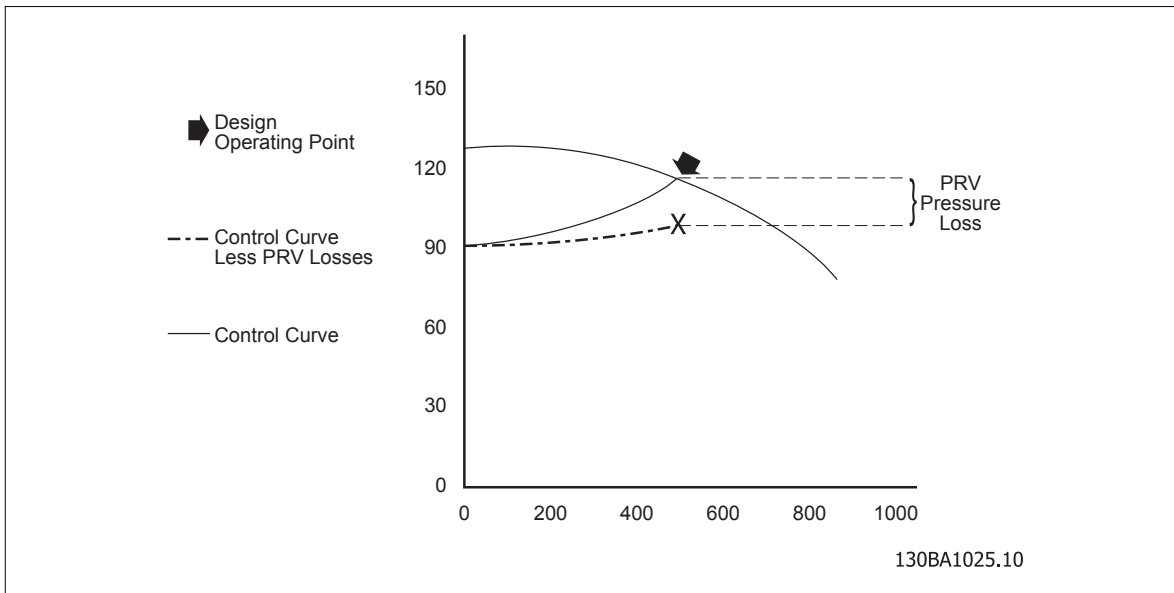


Illustration 9.3: Constant Speed Control Curves

9.2.2 Variable speed booster pump control

9

Variable Speed Pressure booster systems offer several benefits which make installing a variable frequency drive economical. Savings and benefits occur by using a lower control pressure set-point from elimination of the pressure drop associated with the system flow losses. Savings also occur using a variable frequency drive from three additional factors: pump over-sizing, PRV head losses and changing suction pressure.

