Contents

1 How to read this manual

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 neccessary information for getting the frequency converter up and running.
- Design Guide MG.11.Bx.yy entails all technical information about the frequency converter 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 frequency converter 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	Frequency Converter	Frequency Converter: 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 frequency converter 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 feed-back 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 High voltage warning

The voltage of the frequency converter and the MCO 101 option card is dangerous whenever it is connected to mains. Incorrect installation of the motor or frequency converter may cause damage to the equipment, serious injury or death. Consequently, it is essential to comply with the instructions in this manual as well as local and national rules and safety regulations.

1.2.3 Safety instructions

Prior to using functions directly or indirectly influencing personal safety (e.g. **Safe Stop**, **Fire Mode** or other functions either forcing the motor to stop or attempting to keep it functioning) a thorough **risk analysis** and **system test** must be carried through. The system tests **must** include testing failure modes regarding the control signalling (analog and digital signals and serial communication.

NB!
Before using Fire Mode, contact Danfoss

- Make sure the frequency converter is properly connected to earth.
- Do not remove mains connections, motor connections or other power connections while the frequency converter is connected to power.
- Protect users against supply voltage.
- Protect the motor against overloading according to national and local regulations.
- The earth leakage current exceeds 3.5 mA.
- The [OFF] key is not a safety switch. It does not disconnect the frequency converter from mains.

1.2.4 Before commencing repair work

1. Disconnect the frequency converter from mains
2. Disconnect DC bus terminals 88 and 89
3. Wait at least the time mentioned in section General Warning above
4. Remove motor cable

1.2.5 Special conditions

Electrical ratings:
The rating indicated on the nameplate of the frequency converter is based on a typical 3-phase mains power supply, within the specified voltage, current and temperature range, which is expected to be used in most applications.

The frequency converters also support other special applications, which affect the electrical ratings of the frequency converter.
Special conditions which affect the electrical ratings might be:

- Single phase applications
- High temperature applications which require de-rating of the electrical ratings
- Marine applications with more severe environmental conditions.

Other applications might also affect the electrical ratings.

Consult the relevant sections in this manual and in the *VLT HVAC Drive Design Guide, MG.11.BX.YY* for information about the electrical ratings.

Installation requirements:

The overall electrical safety of the frequency converter requires special installation considerations regarding:

- Fuses and circuit breakers for over-current and short-circuit protection
- Selection of power cables (mains, motor, brake, loadsharing and relay)
- Grid configuration (IT,TN, grounded leg, etc.)
- Safety of low-voltage ports (PELV conditions).

Consult the relevant clauses in these instructions and in the *VLT HVAC Drive Design Guide* for information about the installation requirements.

1.2.6 Caution

Caution

The frequency converter DC link capacitors remain charged after power has been disconnected. To avoid an electrical shock hazard, disconnect the frequency converter from the mains before carrying out maintenance. Wait at least as follows before doing service on the frequency converter:

Voltage	Minimum Waiting Time				
	4 min.	**15 min.**	**20 min.**	**30 min.**	**40 min.**
200 - 240 V	1.1 - 3.7 kW	5.5 - 45 kW			
380 - 480 V	1.1 - 7.5 kW	11 - 90 kW	110 -200 kW		250 - 450 kW
525 - 600 V	1.1 - 7.5 kW		110 - 250 kW	315 - 560 kW	
Be aware that there may be high voltage on the DC link even when the LEDs are turned off.					

1.2.7 Installation at high altitudes (PELV)

By altitudes above 2 km, please contact Danfoss regarding PELV.

1.2.8 Avoid unintended start

While the frequency converter is connected to mains, the motor can be started/stopped using digital commands, bus commands, references or via the Local Control Panel.

- Disconnect the frequency converter from mains whenever personal safety considerations make it necessary to avoid unintended start.
- To avoid unintended start, always activate the [OFF] key before changing parameters.
- Unless terminal 37 is turned off, an electronic fault, temporary overload, a fault in the mains supply, or lost motor connection may cause a stopped motor to start.

1.2.9 Safe Stop of the frequency converter

For versions fitted with a Safe Stop terminal 37 input, the frequency converter can perform the safety function *Safe Torque Off* (As defined by draft CD IEC 61800-5-2) or *Stop Category 0* (as defined in EN 60204-1).

It is designed and approved suitable for the requirements of Safety Category 3 in EN 954-1. This functionality is called Safe Stop. Prior to integration and use of Safe Stop in an installation, a thorough risk analysis on the installation must be carried out in order to determine whether the Safe Stop functionality and safety category are appropriate and sufficient. In order to install and use the Safe Stop function in accordance with the requirements of Safety

Category 3 in EN 954-1, the related information and instructions of the *VLT HVAC Drive Design Guide* must be followed! The information and instructions of the Operating Instructions are not sufficient for a correct and safe use of the Safe Stop functionality!

Prüf- und Zertifizierungsstelle
im BG-PRÜFZERT

BGIA
Berufsgenossenschaftliches Institut für Arbeitsschutz
Hauptverband der gewerblichen Berufsgenossenschaften

Translation
In any case, the German original shall prevail.

Type Test Certificate

05 06004
No. of certificate

Name and address of the holder of the certificate: (customer)	Danfoss Drives A/S, Ulnaes 1 DK-6300 Graasten, Dänemark
Name and address of the manufacturer:	Danfoss Drives A/S, Ulnaes 1 DK-6300 Graasten, Dänemark

Ref. of customer:

Ref. of Test and Certification Body:
Apf/Köh VE-Nr. 2003 23220

Date of Issue:
13.04.2005

Product designation:	Frequency converter with integrated safety functions
Type:	VLT® Automation Drive FC 302
Intended purpose:	Implementation of safety function „Safe Stop"
Testing based on:	EN 954-1, 1997-03, DKE AK 226.03, 1998-06, EN ISO 13849-2; 2003-12, EN 61800-3, 2001-02, EN 61800-5-1, 2003-09,
Test certificate:	No.: 2003 23220 from 13.04.2005
Remarks:	The presented types of the frequency converter FC 302 meet the requirements laid down in the test bases. With correct wiring a category 3 according to DIN EN 954-1 is reached for the safety function.

The type tested complies with the provisions laid down in the directive 98/37/EC (Machinery).

Further conditions are laid down in the Rules of Procedure for Testing and Certification of April 2004.

Head of certification body
(Prof. Dr. rer. nat. Dietmar Reinert)

Certification officer
(Dipl.-Ing. R. Apfeld)

PZB10E
01.05

BG-PRÜFZERT

Postal adress:
53754 Sankt Augustin

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53757 Sankt Augustin

Phone: 0 22 41/2 31-02
Fax: 0 22 41/2 31-22 34

130BA491

This certificate also covers FC 102 and FC 202!

1.2.10 IT mains

IT Mains

Do not connect frequency converters with RFI-filters to mains supplies with a voltage between phase and earth of more than 440 V for 400 V converters and 760 V for 690 V converters.

For 400 V IT mains and delta earth (grounded leg), mains voltage may exceed 440 V between phase and earth.

For 690 V IT mains and delta earth (grounded leg), mains voltage may exceed 760 V between phase and earth.

par. 14-50 *RFI Filter* can be used to disconnect the internal RFI capacitiors from the RFI filter to ground.

1.2.11 Software version and approvals: VLT HVAC Drive

VLT HVAC Drive
Software version: 2.9.x

This manual can be used with all VLT HVAC Drive frequency converters with software version 2.9x.
The software version number can be seen from par. 15-43 *Software Version*.

1.2.12 Disposal instruction

Equipment containing electrical components must not be disposed of together with domestic waste.
It must be separately collected with electrical and electronic waste according to local and currently valid legislation.

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, frequency converters 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 frequency converters 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.

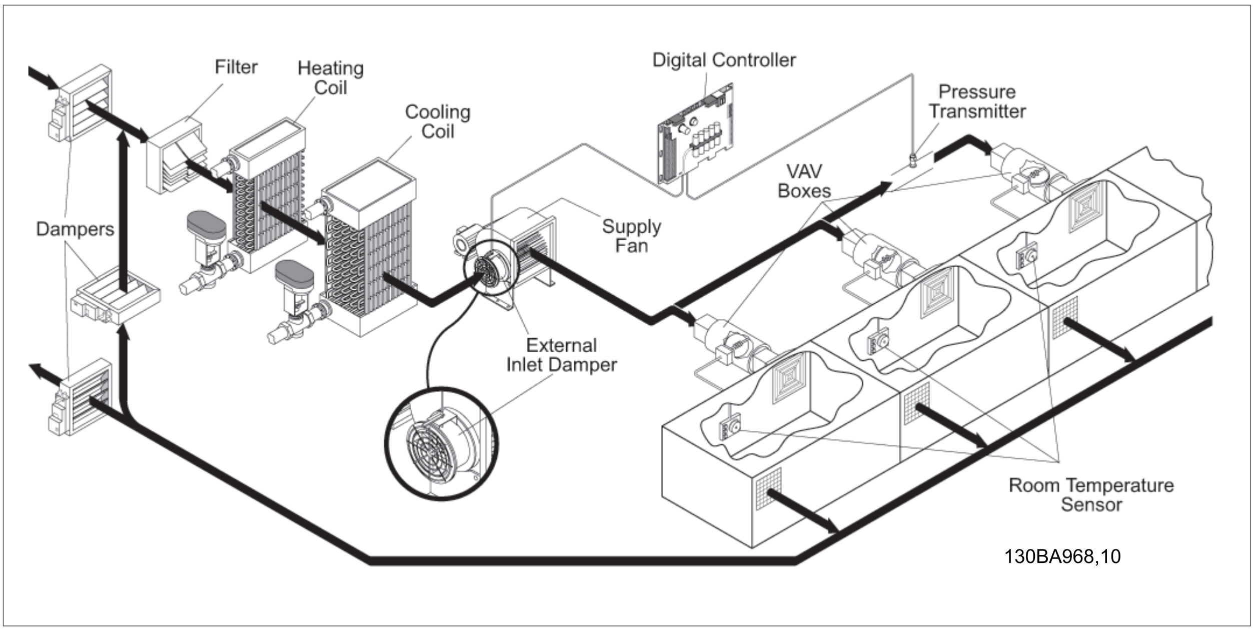

Illustration 2.1: VAV System with Inlet Guide Vanes

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 frequency converter 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 frequency converter will increase the speed of the motor to increase fan volume.

2.1.2 Frequency converter advantages

Frequency Converters 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.

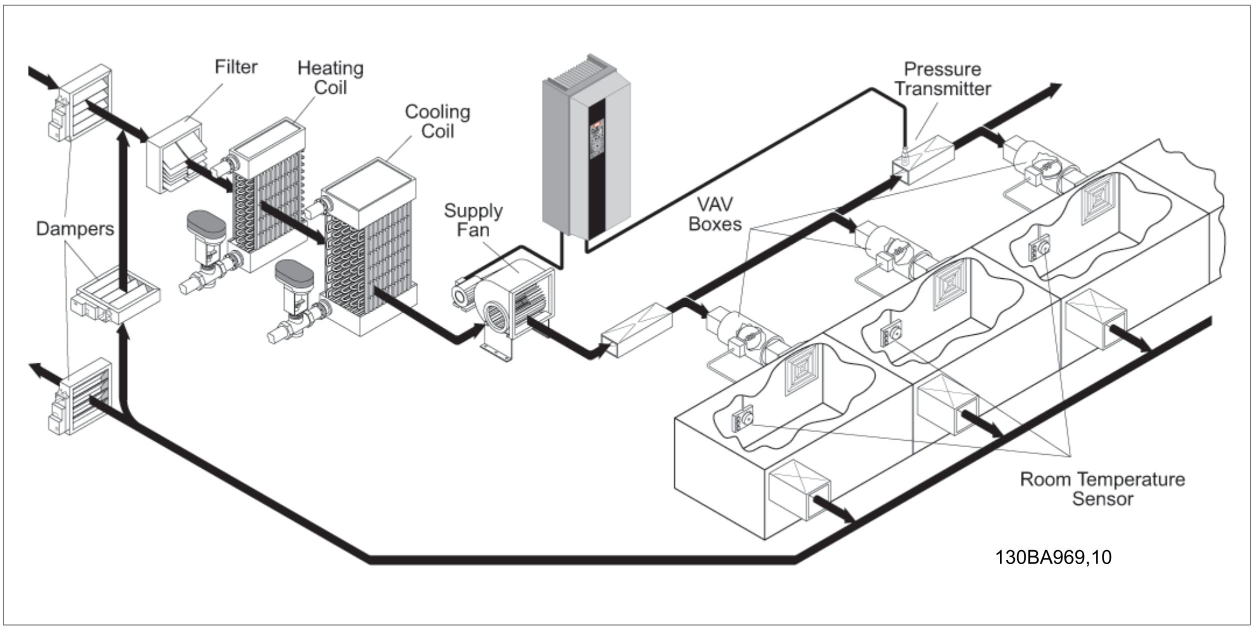

Illustration 2.2: VAV System with Adjustable Speed Drive

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 frequency converter for control of the fan motor.

Additional PID controllers, RTD temperature sensor inputs and analog outputs allow for control of addition 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 frequency converter (curve 2) most closely approximates the energy consumption for the fan affinity laws having the greatest energy efficiency at reduced flows.

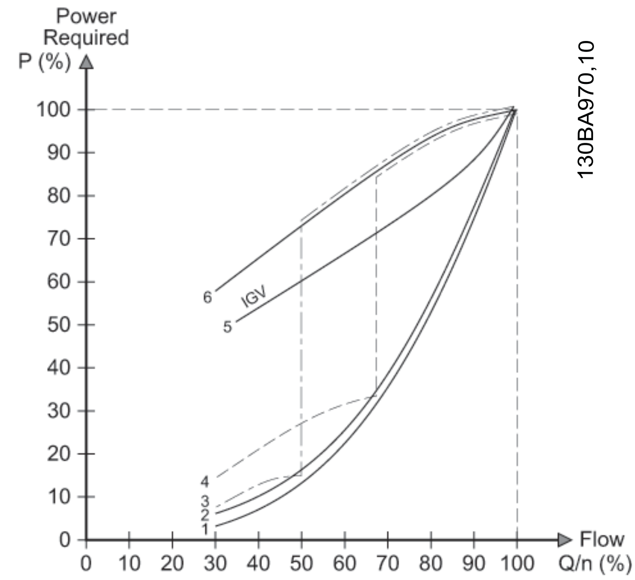

Illustration 2.3: Fan Power Requirements

1. Theoretical Energy Consumption
2. Frequency Converter
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 frequency converter 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'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.

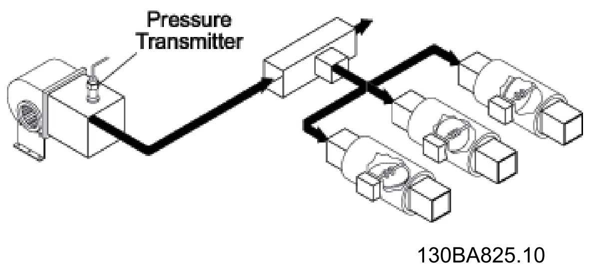	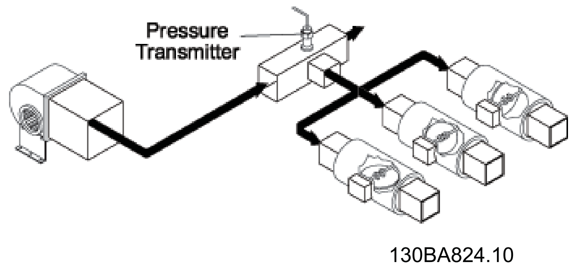
Fan discharge	Supply duct

Table 2.1: Pressure transmitter placement

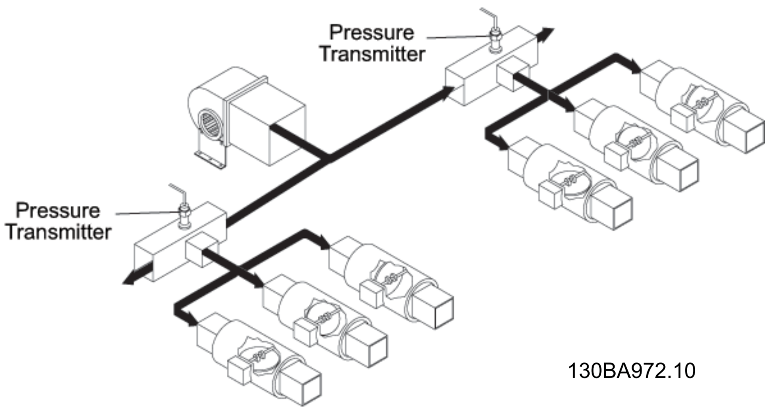

Illustration 2.4: Pressure Transmitter Placement

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'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.

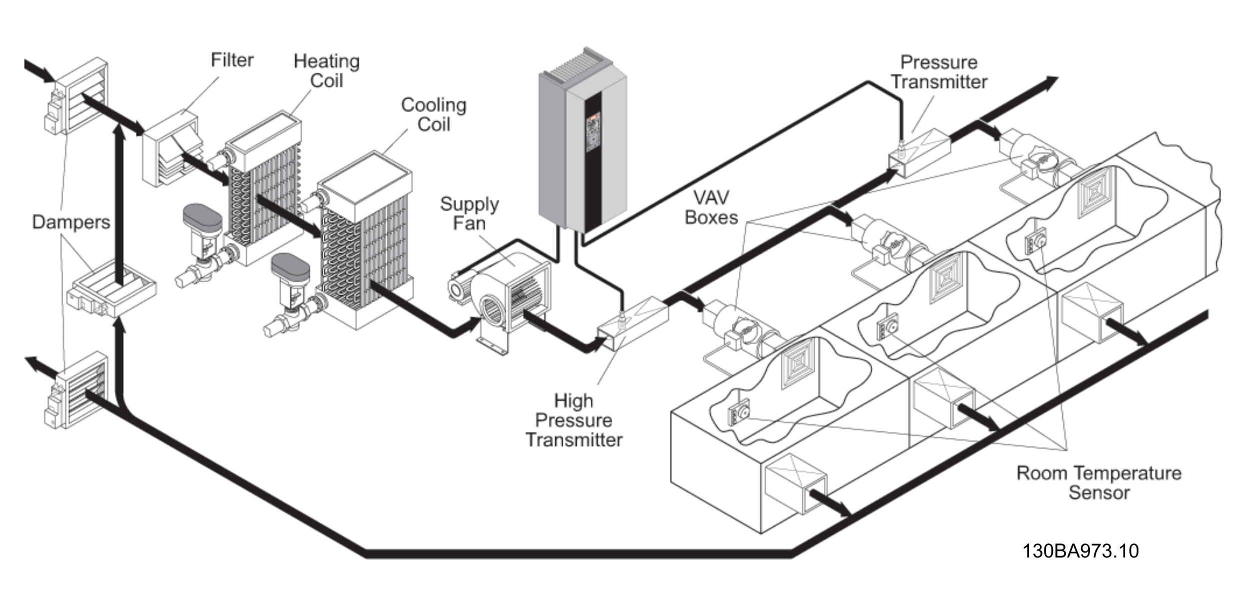

Illustration 2.5: Duct High-Limit Static Pressure Control

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.

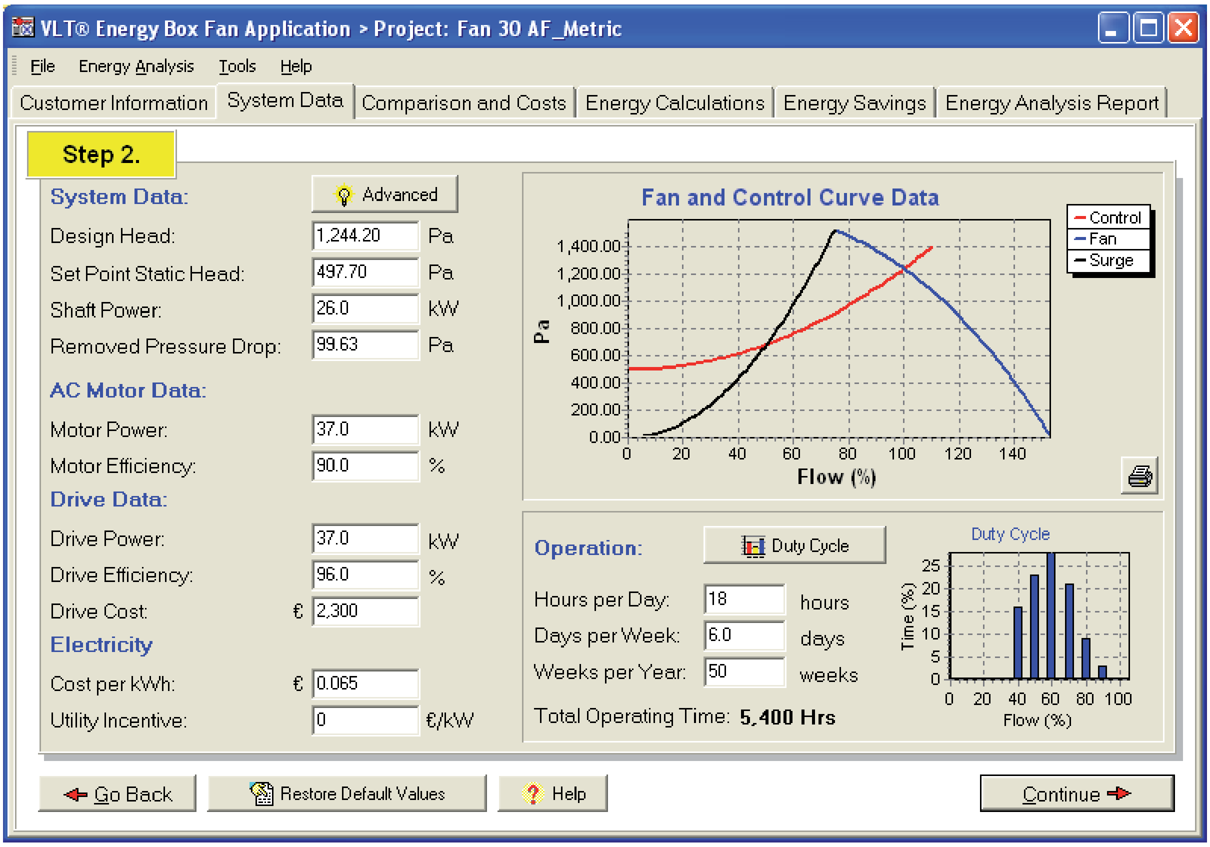

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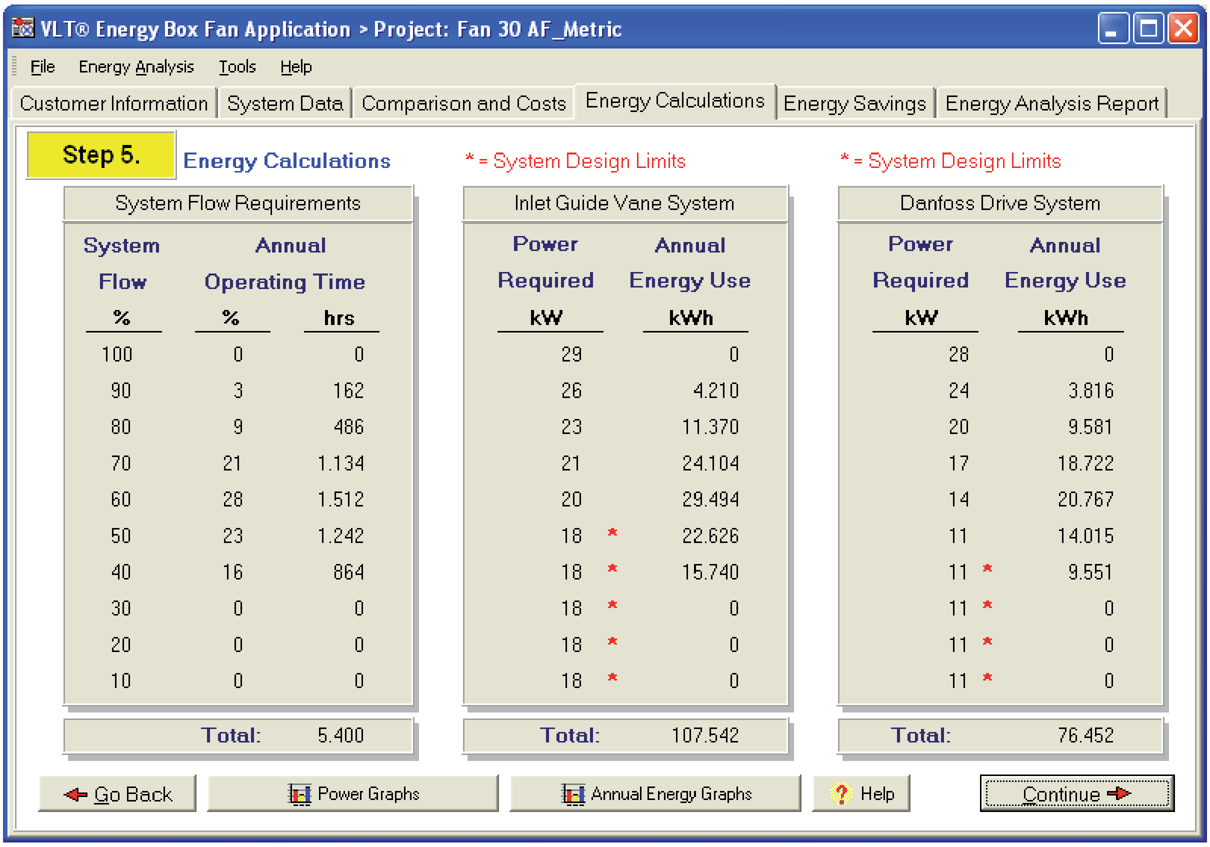
Illustration 2.6: Energy Box Input Data

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.



System Flow Requirements			Inlet Guide Vane System			Danfoss Drive System		
System Flow	Annual Operating Time		Power Required		Annual Energy Use	Power Required		Annual Energy Use
%	%	hrs	kW		kWh	kW		kWh
100	0	0	29		0	28		0
90	3	162	26		4.210	24		3.816
80	9	486	23		11.370	20		9.581
70	21	1.134	21		24.104	17		18.722
60	28	1.512	20		29.494	14		20.767
50	23	1.242	18	*	22.626	11		14.015
40	16	864	18	*	15.740	11	*	9.551
30	0	0	18	*	0	11	*	0
20	0	0	18	*	0	11	*	0
10	0	0	18	*	0	11	*	0
Total:		5.400	Total:		107.542	Total:		76.452

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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 1.33 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.

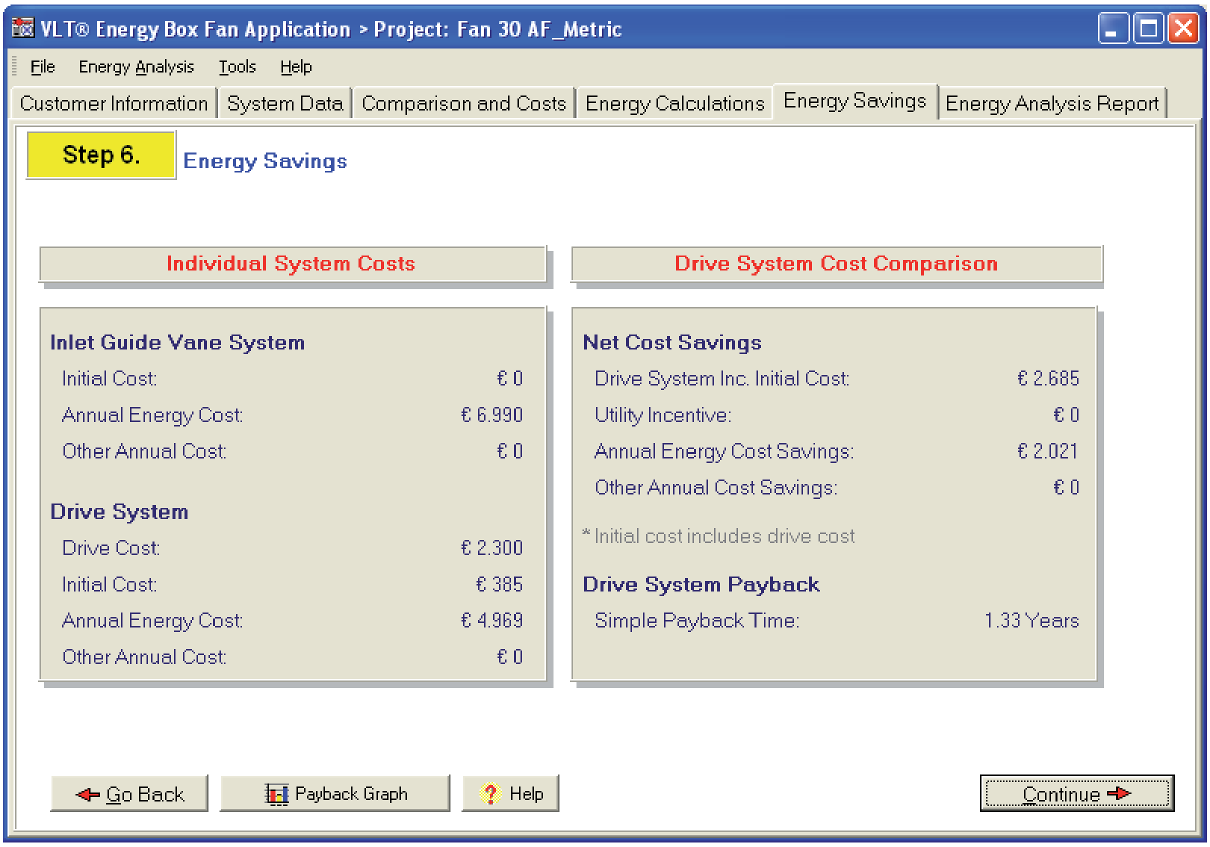

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Illustration 2.8: Energy Box Financial Calculations

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 frequency converter. 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.

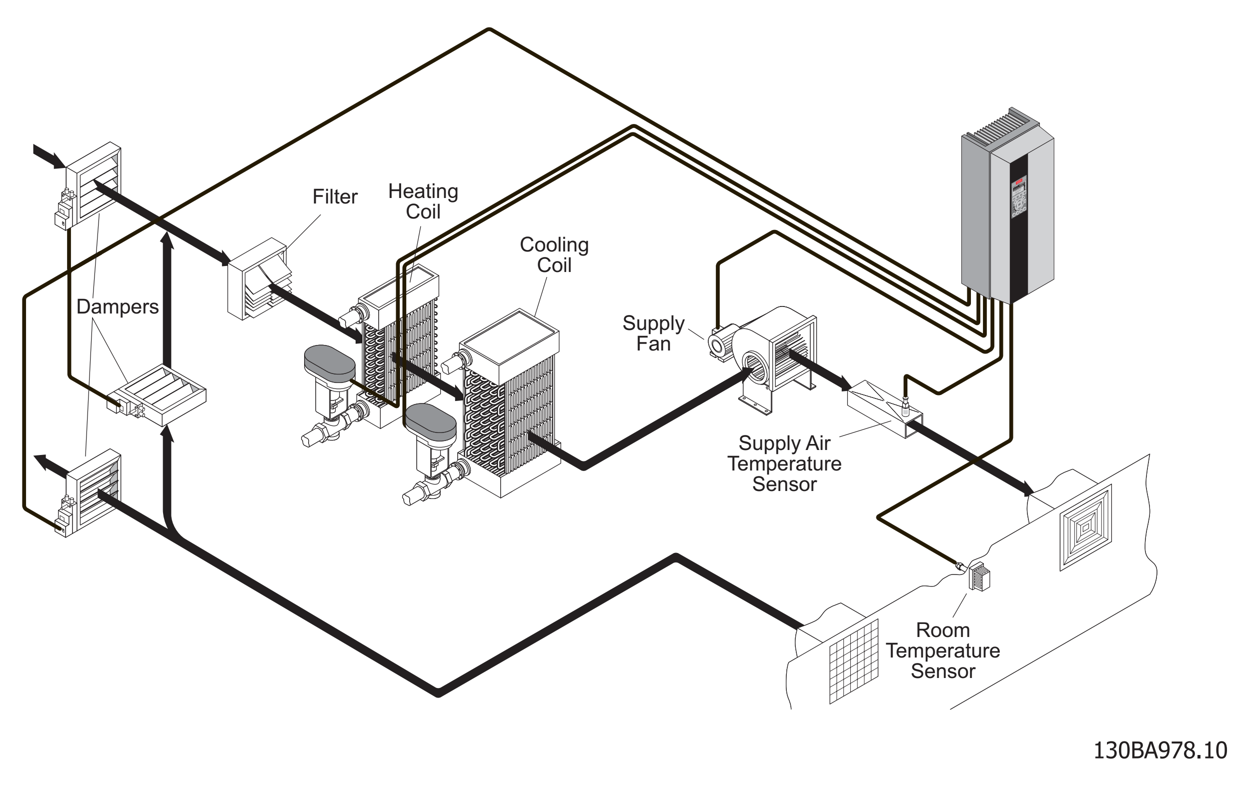

Illustration 2.9: VAV control with Analog I/O Option

Wiring of the sensors and actuators is shown below.

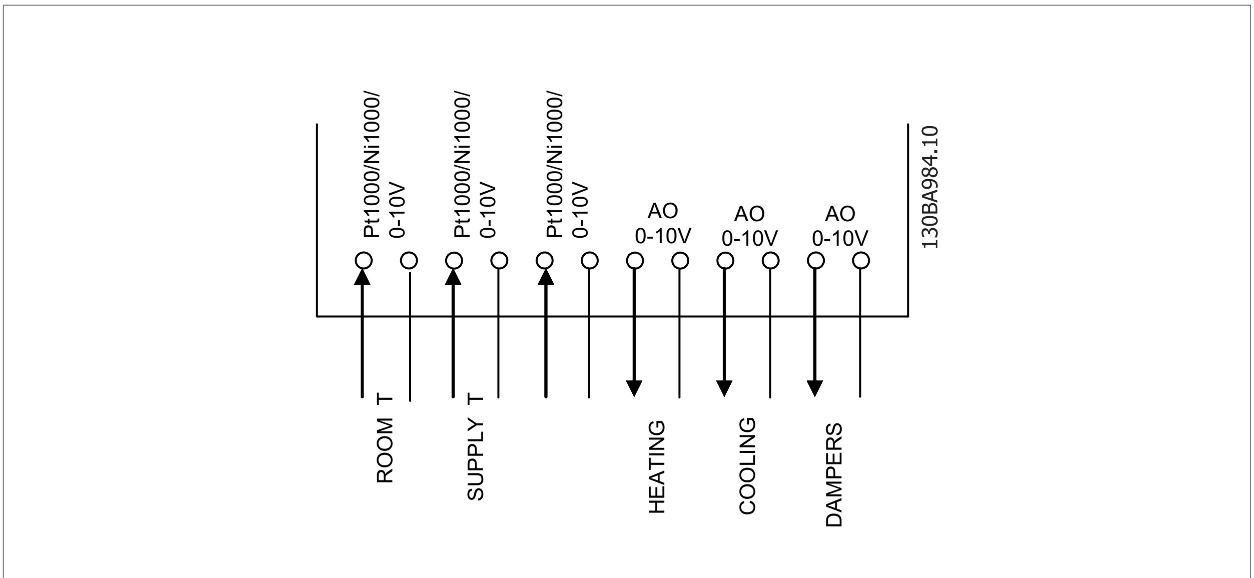

Illustration 2.10: Analog I/O Option Card Wiring

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 multible programming

When a building has many AHU’s, pumps and other frequency converter 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 frequency converter 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 frequency converter 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 frequency converters, reducing or eliminating the need for external devices.

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

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 frequency converter and making minor temperature control modifications. Lower system operating costs are obtained by using a frequency converter 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.

3.2 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.