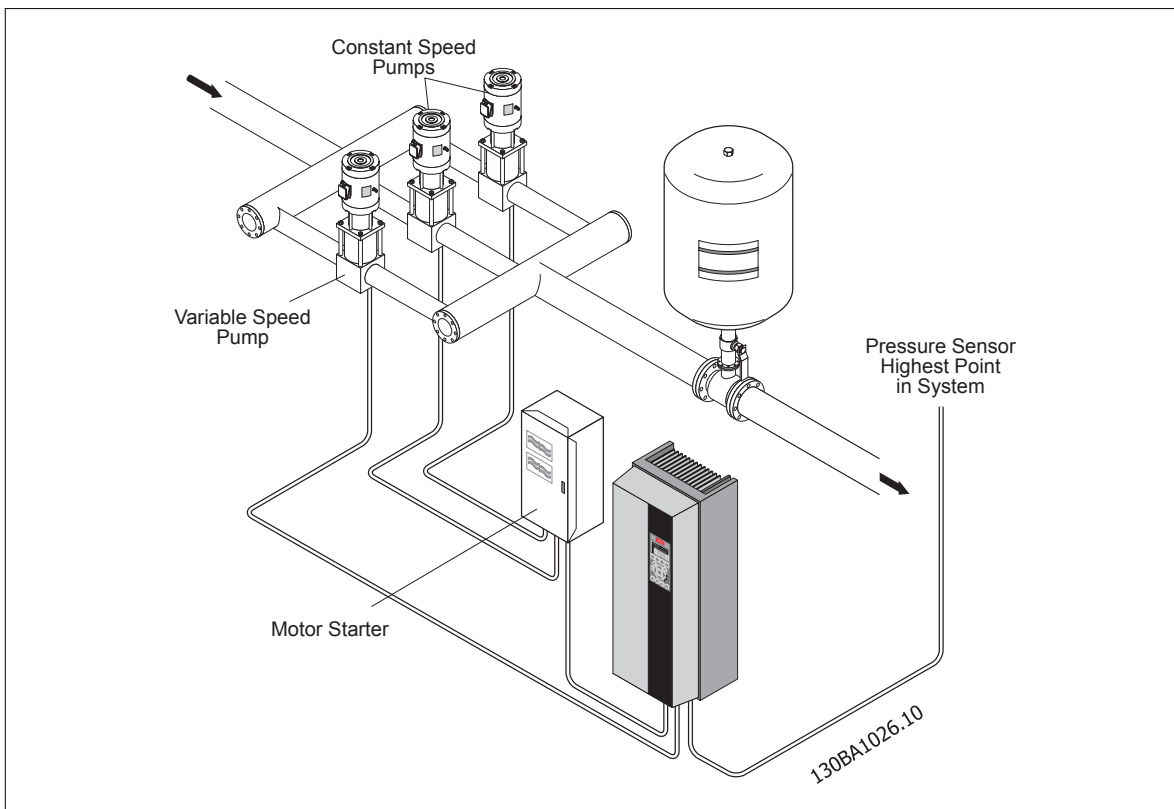


Illustration 9.4: Standard Cascade Controller

A pressure transducer located at the highest point in the system sends a signal to the variable frequency drive to regulate the speed of the controlled pump and to stage the additional constant speed pumps on and off. The illustration above shows the control of the system with the sensor located at the highest point in the system (the most significant distant load). The control curve set-point is only the static height (P_{Lift}) of the building and the design pressure (P_{Design}). The system flow losses through the building piping system (P_{System}) are not included.

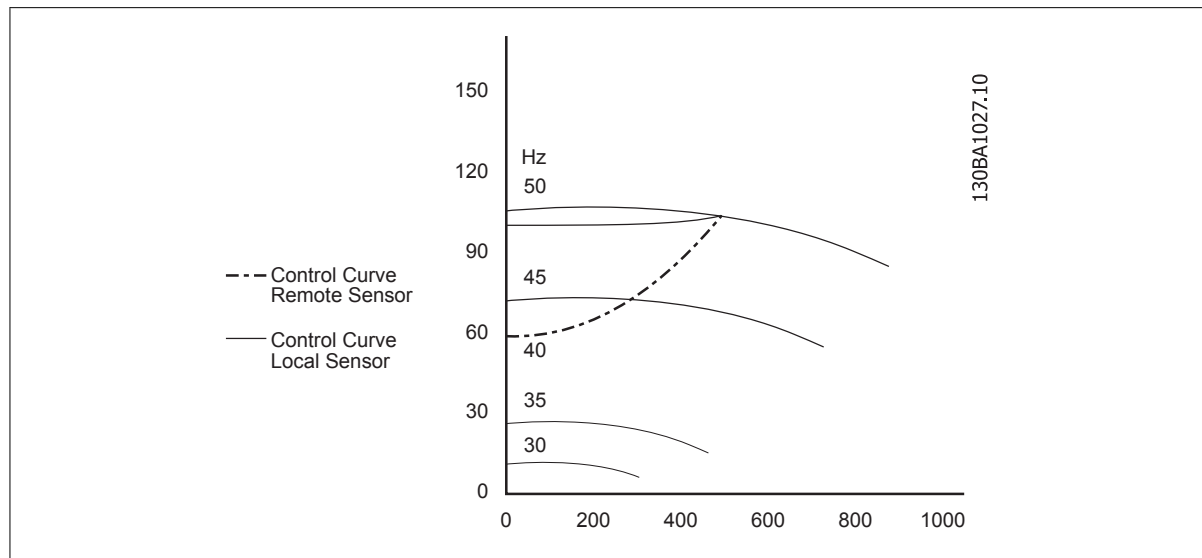


Illustration 9.5: Variable Speed Control Curve

9.3 Selection

9.3.1 Pump oversizing

Pump over-sizing occurs because system loads are calculated using a conservative estimate of how many plumbing fixtures will be in operation simultaneously. In addition, other loads which do not always occur, such as kitchens or laundries are included in the maximum total system flow as well as a safety factor to guarantee that the pump is not undersized.

A variable frequency drive produces only enough flow to satisfy the system requirements. Energy is saved by not producing excess capacity.

9.3.2 Pressure reducing valve - PRV

A PRV is used with a constant speed pump to protect against over-pressurizing the water booster system. The PRV absorbs excess pressure produced by the pump. The problem is that the absorbed PRV loss is an energy loss. A variable frequency drive tracks the control curve and lower head pressure and flow rates are the result of slowing the pump.

9.3.3 Changing suction pressure

When selecting a pressure booster pump, the lowest suction pressure that will ever supply the pump is used for pump sizing. This ensures the pump will be large enough to satisfy system requirements when the suction pressure is at its lowest value. Actual suction pressure will probably be higher than its design minimum. When the suction pressure is higher than the design minimum a variable frequency drive decreases speed and only operates at the required load.

9.4 Sensors

9.4.1 Sensor type and placement

While the energy savings of a properly installed variable frequency drive is significant, the importance of pressure sensor type and sensor location is critical for proper control of the pump and to achieve the most energy savings.