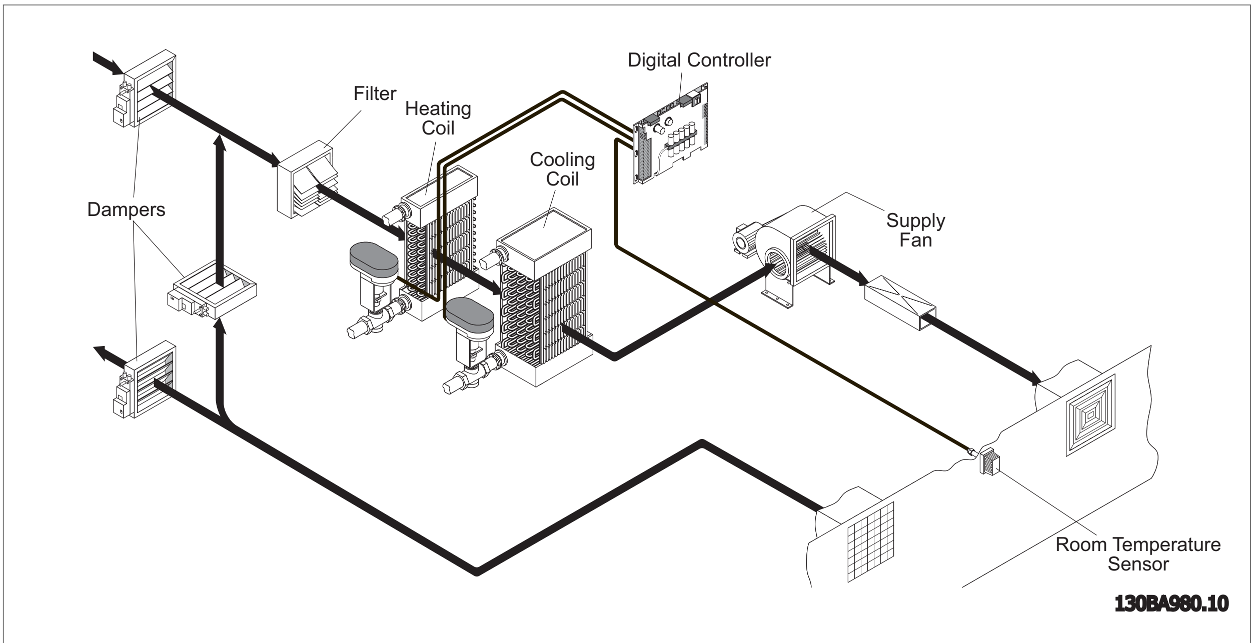

Illustration 3.1: Single Zone Constant Volume system

Installing a frequency converter 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 frequency converter is installed to control the fan speed.

The room temperature sensor is connected directly to the frequency converter. 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

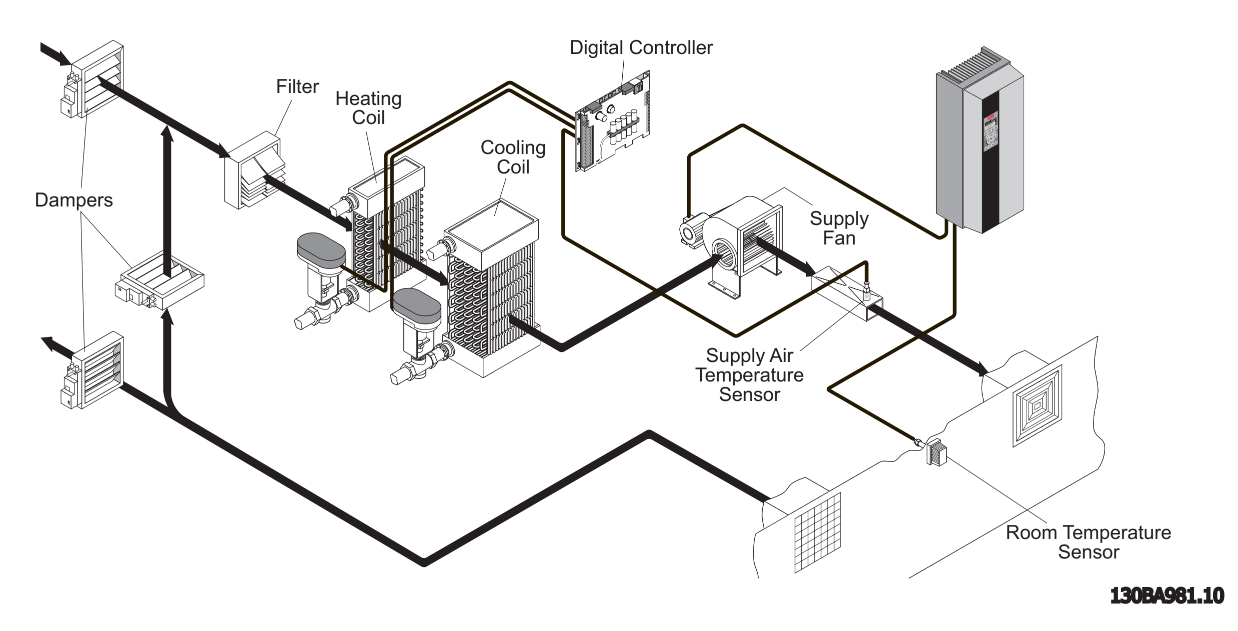

Illustration 3.2: Single Zone Variable Volume system with adjustable speed drive

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

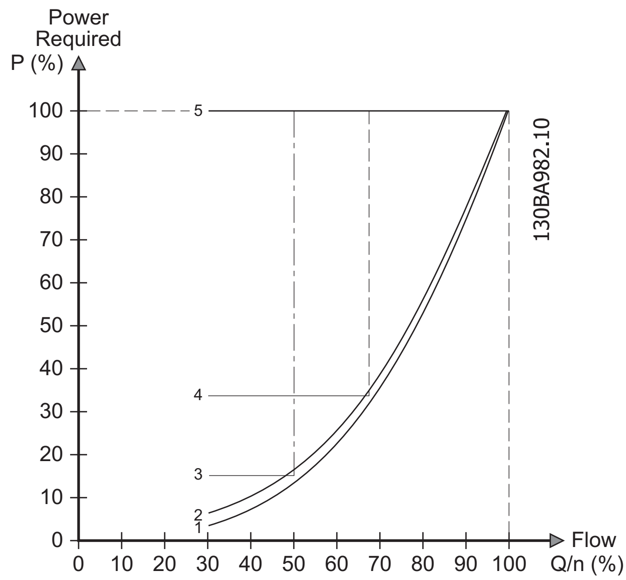

Illustration 3.3: Power requirements for Variable Speed CAV Control

1 Theoretical power requirement

2 Frequency converter

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 frequency converters over constant speed or two-speed motor operation. Power consumption closely follows the theoretical power requirement.

3.3 Frequency converter advantages

Frequency converters 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 CO_2, or other air quality can be used to increase energy savings.

When controlling air quality using a CO_2 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 CO_2 and the drive slows the supply fan's speed. When occupancy increases, the CO_2 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.

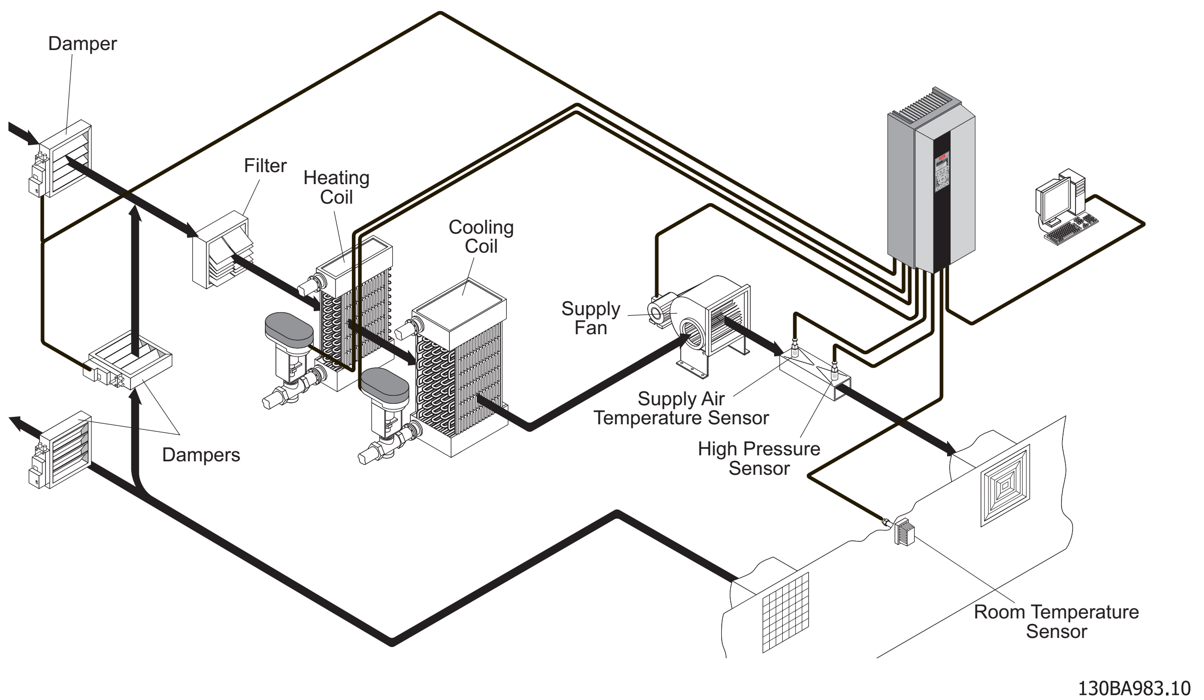

Illustration 3.4: CAV to VAV conversion with Analog I/O Option

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

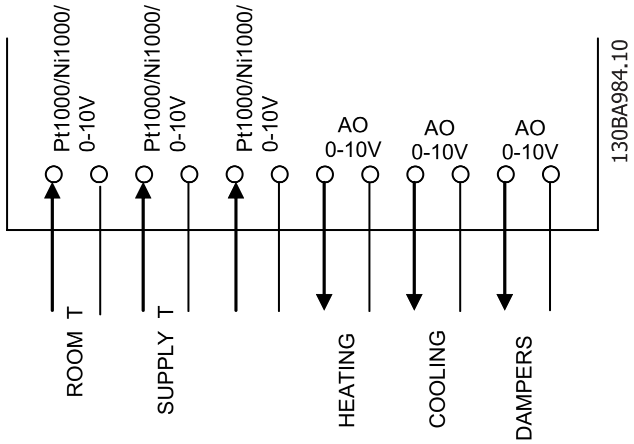

Illustration 3.5: Typical MCB 109 I/O Wiring

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.

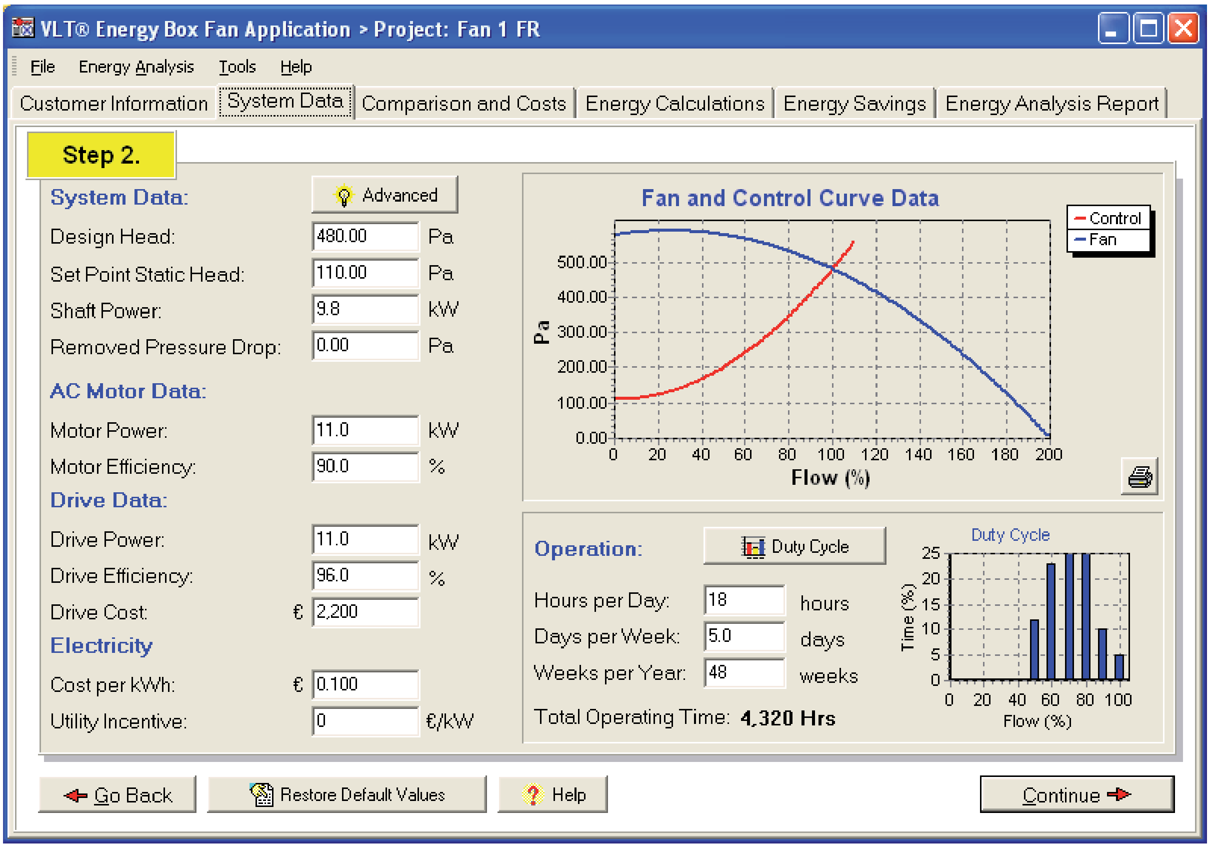

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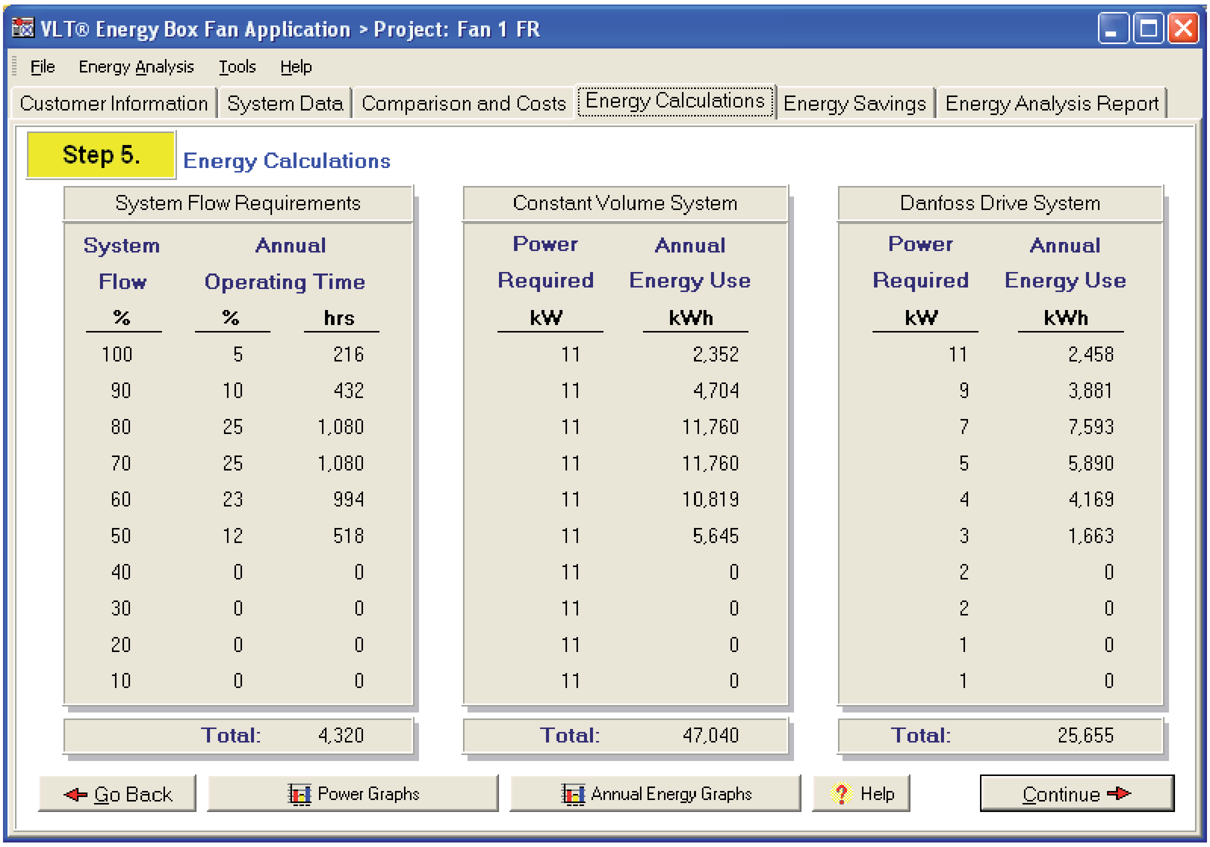
Illustration 3.6: Energy Box input data

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.



System Flow Requirements			Constant Volume System		Danfoss Drive System	
System Flow %	Annual Operating Time %	Annual Operating Time hrs	Power Required kW	Annual Energy Use kWh	Power Required kW	Annual Energy Use kWh
100	5	216	11	2,352	11	2,458
90	10	432	11	4,704	9	3,881
80	25	1,080	11	11,760	7	7,593
70	25	1,080	11	11,760	5	5,890
60	23	994	11	10,819	4	4,169
50	12	518	11	5,645	3	1,663
40	0	0	11	0	2	0
30	0	0	11	0	2	0
20	0	0	11	0	1	0
10	0	0	11	0	1	0
	Total:	4,320	Total:	47,040	Total:	25,655

130BA986.10

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 1.26 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.