Some installations locate the pressure sensor near the pump discharge, usually to reduce installation costs as shown in Constant Speed Control Curves (chapter 9.2.1). The illustration next page shows the significant impact that local sensor placement has on energy savings. The set-point of the frequency controller is the total pressure head because the local pressure sensor cannot give an indication of the variable system pressure losses. The slight rise shown of the control curve is due to the variable system loss in the piping, valves and fittings between the pump and pressure sensor. The variable frequency drive provides only a small reduction in pump speed, which can occur with a flat control curve.

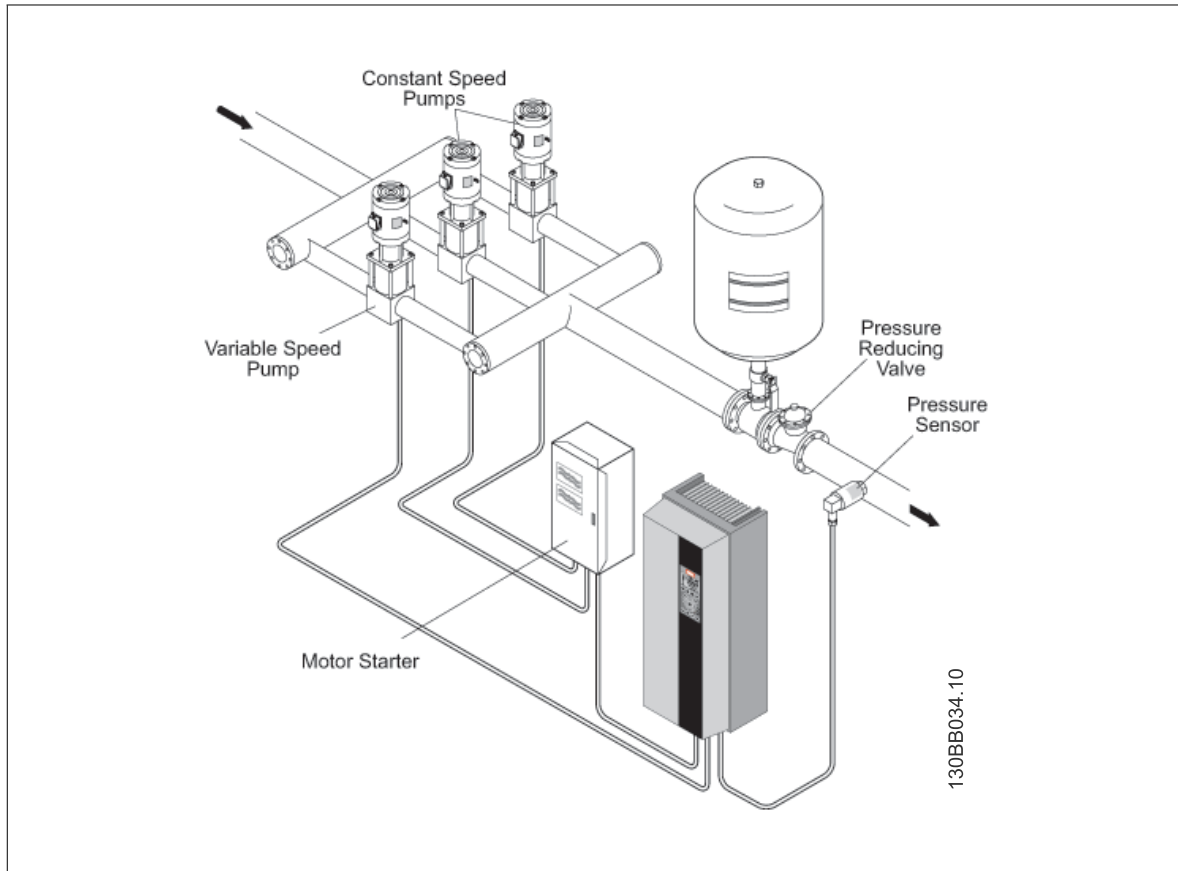


Illustration 9.6: Local sensor placement

By placing the sensor at the highest point in the system (see Standard Cascade Controller, chapter 9.2.2), the variable frequency drive has the ability to follow a steeper control curve, as shown in the illustration 'Variable Speed Control Curve', allowing slower operating speeds and increased cost savings.

9.5 Energy Savings

9.5.1 Energy savings estimation

Savings from installing a VLT® HVAC Drive compared to the PRV method of booster pump control can be estimated using the Danfoss VLT® Energy Box software. The program compares energy consumption for a booster pump running at full speed to the pump running at reduced speed using the VLT® HVAC Drive and then provides a simple payback calculation.

A minimum of design data to plot the pump and system curve is required. If a PRV is partially closed, the pressure drop it imposes on the system is included in the data. System operating hours are also entered.