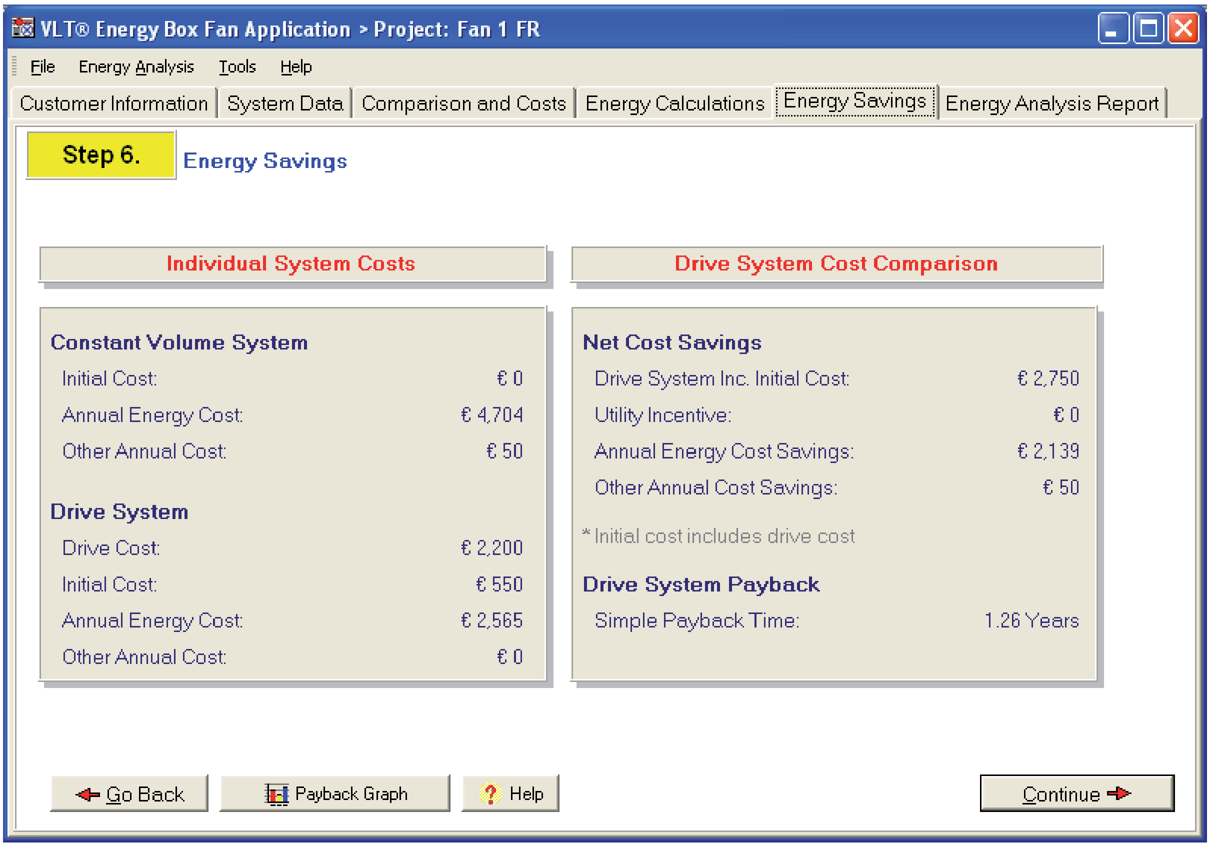


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Illustration 3.8: Energy Box financial calculation

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 multible drive programming

When a building has many AHU's, pumps and other frequency converter 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.

3.5.5 Energy log and trending

The VLT® HVAC Drive continuously accumulates the consumption of the actual power from the frequency converter 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 frequency converters, reducing or eliminating the need for external devices.

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

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 waters 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.

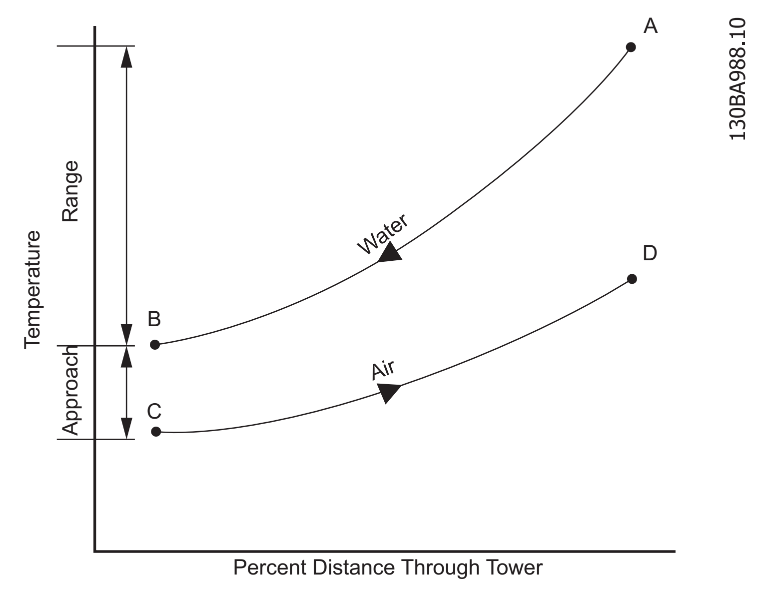


Illustration 4.1: Cooling Tower Temperature Relationships

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.

Frequency converters 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 frequency converter 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.

The illustration below shows a basic cooling tower fan application. A frequency converter 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.

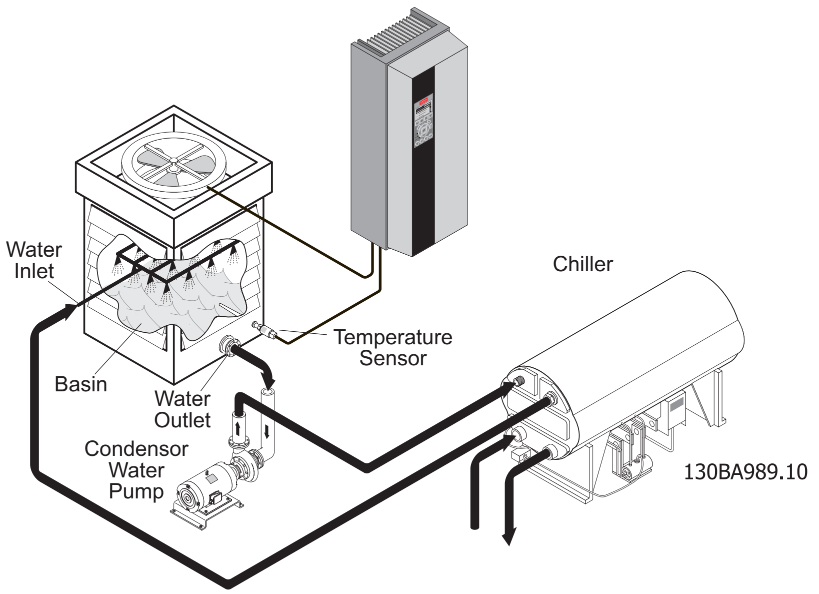


Illustration 4.2: Cooling Tower and Chiller Condenser System with frequency converter

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 frequency converter 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.

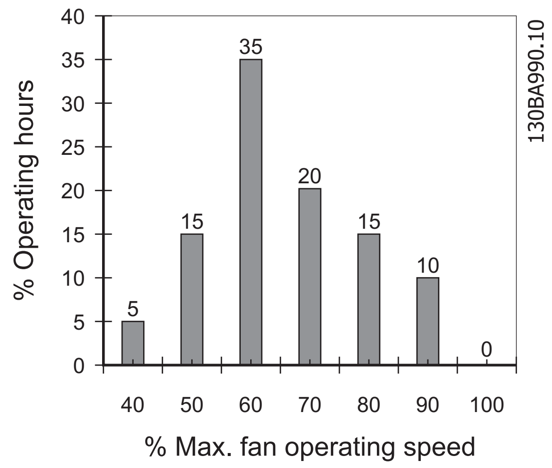


Illustration 4.3: Cooling tower operating hours and fan speed

In the energy calculation shown in the table below, a 30 kW 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 frequency converter. The comparison shows energy savings of 44% with the frequency converter across all operation requirements.

Flow	Hours	Hours	Electrical power required (kW)		Energy consumption for fan motor (kWh)	
(%)	(%)	Run	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 30 kW 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 frequency converter 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 frequency converter. 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 frequency converter is always available to run when the preset "wakeup" 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 frequency converter 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 frequency converter 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.

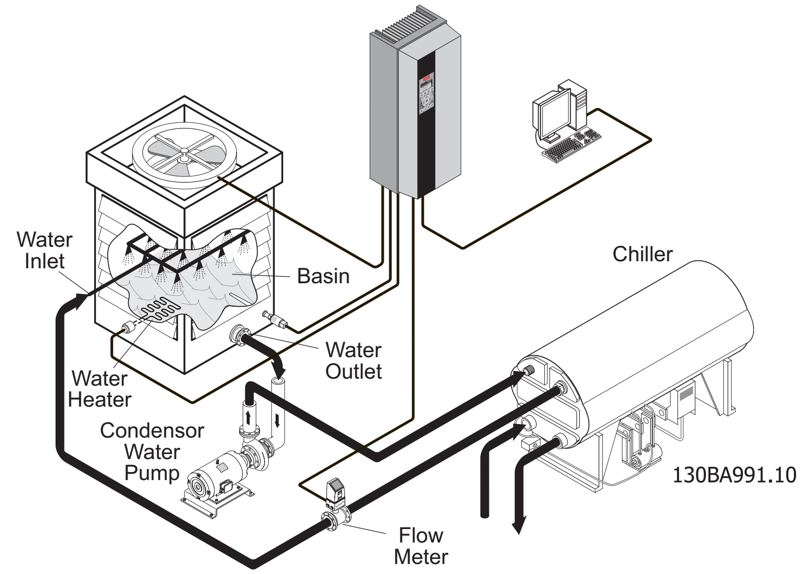


Illustration 4.4: Integrated Cooling Tower Control (Drawing needs to be revised)

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.

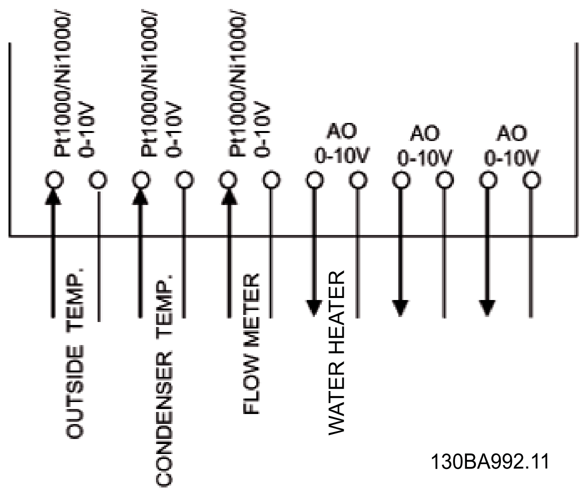


Illustration 4.5: Typical MCB 109 I/O wiring

4.4.7 Energy log and trending

The frequency converter continuously accumulates the consumption of the actual power from the frequency converter 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 frequency converters, reducing or eliminating the need for external devices.

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

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.

5.2 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.

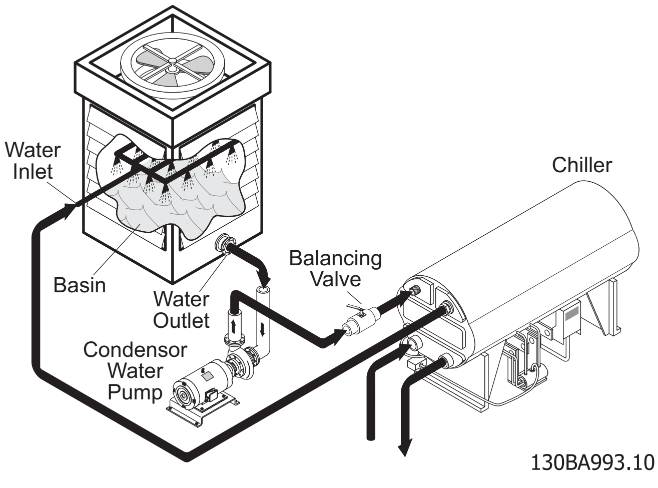


Illustration 5.1: Traditional Condenser Pump System

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.

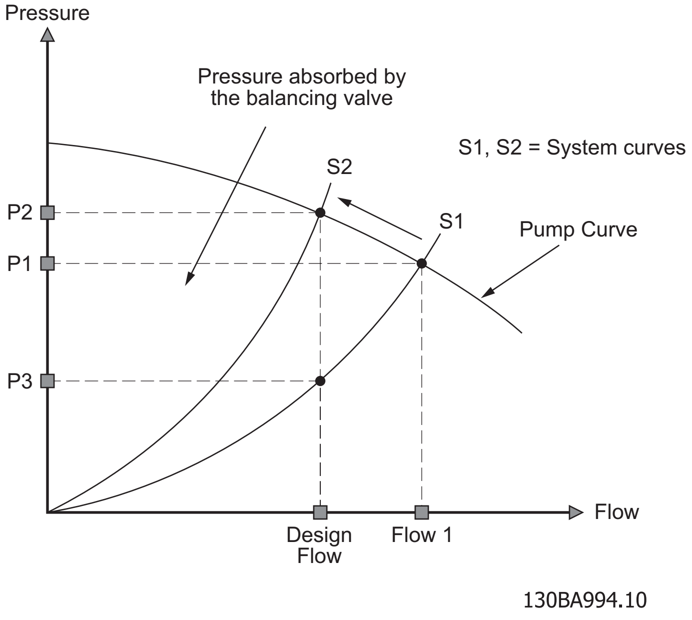


Illustration 5.2: Balancing Valve Pressure Loss

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.

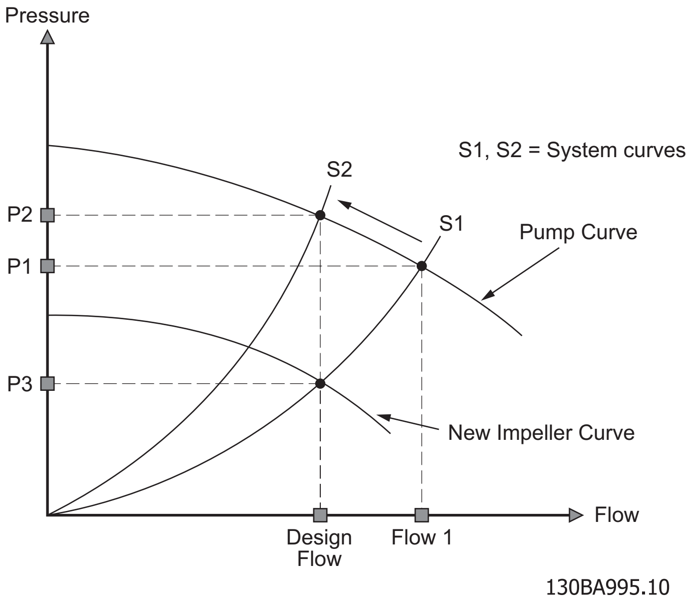


Illustration 5.3: Pump Impeller Trimming

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.

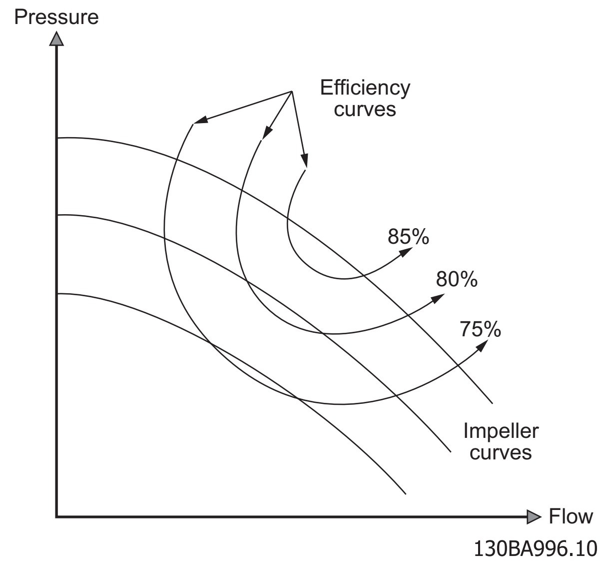


Illustration 5.4: Pump Efficiency Curves

5.3 Frequency Converter Advantages

Based on the size of the system, the energy consumption of the condenser water loop can be substantial. A frequency converter 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 show in the illustration below. Using a frequency converter 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 frequency converter are based on the amount the balancing valve is closed.

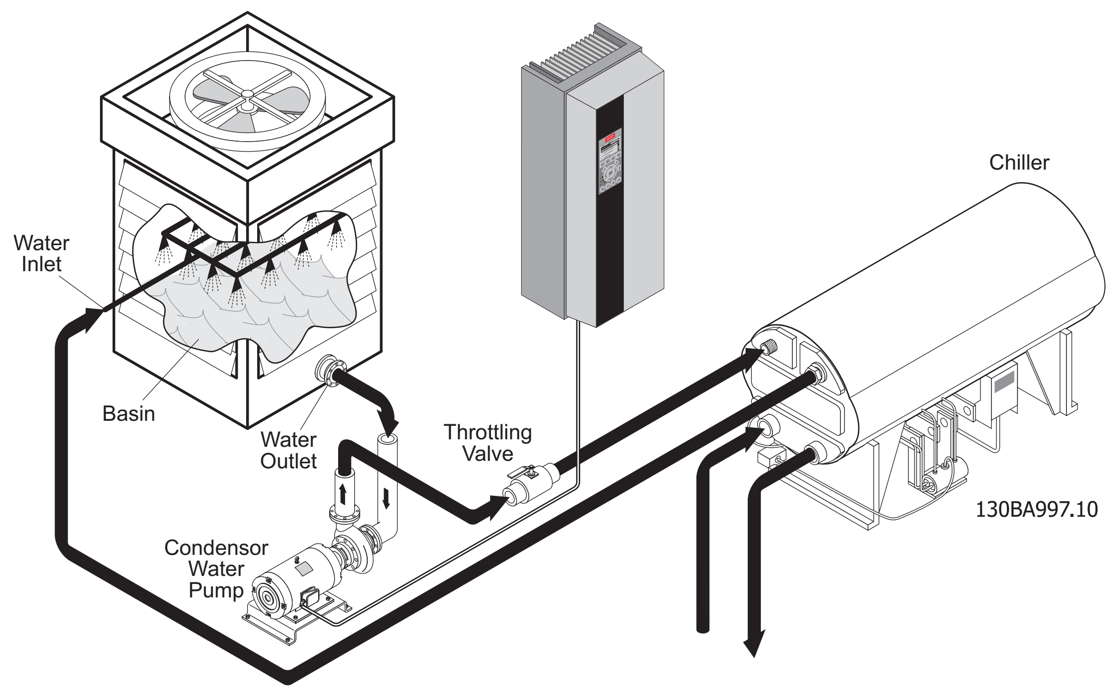


Illustration 5.5: Condenser Pump Control with Frequency Control

Using the frequency converter 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.