To calculate the potential savings, a duty cycle or load profile is entered. The duty cycle indicates the amount of flow the system requires to satisfy the building load. Duty cycles vary depending on the specific building and system operation. The program has a default profile that can easily be changed.

Typical input data are shown in the illustration below. After the pump and system data are entered, the program calculates the estimated energy consumption for the VLT® HVAC Drive and the comparison system.

Project: Booster Pump 2

System Name: Step 2.1

System Data:		Motor and Drive Data:		Utility / Electricity Data:	
Design Head:	<input type="text" value="85.30"/> ft.wg	Motor Power:	<input type="text" value="10.0"/> HP	Average Cost per kWh:	<input type="text" value="\$ 0.063"/>
Design Flow:	<input type="text" value="235.44"/> GPM	Motor Efficiency:	<input type="text" value="92.0"/> %	Utility Incentive:	<input type="text" value="0"/> \$/HP
Shaft Power:	<input type="text" value="7.4"/> HP	Drive Power:	<input type="text" value="10.0"/> HP	Operation:	
Design Efficiency:	<input type="text" value="86.0"/> %	Drive Efficiency:	<input type="text" value="97.0"/> %	Hours per Day:	<input type="text" value="24"/> hours
Set Point Static Head:	<input type="text" value="39.40"/> ft.wg	Drive Cost:	<input type="text" value="\$ 950"/>	Days per Week:	<input type="text" value="7.0"/> days
Removed Pressure Drop:	<input type="text" value="13.12"/> ft.wg			Weeks per Year:	<input type="text" value="52"/> weeks

Pump and Control Curve Data

Duty Cycle

Total Operating Time: **8,760 Hrs**

130BA1028.10

Illustration 9.7: Energy Box Input Data

The illustration below shows annual energy consumption for a pressure booster pump with a PRV compared to a variable speed secondary pump with the Danfoss Drive System. Significant energy savings are achieved by using a VLT® HVAC Drive with a pressure booster system.

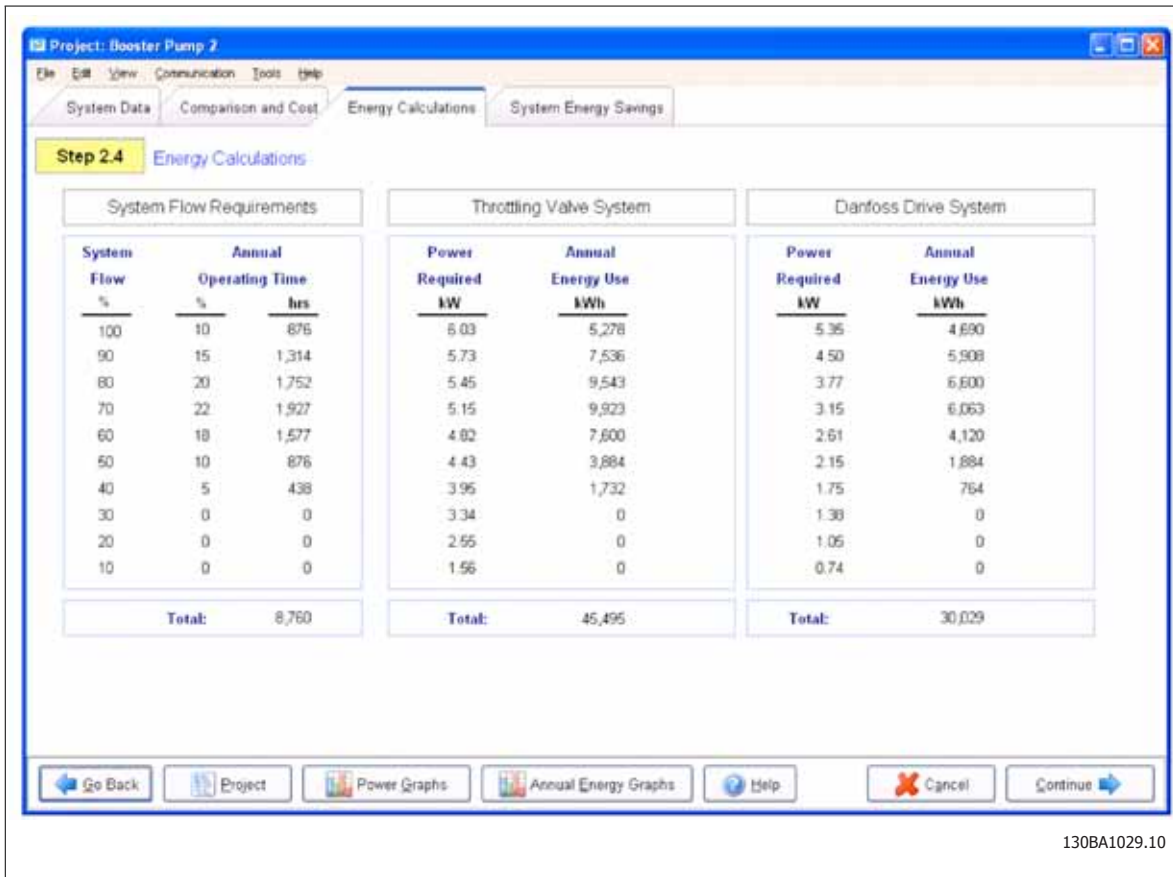


Illustration 9.8: Annual Energy Consumption

The program also calculates the simple payback period for the variable frequency drive including cost data for the drive, installation, wiring and other control components such as sensors. The illustration below shows a payback of 1.84 years to use a VLT® HVAC Drive for a booster pump application. The Energy Box Analysis and report can be printed, faxed or emailed.

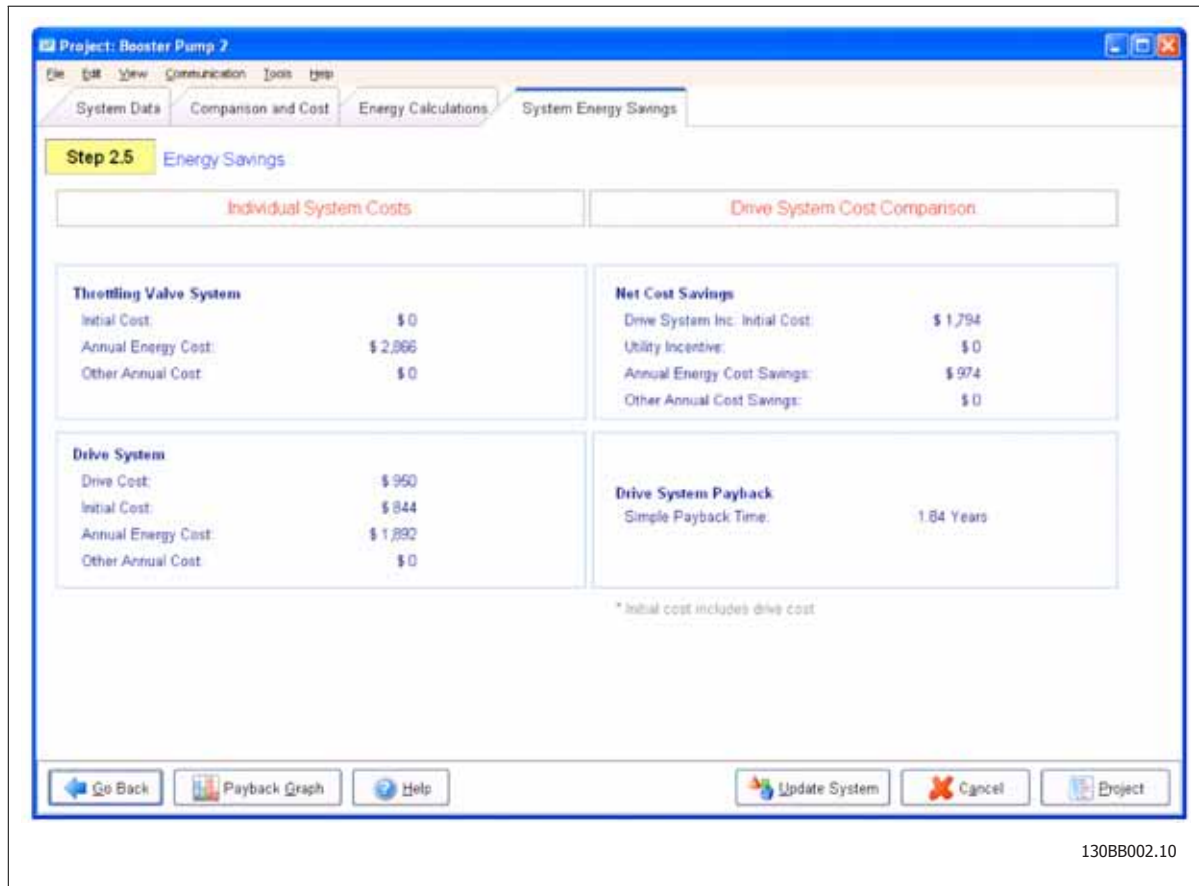


Illustration 9.9: Energy Box Financial Calculation

9.6 Drive Features

The Danfoss VLT® HVAC Drive is designed with features tailored for the unique control requirements of HVAC systems, including primary pump control. The following software features are incorporated, as standard, to optimize system performance.

9.6.2 Cascade controller

A built-in cascade controller can control up to three equal size pumps in parallel for pressure booster systems, multi-cell cooling towers and other water distribution systems. Multiple pumps in parallel, discharging into common supply piping are switched on and off to match the system demand, maintaining a constant pressure. Two Form C, 250 V, 2 A relays are included, as standard, for control of the additional motors.