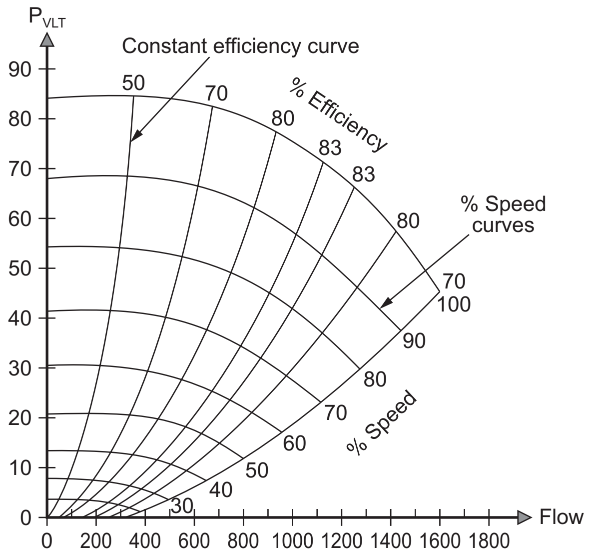


Illustration 5.6: Pump Efficiencies with Variable Speed

5.3.1 Retrofit chiller applications

Frequency converters 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 frequency converter 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

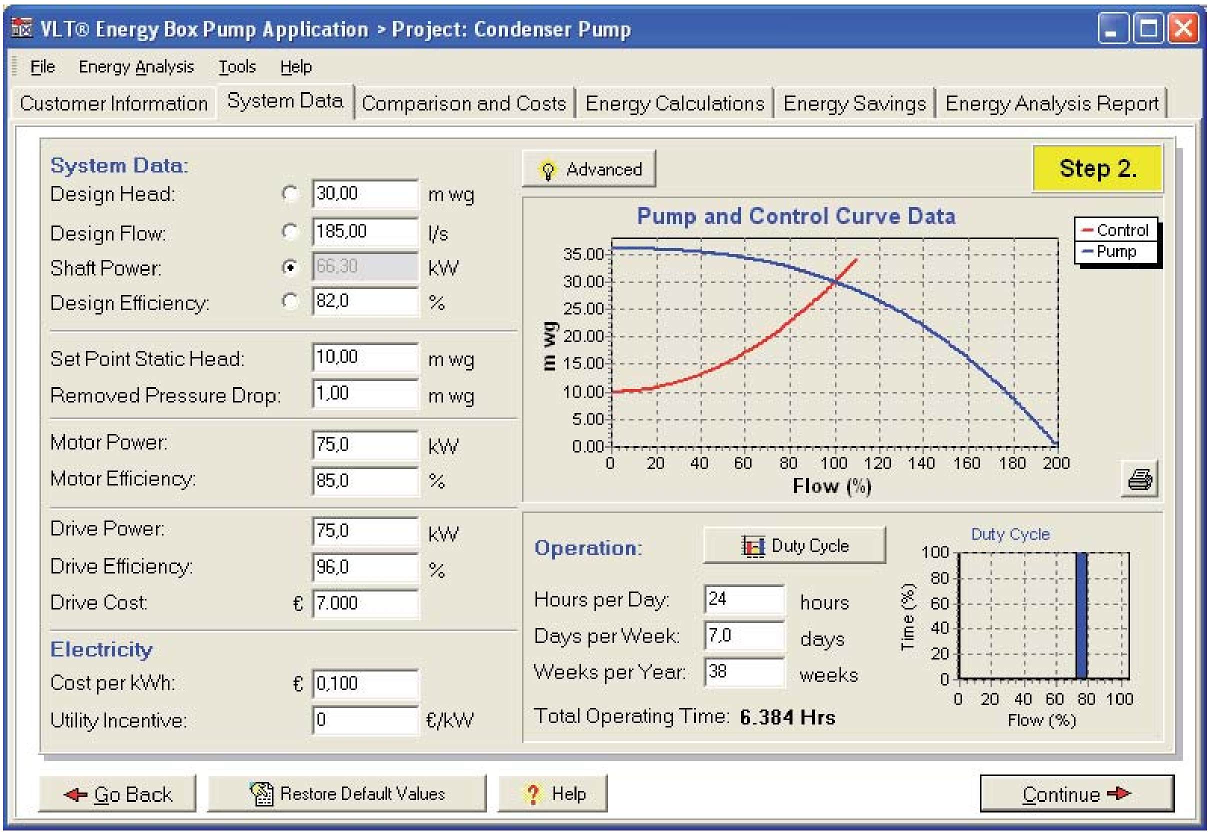
5.4.1 Energy savings estimation

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.

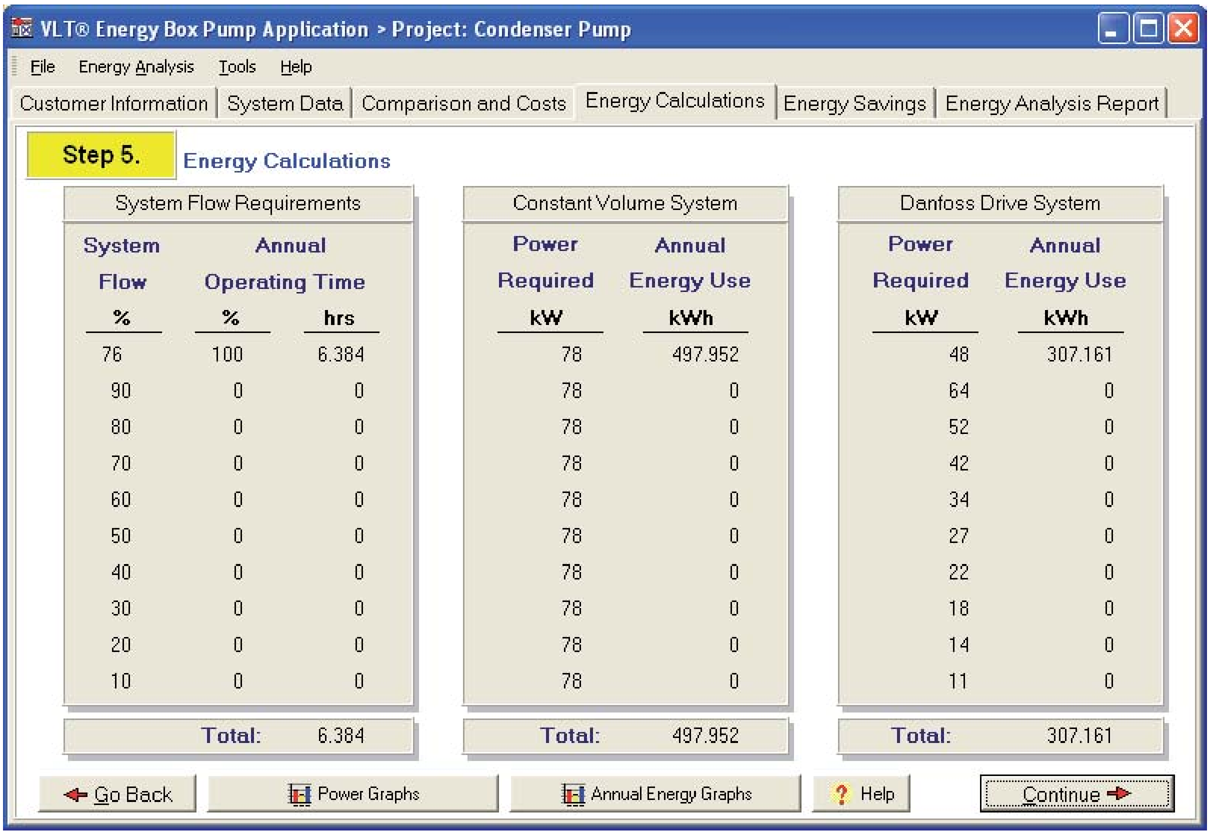
Typical input data is shown in the illustration below. It is estimated that the condenser pump flow can be reduced to 76% using a frequency converter and opening the balancing valve. After the pump and system data is entered, the program calculates the estimated energy consumption for the VLT® HVAC Drive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



130BA999.10

Illustration 5.7: Energy Box Input Data

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.



System Flow Requirements			Constant Volume System		Danfoss Drive System	
System Flow	Annual Operating Time		Power Required	Annual Energy Use	Power Required	Annual Energy Use
%	%	hrs	kW	kWh	kW	kWh
76	100	6.384	78	497.952	48	307.161
90	0	0	78	0	64	0
80	0	0	78	0	52	0
70	0	0	78	0	42	0
60	0	0	78	0	34	0
50	0	0	78	0	27	0
40	0	0	78	0	22	0
30	0	0	78	0	18	0
20	0	0	78	0	14	0
10	0	0	78	0	11	0
	Total:	6.384	Total:	497.952	Total:	307.161

130BA1000.10

Illustration 5.8: Annual Energy Consumption

The program also calculates the simple payback period for the frequency converter including cost for the drive, installation, wiring and other control components that may be needed. Below illustration shows a payback of 0.58 years to upgrade an existing condenser water pump system. The Energy Box Analysis and report can be printed, faxed or emailed.

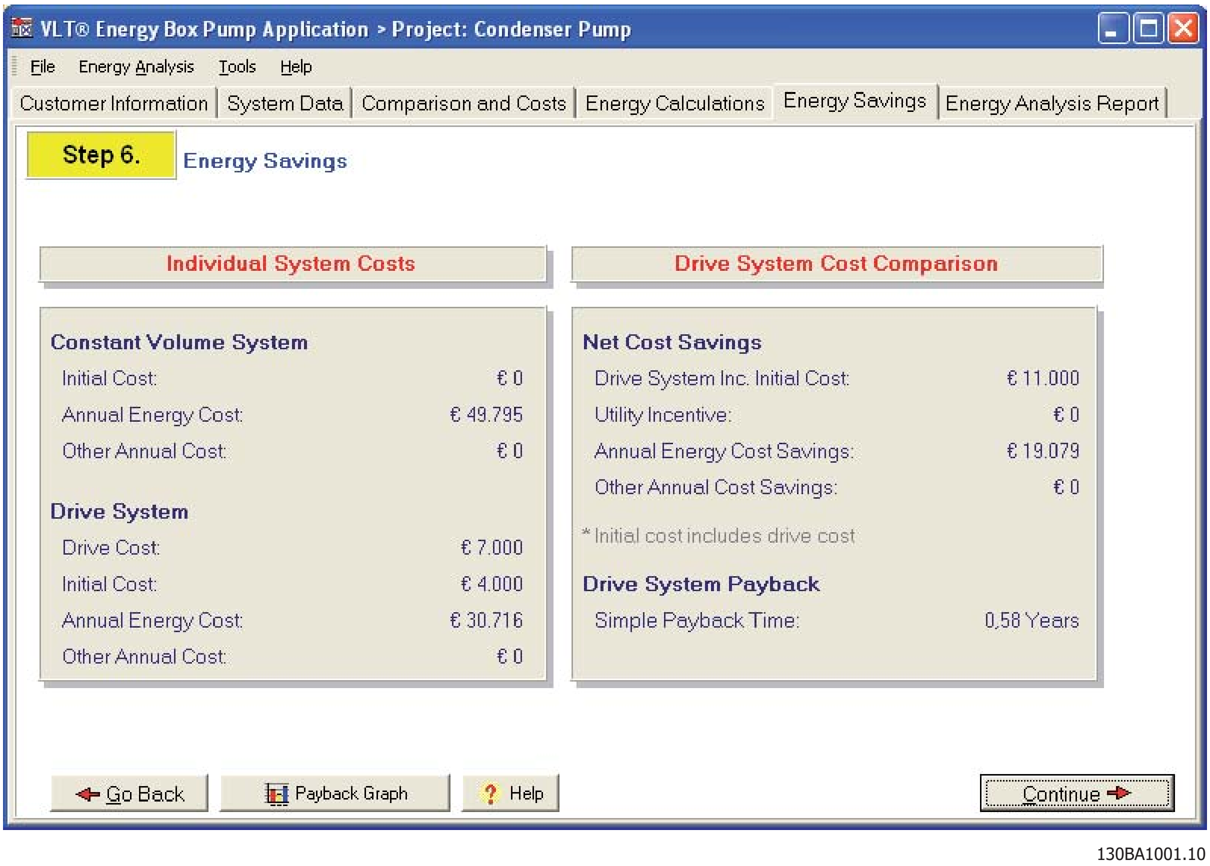


Illustration 5.9: Energy Box Financial Calculation

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 frequency converter 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 that 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 frequency converter 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 frequency converter 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 frequency converter speed increases to maximum speed to attempt to produce the full pressure. If the frequency converter 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.

5.5.4 Energy log and trending

The frequency converter continuously accumulates the consumption of the actual power from the frequency converter 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 frequency converters, reducing or eliminating the need for external devices.

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

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

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.

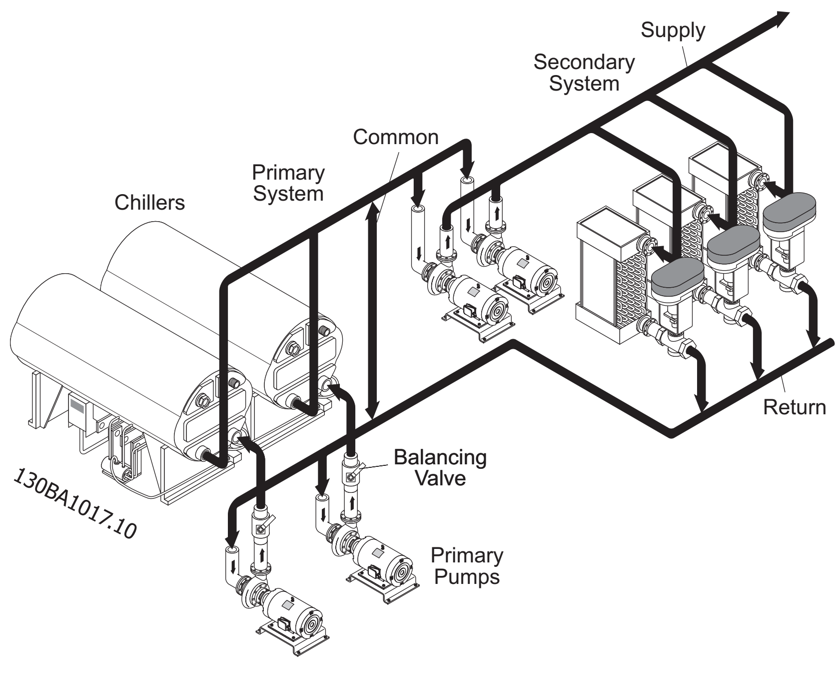


Illustration 6.1: Traditional Primary/Secondary Pumping System Design

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.

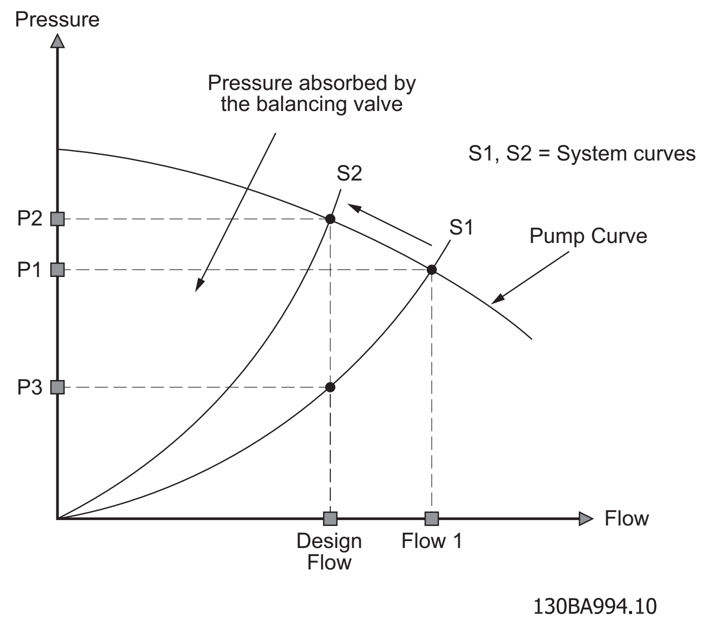


Illustration 6.2: Balancing Valve Pressure Loss

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.

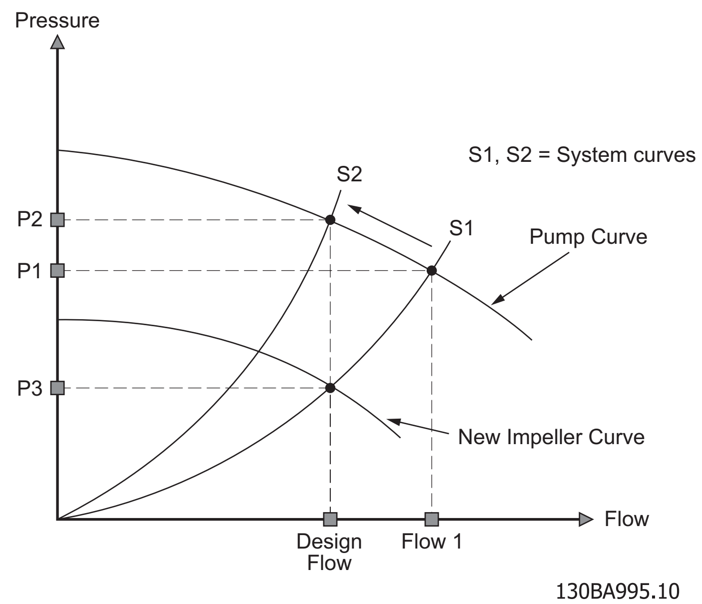


Illustration 6.3: Pump Impeller Trimming

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.

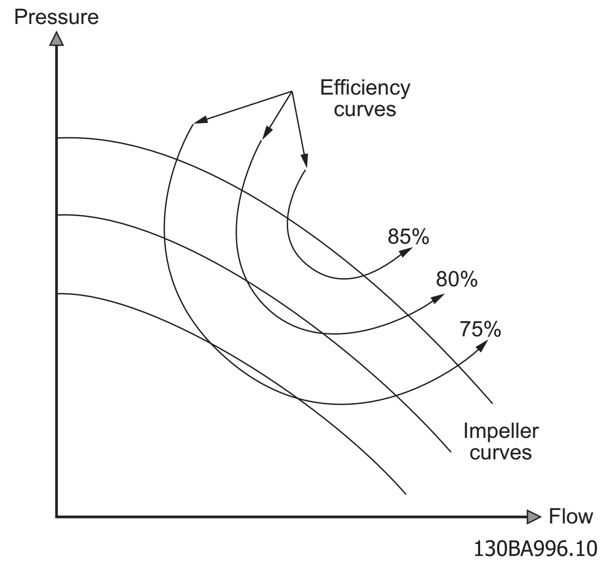


Illustration 6.4: Pump Efficiency Curves

6.2.2 Frequency converter primary loop control

Based on the size of the system, the energy consumption of the primary water loop can be substantial. A frequency converter 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 frequency converter 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 frequency converter to maintain the appropriate flow rate. The frequency converter automatically compensates for scale buildup and changing resistance in the primary piping loop as chillers and pumps are staged on and off.