The cascade controller has two configurations for operation, fixed lead pump or alternating lead pump. In fixed lead pump, the VLT variable frequency drive controls the speed of the first motor and the built-in relays are used to stage on and off two additional motors. The motors must be of equal size.

Lead pump alternation equalizes the use of pumps by periodically changing the pump that is speed controlled. This ensures that pumps are equally used over time. Each pump can alternate as the variable speed lead pump. Alternation equalizes the usage of pumps by always choosing the pump with the lower number of running hours to stage on. The motors must be of equal size and are controlled by the built-in relays.

9.6.3 Sleep mode

The FC can cycle the booster pump on or off, by utilizing a feature called "sleep mode." This automatically stops the pump when the system pressure is at a low level for a pre-determined amount of time. When the pressure increases, the FC restarts the motor to reach the required output. This results in fewer pump motor operation hours and increased savings. Unlike a setback timer, the variable frequency drive is always available to run, when the preset "wake-up" pressure is reached.

9.6.4 No-flow

This feature is useful for detecting conditions where a pump is producing no-flow but is running. A no-flow condition can cause pump damage if not detected and corrected. No-Flow detection does not require the use of external differential pressure switches or flow meters and associated wiring.

No-flow Detection is based on the measurement of power at specific motor speeds. The variable frequency drive monitors actual power and motor frequency and compares these with the calculated power at specific speeds. If the power measured at a specific frequency is greater than the calculated power stored in the drive, the pump is producing flow. If the power measured at a specific frequency is less than the calculated power stored in the drive, a warning or alarm is generated to notify the operator of the condition.

9.6.5 Dry pump

This feature is useful for detecting a condition when the pump is running but no water is in the system. A dry pump condition can cause pump damage if not detected and corrected. Dry pump detection does not require the use of external differential pressure switches or flow meters and associated wiring.

If there is no water in the system, the pump will not produce pressure. The variable frequency drive will go to maximum speed to try to produce pressure. Because there is no water, the load on the motor will be low and power consumption will be low. If the variable frequency drive is running at the maximum speed and the system power consumption is low, a warning or alarm is generated to notify the operator of the condition.

9

9.6.6 End of curve

This feature is used to detect leakage in a pipe system or the loss of pressure in the system. End of Curve detection does not require the use of external pressure sensors or flow meters and associated wiring.

End of curve occurs if a pump is delivering a large volume of water but cannot maintain the set static head. When there is a water leak in the pipe system, the pump will not produce full pressure. The variable frequency drive speed increases to maximum speed to attempt to produce the full pressure. If the variable frequency drive is running at the maximum speed and the system pressure is low, a warning or alarm is generated to notify the operator of the condition.

9.6.7 Energy log and trending

The variable frequency drive continuously accumulates the consumption of the actual power from the variable frequency drive to the motor. Data can be used in an Energy Log function allowing the user to analyze the energy consumption related to time. Data can be accumulated in two ways: a preset date and time for start and stop, or a predefined time period (such as the last 24 hours, seven days or month).

Trending is used to monitor how the variable changes over a period of time. The value of the trended variable is recorded in one of ten user-defined bins (data ranges). Common Trending variables for primary pump applications are motor power and output frequency.

The trending feature makes it possible to determine how much power reduction occurs for the primary pump system operation. Using this trending data with VLT® Energy Box software determines the actual savings obtained for control of primary pumps with the VLT HVAC Drive.

9.6.8 Serial communications

The VLT® HVAC Drive offers communication capabilities that are unmatched in variable frequency drives, reducing or eliminating the need for external devices.

Built-in serial communications options include: BACnet™, Modbus RTU, Johnson Controls Metasys® N2, and Siemens Apogee® FLN. Enhanced BACnet™ and LonWorks® are available as field-installed option cards that mount easily inside the VLT® HVAC Drive. Consult Danfoss for other serial communications options.

Index

A

Abbreviation List	4
Adjustable Speed Drive	6
Ahu	15
Air Handling Unit	15
Air Handling Units (ahu's)	9
Air Handling Units (ahu's)	15
Air Volume Control	5, 15
Alternating Lead Pump	71
Analog I/o Option	12
Analog Inputs	17
Analog I/o Option	26
Annual Energy Consumption	43, 60
Auto-tuning	21, 54, 61

B

Balancing Valve	38
Bms	12, 27
Booster Pumping Systems	63
Building Management System (bms)	12
Built-in Cascade Controller	71
Bypass Flow	55

C

Cascade Controller	71
Cav System	16
Cav To Vav System	18
Changing Resistance	40
Changing Suction Pressure	67
Chilled Water Systems	55
Chiller	23
Chiller Condenser	23
Chiller Retrofit Applications	32
Cold Start	26
Common Trending Variables	22
Condenser Pump Control	29
Constant Flow	47
Constant Speed Booster Pump Control	65
Constant Speed Pressure Booster System	65
Constant Volume System	18
Control Components	71
Control Curve	49, 56
Control Of A Condenser Pump	31
Cooling Coil Differential Head	56
Cooling Tower	23
Cooling Tower Control	27
Cooling Tower Load Profile	25