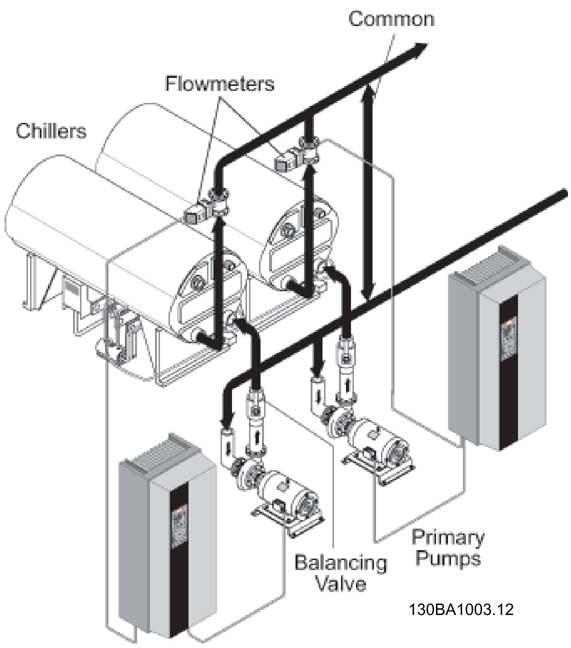


Illustration 6.5: Frequency Converters for Primary Loop Control

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 frequency converters can control primary water pumps without the need to close a balancing valve in the system or reducing impeller size. Using a frequency converter 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 frequency converter are based on the amount the balancing valve is closed.

Using the frequency converter 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.

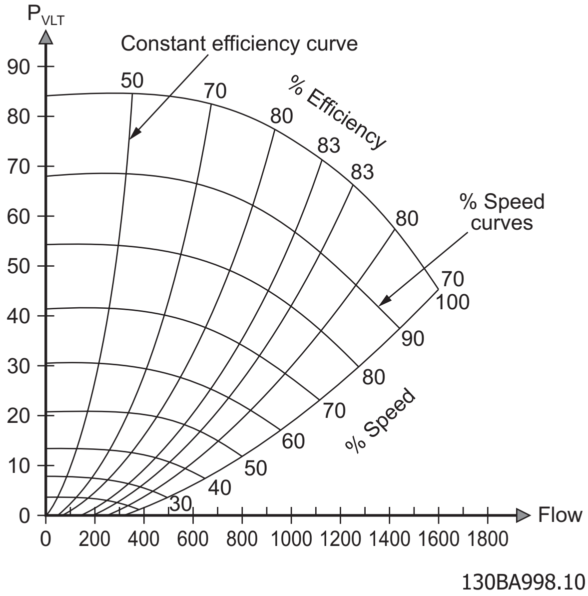


Illustration 6.6: Pump Efficiencies with Variable Speed

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 if the illustration below. It is estimated that the primary pump flow can be reduced to 90% by using a frequency converter 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.

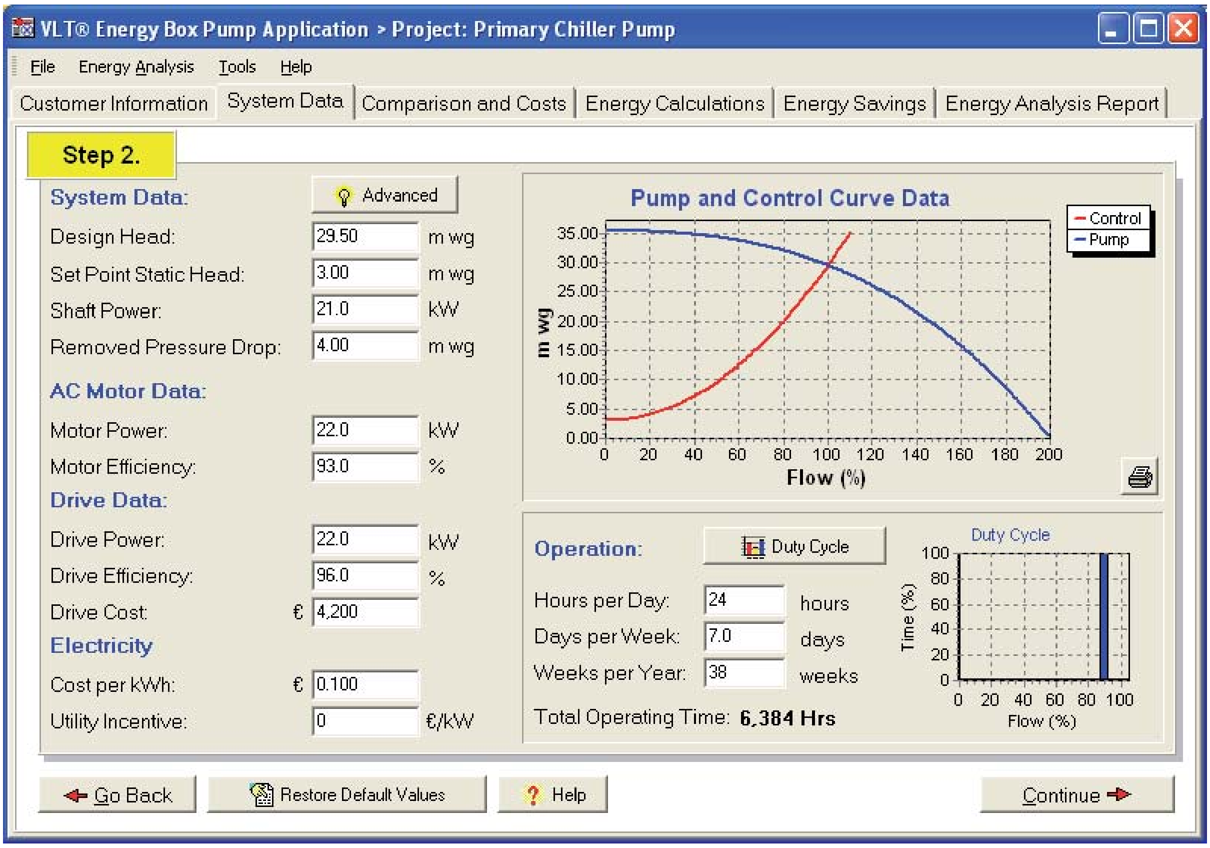
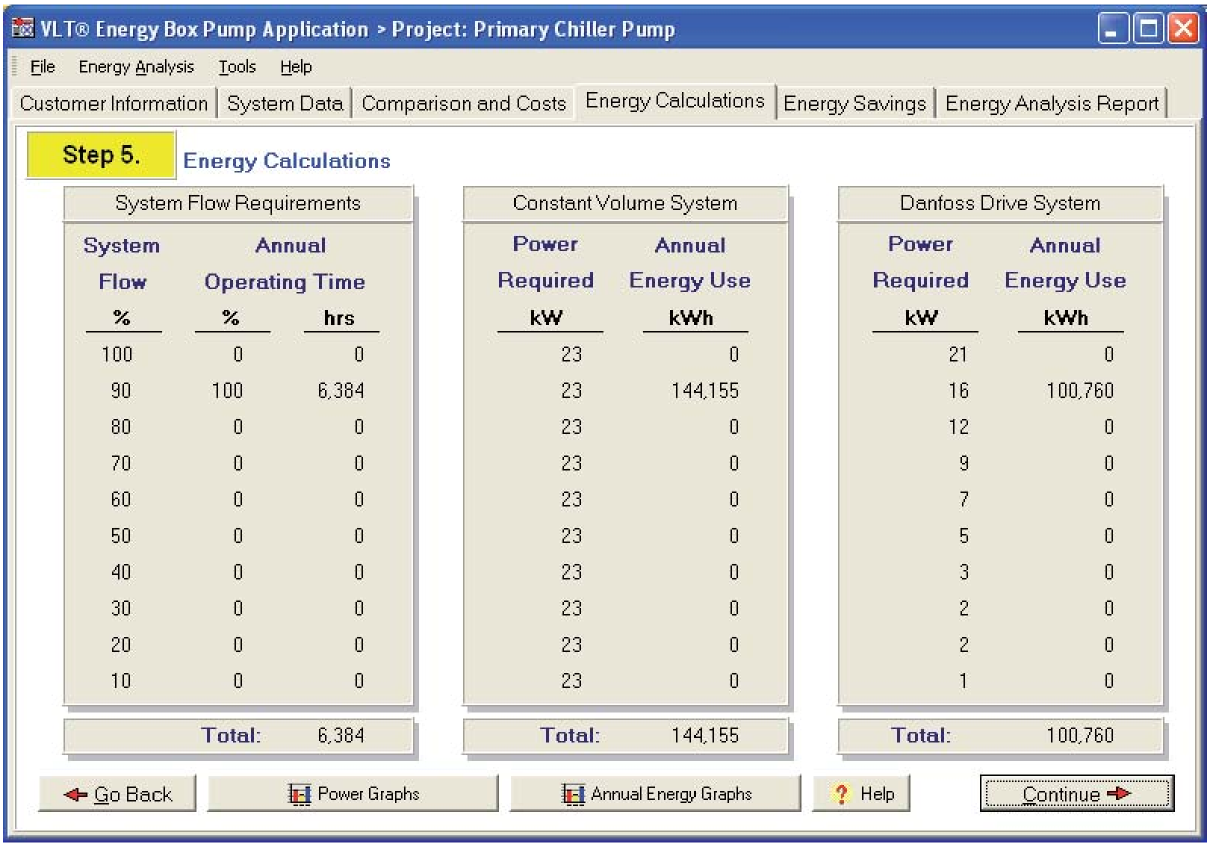


Illustration 6.7: Energy Box Input Data

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.



System Flow Requirements			Constant Volume System		Danfoss Drive System	
System Flow %	Annual Operating Time %	Annual Operating Time hrs	Power Required kW	Annual Energy Use kWh	Power Required kW	Annual Energy Use kWh
100	0	0	23	0	21	0
90	100	6,384	23	144,155	16	100,760
80	0	0	23	0	12	0
70	0	0	23	0	9	0
60	0	0	23	0	7	0
50	0	0	23	0	5	0
40	0	0	23	0	3	0
30	0	0	23	0	2	0
20	0	0	23	0	2	0
10	0	0	23	0	1	0
	Total:	6,384	Total:	144,155	Total:	100,760

130BA1005.10

Illustration 6.8: Annual Energy Consumption

6

The program also calculates the simple payback period for the frequency converter including cost for the drive, installation, wiring and other control components that may be needed. The illustration below shows a payback of 1.42 years to upgrade an existing primary pump system. The Energy Box Analysis and report can be printed, faxed or emailed.

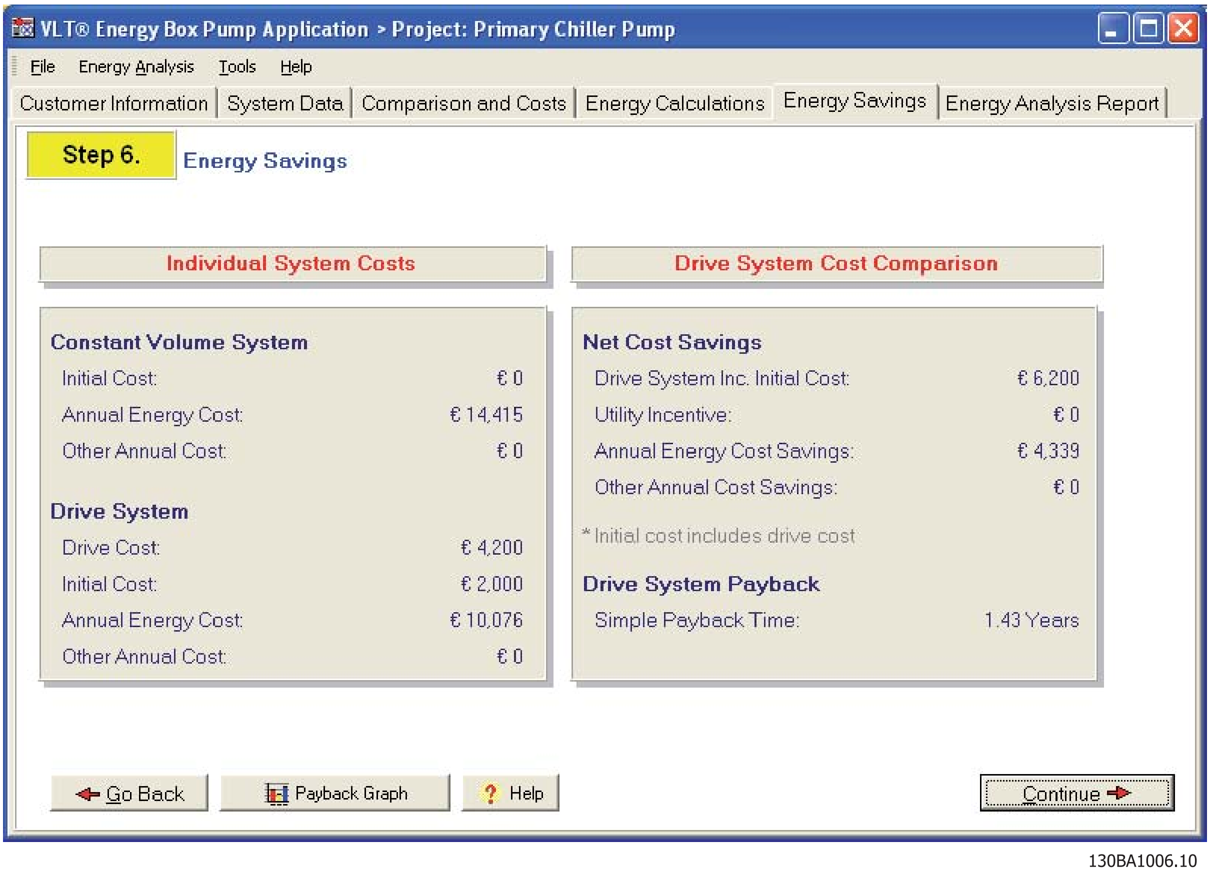


Illustration 6.9: Energy Box Financial Calculation

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 frequency converter 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 that 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 frequency converter 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 frequency converter 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 frequency converter speed increases to maximum speed to attempt to produce the full pressure. If the frequency converter 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 frequency converter continuously accumulates the consumption of the actual power from the frequency converter 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 frequency converters, reducing or eliminating the need for external devices.

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

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.

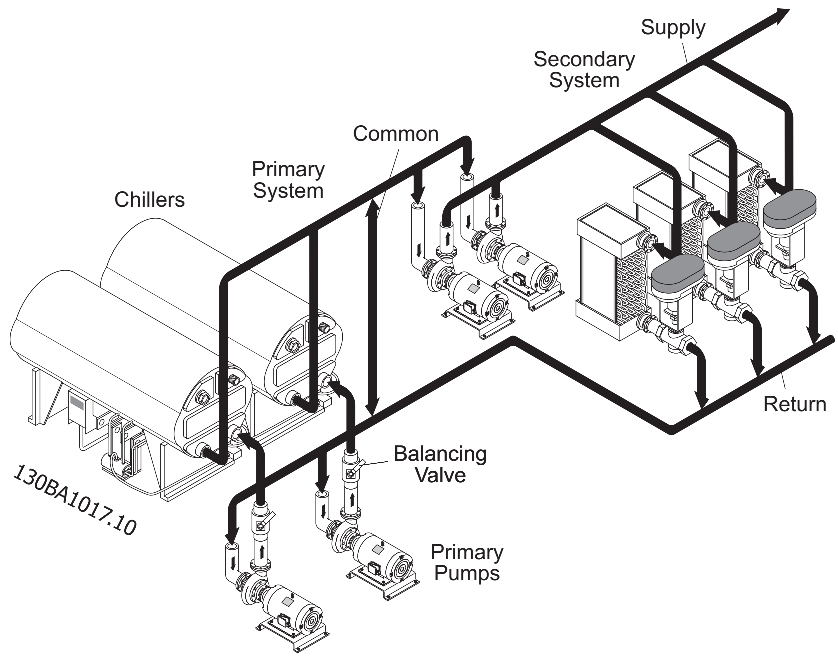


Illustration 7.1: Primary/Secondary Pumping System

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.

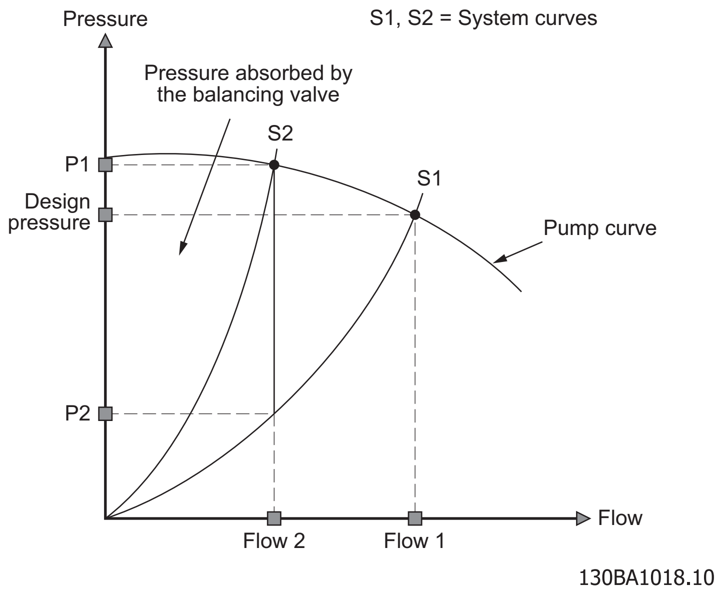


Illustration 7.2: Pressure Absorbed by Two-way Valve

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 Δ T 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 frequency converters 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 frequency converter slows the pump to maintain the differential pressure set-point value. The frequency converter 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.

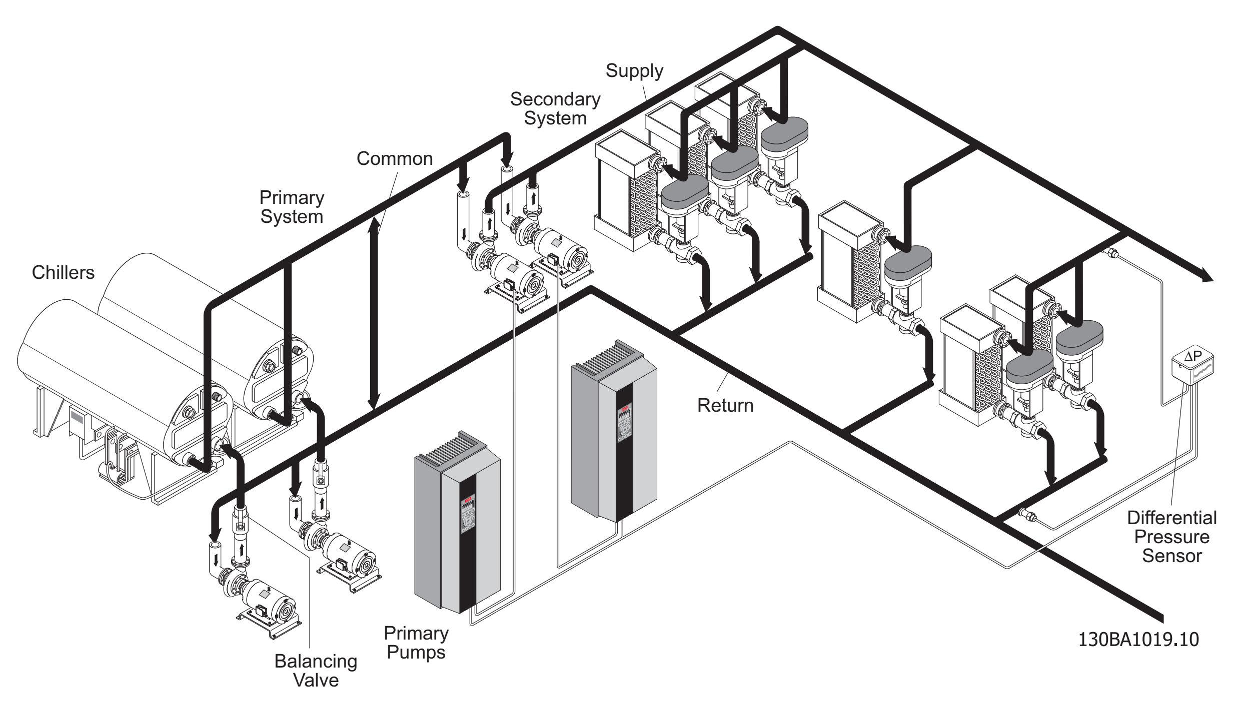


Illustration 7.3: Secondary Pumping System with Frequency Converters

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 frequency converter 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.

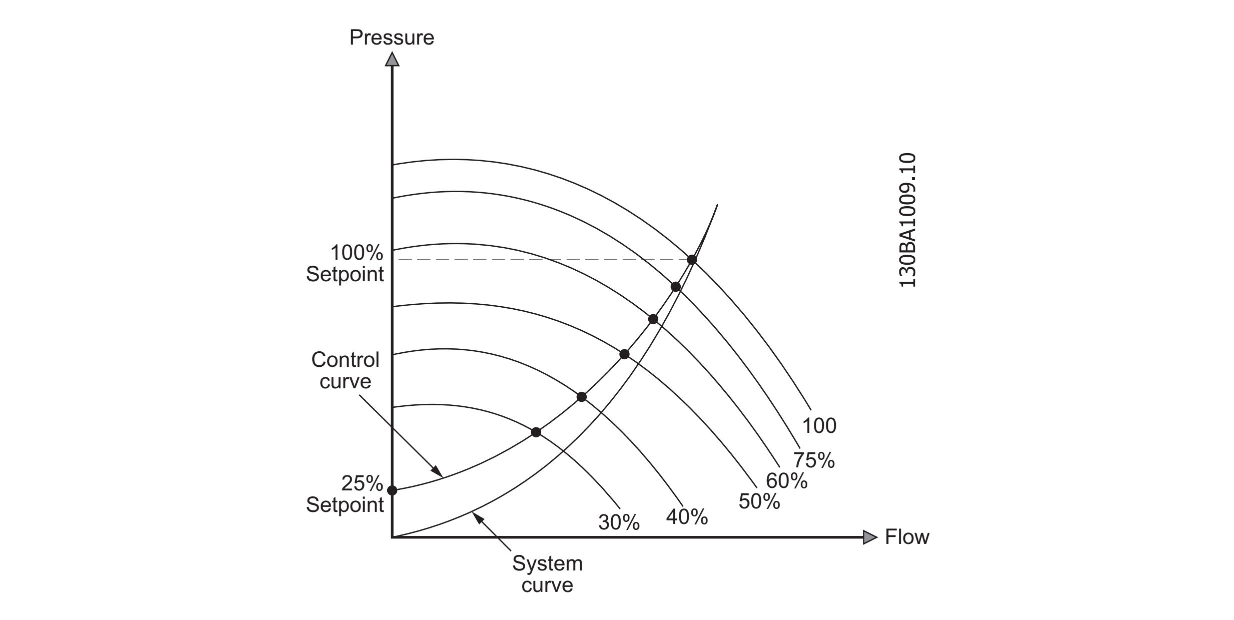


Illustration 7.4: Variable Speed Pump Curves

7.3 Sensors

7.3.1 Sensor type and placement

While the energy savings of a properly installed frequency converter 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 frequency converter 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.

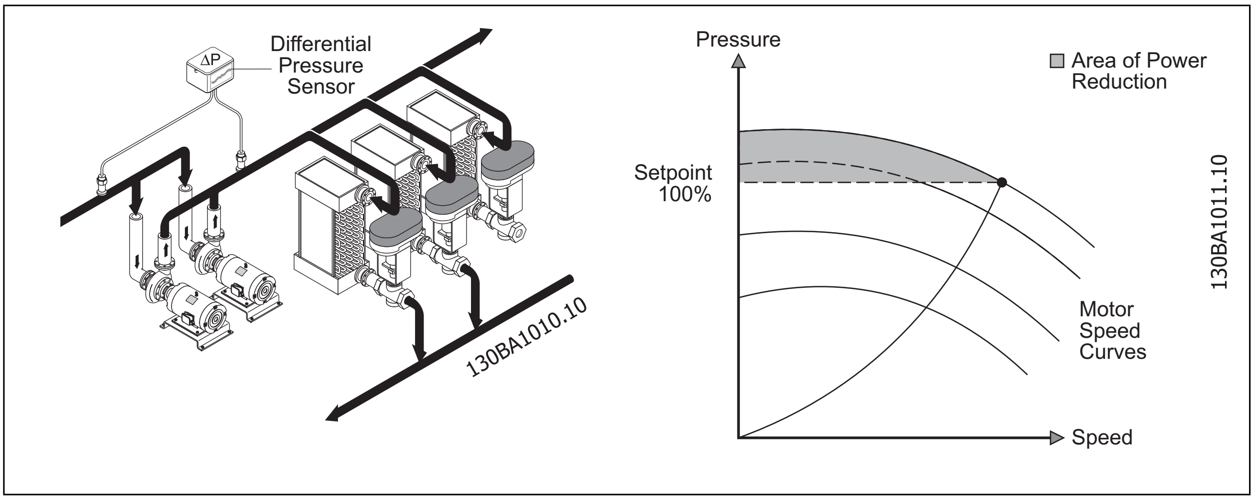


Table 7.1: Sensor Location with 100% Set-point (Across Pump)

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.

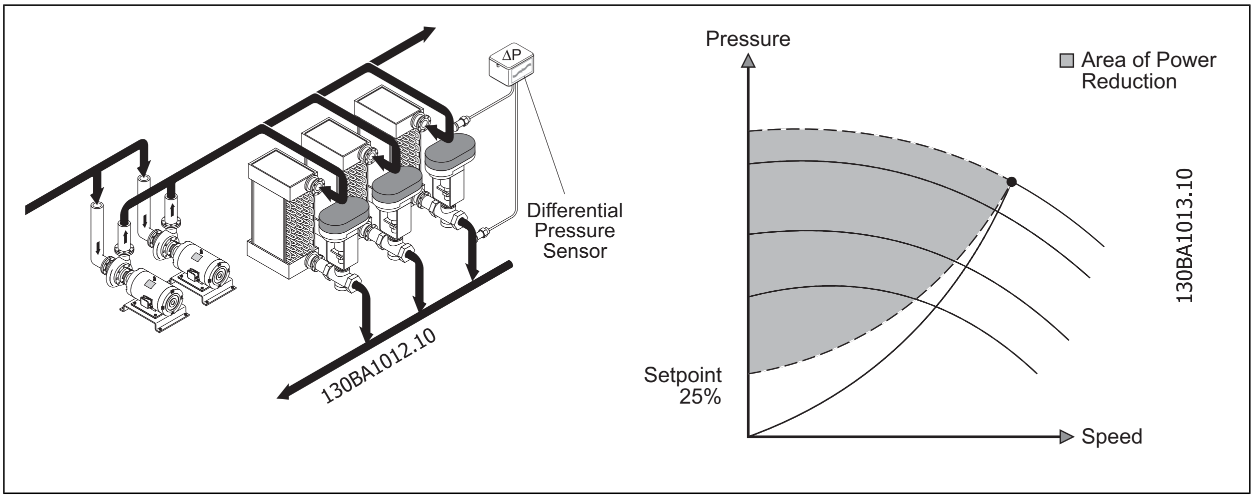


Table 7.2: Sensor Location with 25% Set-point (Across Load)

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.

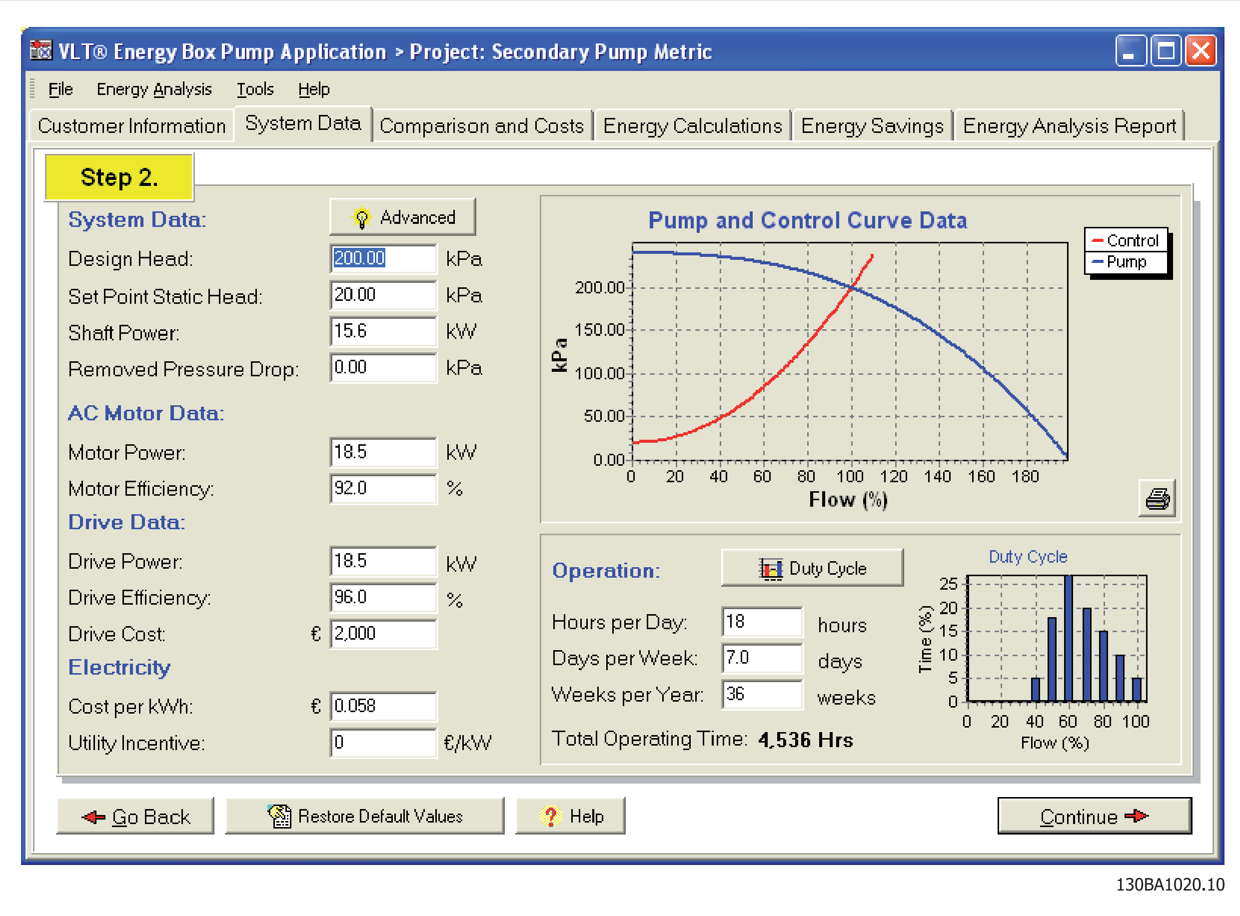
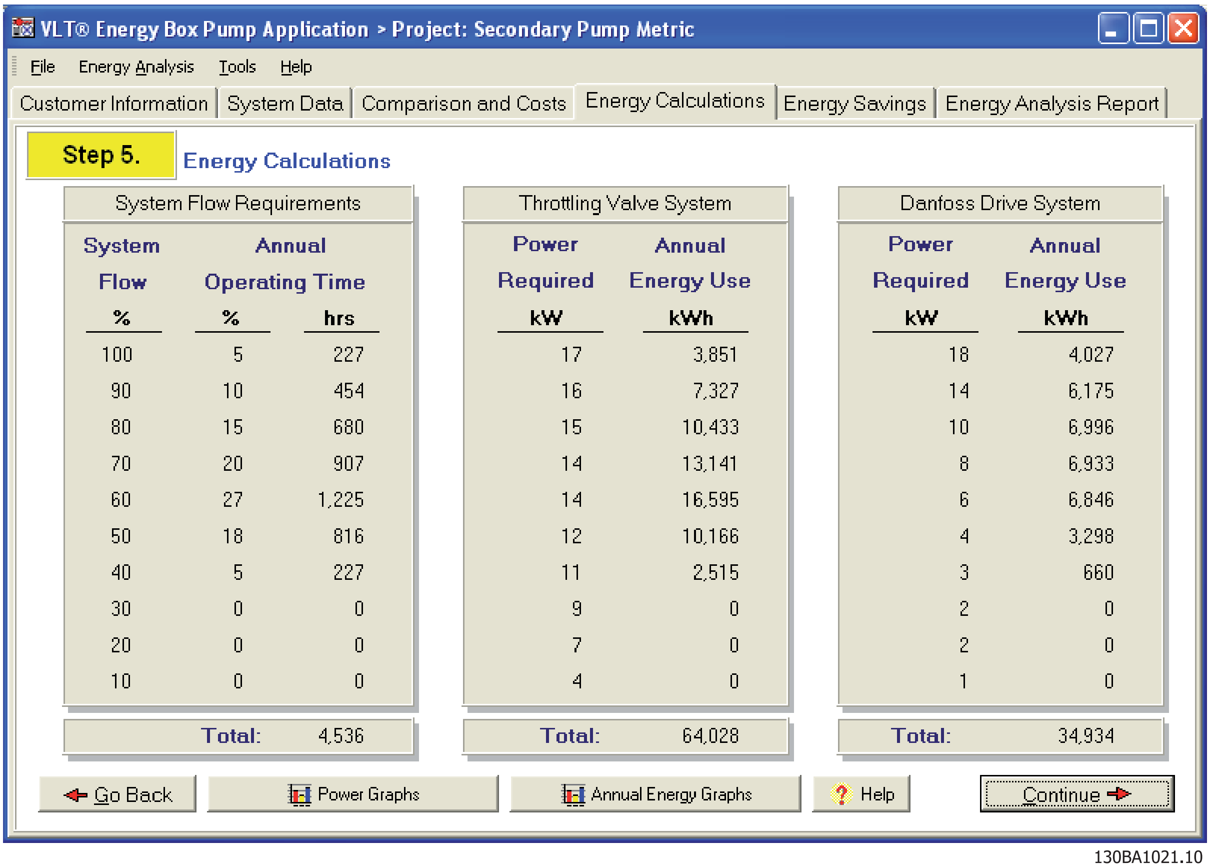


Illustration 7.5: Energy Box Input Data

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.



System Flow %	Annual Operating Time %	Annual Operating Time hrs	Throttling Valve System Power Required kW	Throttling Valve System Annual Energy Use kWh	Danfoss Drive System Power Required kW	Danfoss Drive System Annual Energy Use kWh
100	5	227	17	3,851	18	4,027
90	10	454	16	7,327	14	6,175
80	15	680	15	10,433	10	6,996
70	20	907	14	13,141	8	6,933
60	27	1,225	14	16,595	6	6,846
50	18	816	12	10,166	4	3,298
40	5	227	11	2,515	3	660
30	0	0	9	0	2	0
20	0	0	7	0	2	0
10	0	0	4	0	1	0
	Total:	4,536	Total:	64,028	Total:	34,934

Illustration 7.6: Annual Energy Consumption

The program also calculates the simple payback period for the frequency converter including cost data for the drive, installation, wiring and other control components such as sensors. The illustration below shows a payback of 1.69 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.