D

Decrease The Pump Speed	32
Decreased Flow Requirements	32
De-icing	26
Design Static Head	58
Design Water Pressure	65
Differential Head	49
Differential Pressure	56
Differential Pressure Sensor	50, 56, 61
Discharge Dampers	6
Dissimilar Loads	53
Drive Features	12, 21, 44, 61
Drive Features	35
Dry Pump	35, 45, 54, 62, 72
Duct Static Pressure Transmitters	6

Duty Cycle	58
E	
Easy Multiple Drive Programming	22
Easy Multiple Programming	14
End Of Curve	36, 45, 54, 62, 72
Energy Box Analysis	21
Energy Box Analysis	71
Energy Box Software	18, 41
Energy Consumption	42
Energy Log And Trending	14, 22, 27, 36, 45, 54, 62, 72
Energy Saving Potential	16
Energy Savings	25
Energy Savings	24
Energy Savings Estimation	9, 18, 32, 41, 51, 68
Energy Savings Estimation	58
Estimated Energy Consumption	20
Extended Pid Controllers	13, 21
F	
Fan And System Curve	10
Fan Cycling	24
Fan Power Requirements	7
Fan Speed Control	23
Fc Advantages	17
Fc Output Frequency	40
Feedback Signals	53
Fixed Lead Pump	71
Flow Meter	61
Flow Requirements	48
Frequency Bypass	25
Frequency Converter Advantages	6, 39
Frequency Converter Primary Loop Control	39
G	
Gear Speed Reducers	25
General Warning.	4
H	
Heat Exchange	23
High-voltage Warning	4
Hvac Intelligent Control	61
I	
Ice Build-up	26
Inlet Guide Vanes	5
Inlet Guide Vanes (igv)	5
Input Data	42
Integral Time	21
Integral Time	54
Introduction	5
L	
Literature	3
Local Speed Control	40
M	
Maintaining A Constant Impeller Size	41
Mcb 101 General Purpose I/o	13, 21

Mcb 109 Analog I/o Option	21, 26
Mcb 109 Analog I/o Option Board	12
Mechanical Vibration	25
Minimum Frequency	25
Minimum Output Frequency	25
Motor Preheat	26
Motor Speed Savings	58
Multi-cell Cooling Towers	71
Multiple Pumps In Parallel	71
Multi-sensor Locations	8
Muti-zone Control	53

N

No-flow	35, 44, 54, 62, 72
---------	--------------------

O

Optimized Chiller Flow Rate	32
-----------------------------	----

P

Packaged System	65
Payback	44
Payback Period	35
Pid Auto-tuning	14, 21, 54, 61
Pid Control	21
Pid Controller	6, 57
Potential Savings	41, 58
Power Requirements	16
Pressure Booster Systems	71
Pressure Difference	56
Pressure Reducing Valve - Prv	67
Pressure Reducing Valve (prv)	65
Pressure Sensor	8, 50, 57
Pressure Sensor Type	68
Primary Loop Pump Control	37
Primary Pump Control	61
Primary Water Loop	39
Primary/secondary Systems	37
Programmable Analog Inputs And Outputs	12, 26
Proportional Gain	21
Proportional Gain	54
Prv	65, 67
Pump Efficiency	32, 41
Pump Efficiency Curves	39
Pump Impeller Trimming	38
Pump Output	40
Pump Oversizing	67
Pump Speed	41
Pump Suction Pressure	65

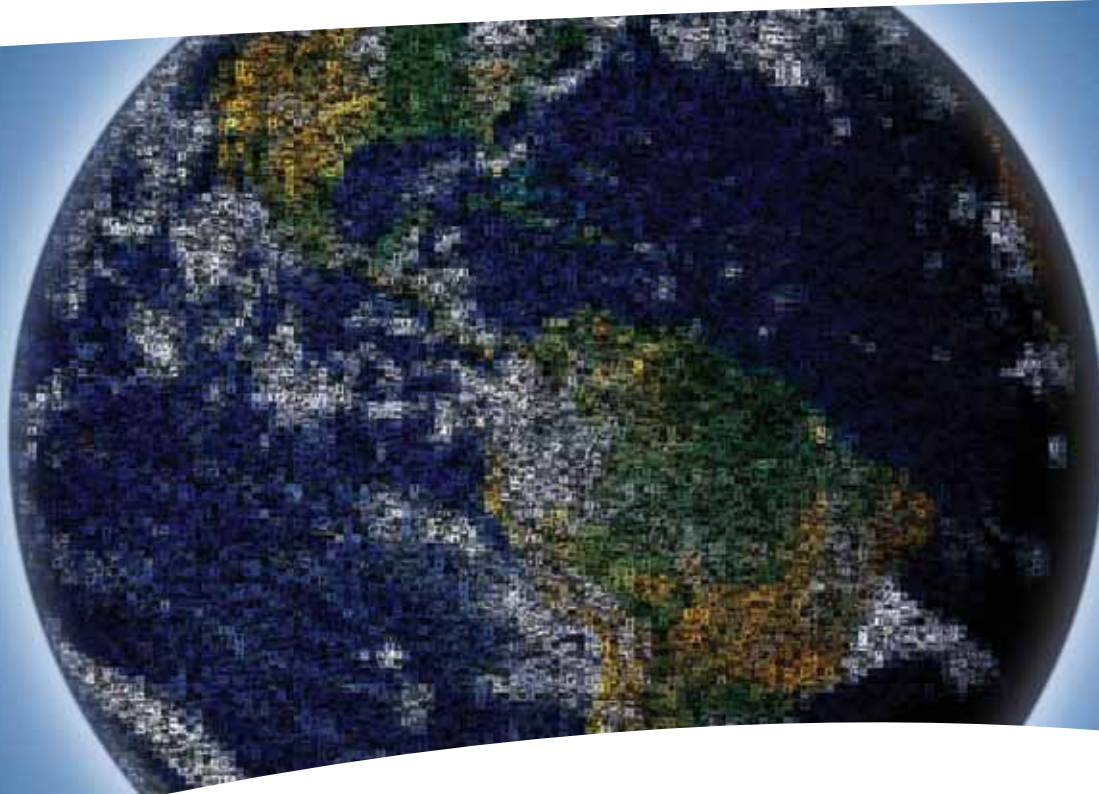
R

Reduce The Pump Motor Speed	32
Reduction In Energy	43
Required Chiller Flow	41
Retrofit Chiller Applications	32

S

Scale Buildup	40
Secondary Loop Pump Control	47
Semi-automatic Bypass	25
Sensor	50
Sensor Inputs	26
Sensor Location	68
Sensor Placement	50

Sensor Placement	7
Sensor Type And Placement	50, 57, 68
Sensors	57
Serial Communications	14, 22, 27, 36, 45, 54, 62, 72
Simple Payback Calculation	41
Simple Payback Period	21, 61
Single Zone Cav System	15
Single Zone Constant Volume System	15
Single Zone Variable Volume System	16
Sleep Mode	26, 72
Static High-limit Control	9
Static Pressure Drop	57
Static Pressure Sensor	8
Static Pressure Transmitter	9
System Loads	67
System Piping	65
T	
Temperature Sensor	24
The Energy Box Analysis	35
Thermal Performance	23
Trending	27, 45, 54, 62
Trending Data	62
Trending Variables	27, 45, 54
Typical Input Data	51
V	
Variable Air Volume (vav) Systems	5
Variable Head Loss	57
Variable Primary Flow	55
Variable Primary Flow Loop Control	55
Variable Primary Flow System	55
Variable Speed Booster Pump Control	66
Variable Speed Pump Control	56
Variable Speed Secondary Loop Pump Control	48
Variable System Loss	68
Variation In Flow Or Power	62
Vav Box Control	6
Vav Boxes	5, 7, 8
Vav Control	15
Vav System	6
Vav Systems	8
Vibration Free Operation	25
Vlt Motion Control Tool Mct 10	22
W	
Water Distribution Systems	71



EnVisioneering

As a world leader in components and solutions, Danfoss meets our customers' challenges through "EnVisioneering." This approach expresses our views on engineering innovation, energy efficiency, environmental responsibility and sustainable business growth that create strong customer partnerships. This vision is realized through a global production, sales, and service network focused on refrigeration, air conditioning, heating and water, and motion control. Through EnVisioneering, Danfoss is Making Modern Living Possible.

Danfoss "EnVisioneering":

- Engineered solutions to improve performance and profitability
- Energy efficiency to meet higher standards and to lower operating costs
- Environmental sustainability to provide a financial and social payback
- Engaged partnerships to foster trust, reliability, and technological superiority

www.danfossdrives.com

Danfoss can accept no responsibility for possible errors in catalogs, brochures and other printed material. Danfoss reserves the right to alter its products without notice. This also applies to products already on order provided that such alterations can be made without subsequent changes being necessary in specifications already agreed. All trademarks in this material are property of the respective companies. Danfoss and the Danfoss logotype are trademarks of Danfoss A/S. All rights reserved.

Danfoss VLT Drives
4401 N. Bell School Rd.
Loves Park, IL 61111, USA
Phone: 1.800.432.6367
1.815.639.8600
Fax: 1.815.639.8002

Danfoss VLT Drives
8800 W. Bradley Rd.
Milwaukee, WI 53224, USA
Phone: 1.800.621.8806
1.414.355.8800
Fax: 1.414.355.6117