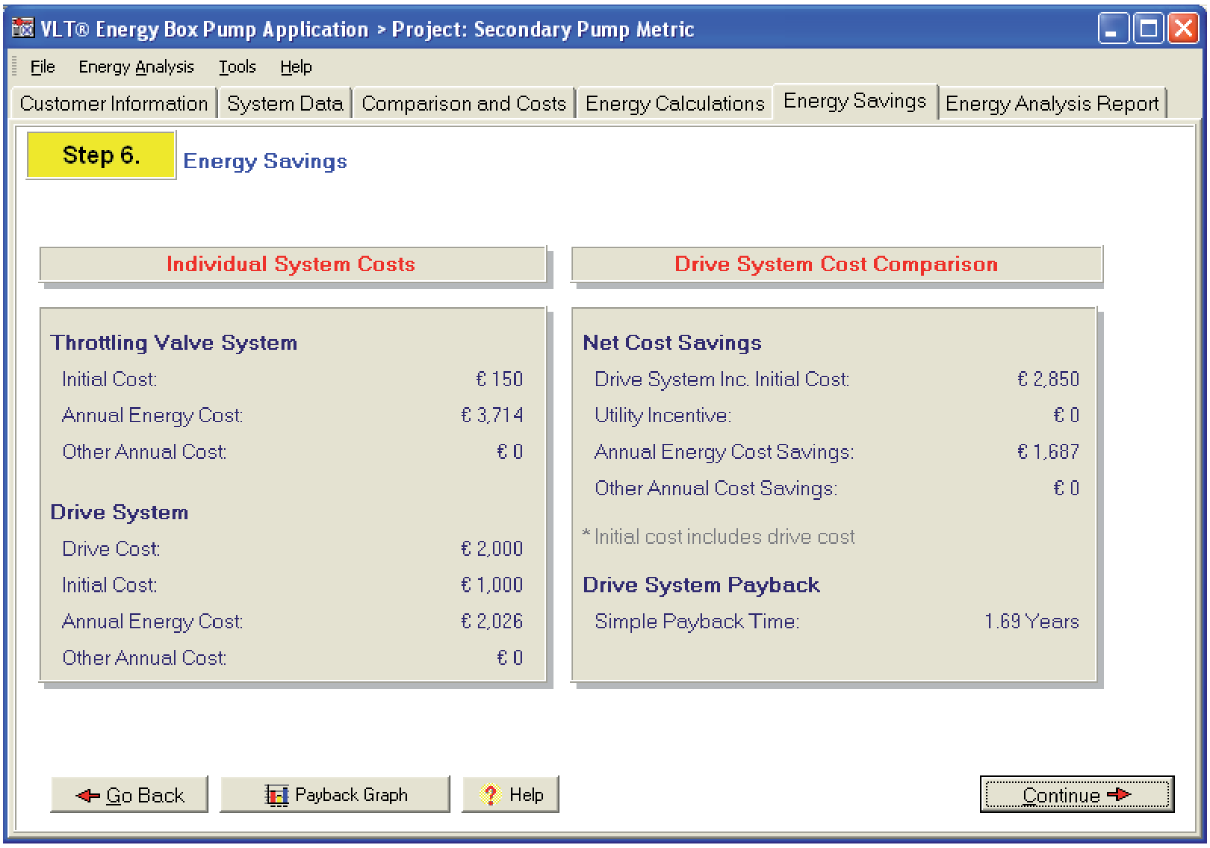


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Illustration 7.7: Energy Box Financial Calculation

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 Muti-zone control

The frequency converter 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 frequency converter 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 frequency converter 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 frequency converter 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 that 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

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 frequency converter 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 frequency converter 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 frequency converter speed increases to maximum speed to attempt to produce the full pressure. If the frequency converter 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 frequency converter continuously accumulates the consumption of the actual power from the frequency converter 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 frequency converters, reducing or eliminating the need for external devices.

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

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.

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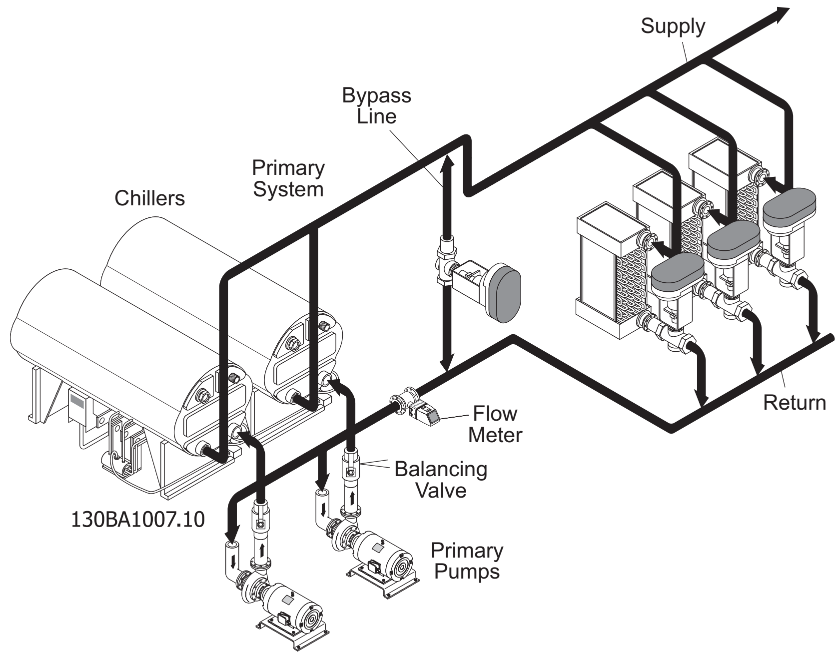

Illustration 8.1: Variable Primary Flow System

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.

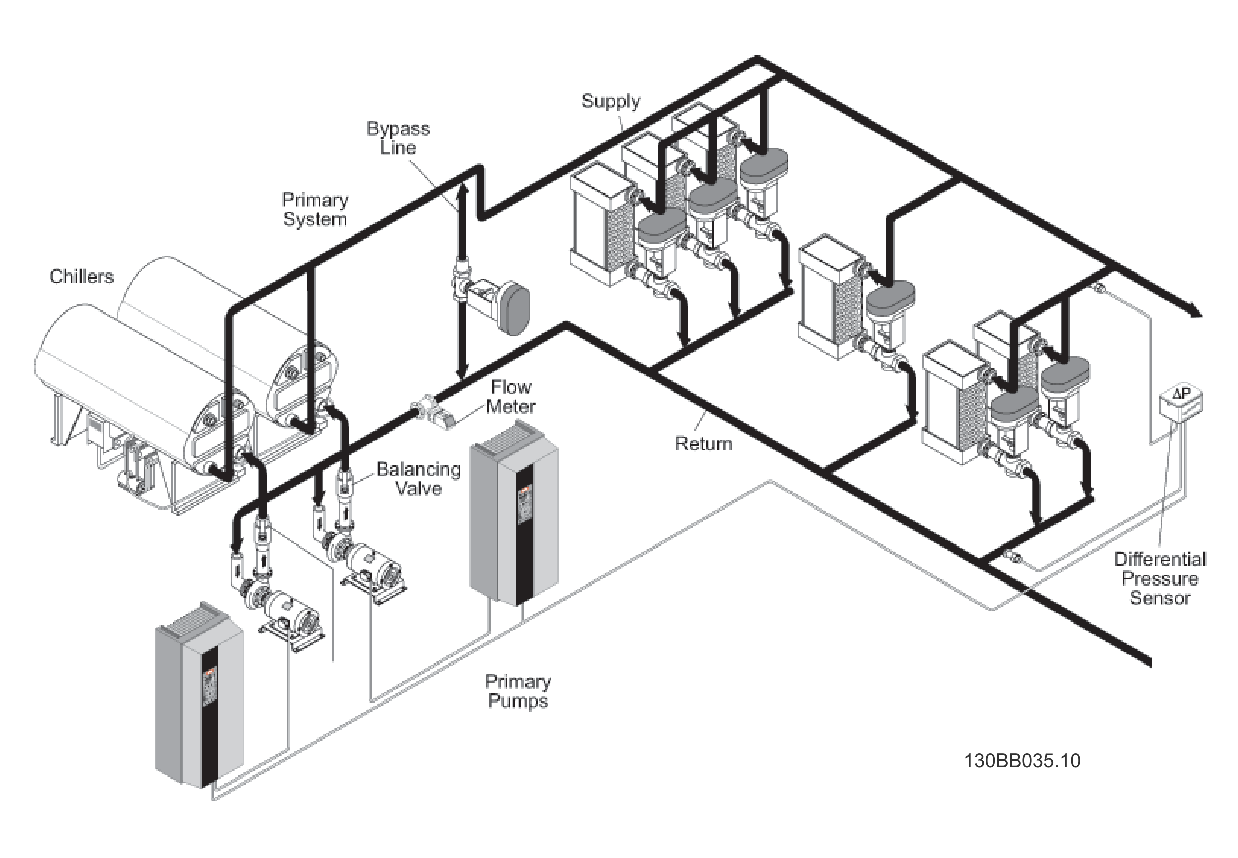

Illustration 8.2: Variable Primary Flow System with frequency converters

When less flow is required, the differential pressure sensor (DP) adjusts the speed of pump frequency converter. 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 frequency converter 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.

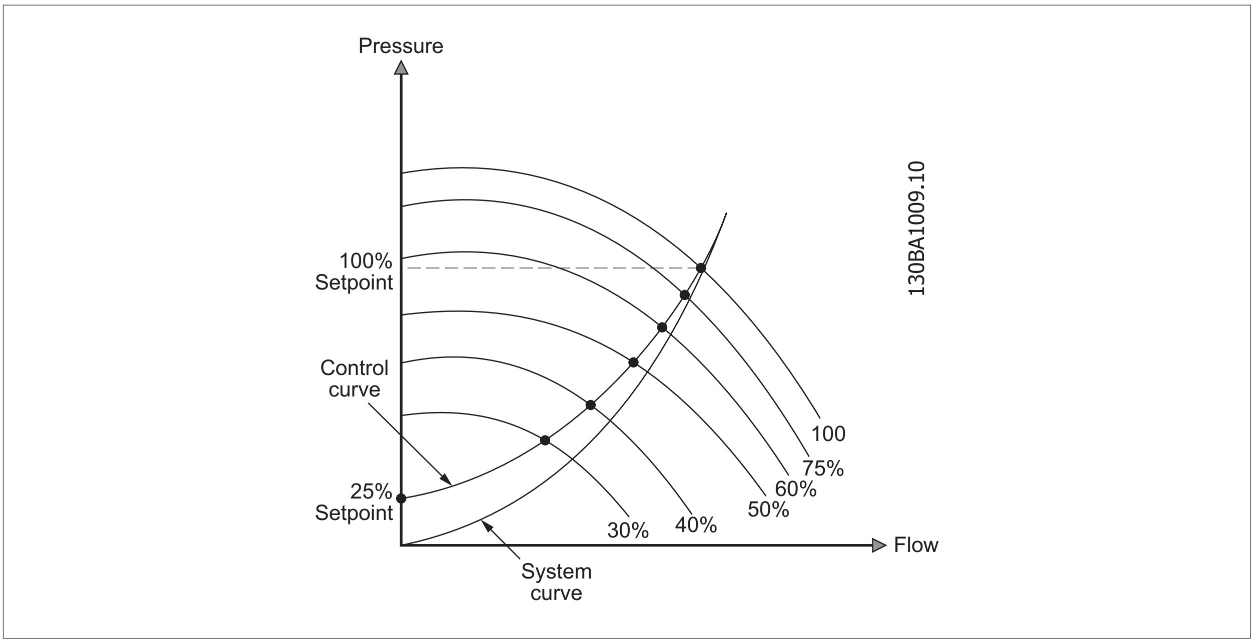

Illustration 8.3: Variable Speed Pump Curves

8.3 Sensors

8.3.1 Sensor type and placement

While the energy savings of a properly installed frequency converter 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 frequency converter 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 cooing 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.

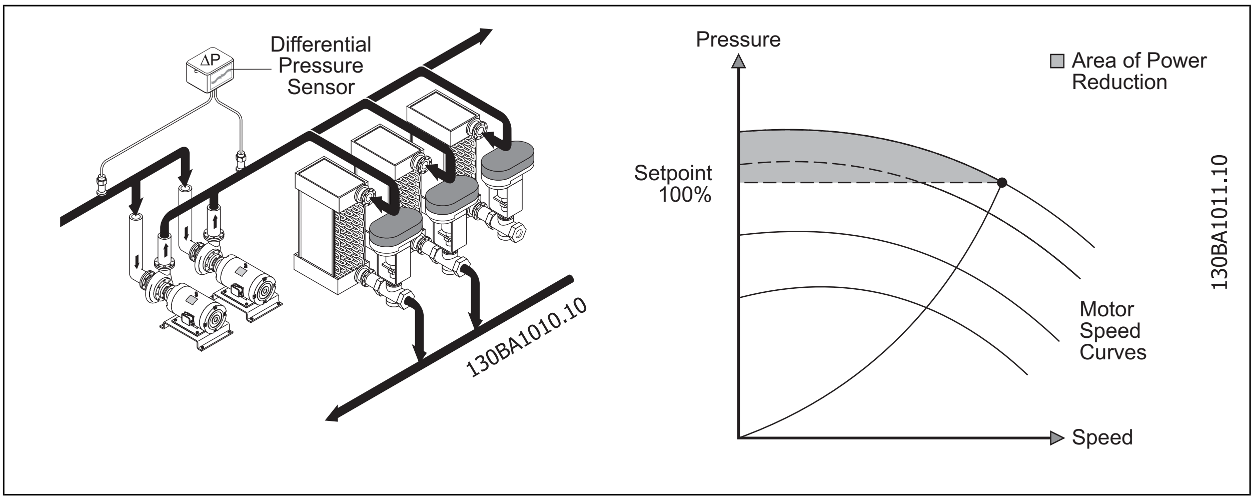

Table 8.1: Sensor Location with 100% Set-point (Across Pump)

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.

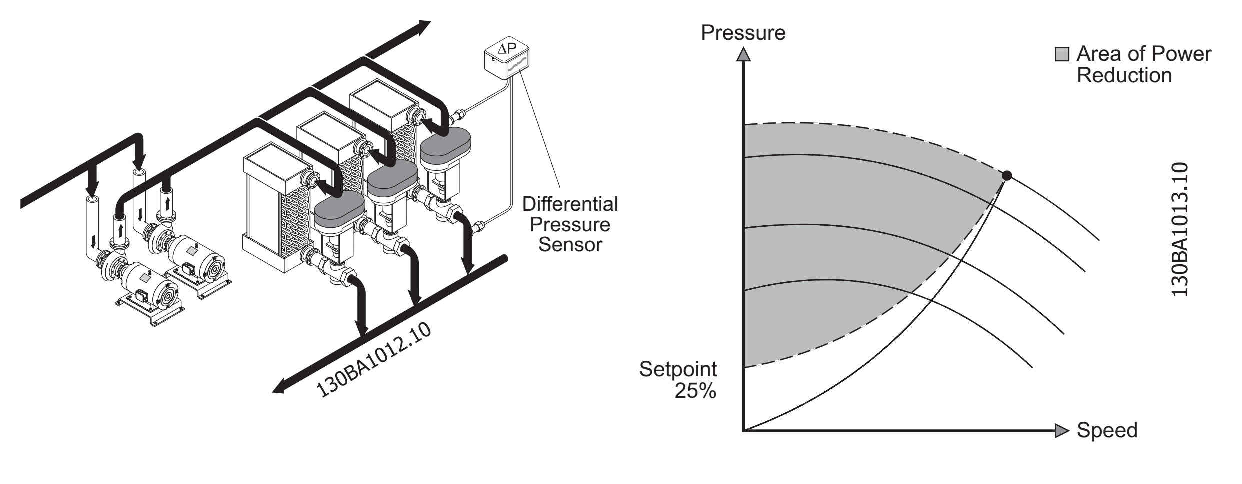

Table 8.2: Sensor Location with 25% Set-point (Across Load)

8.4 Energy Savings Potential

8.4.1 Energy Savings Estimation

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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.

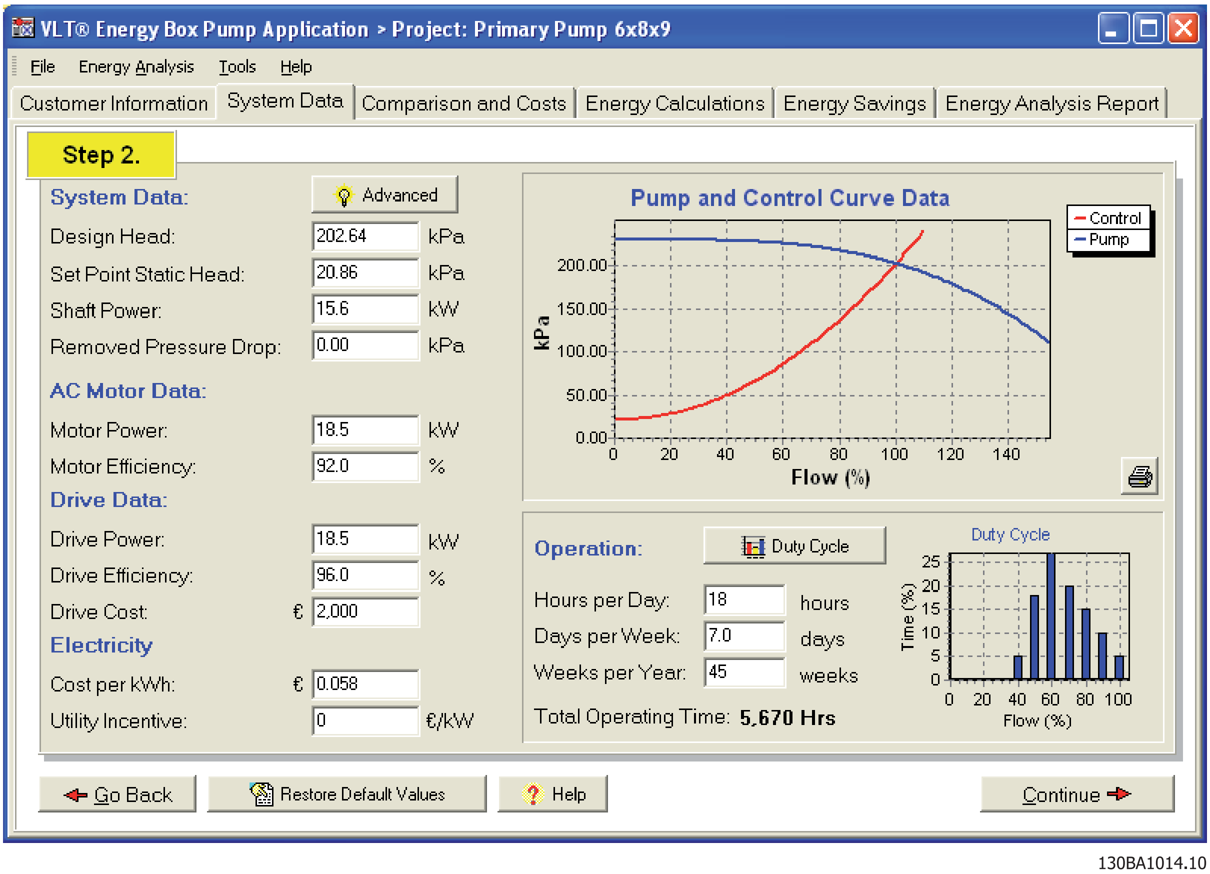
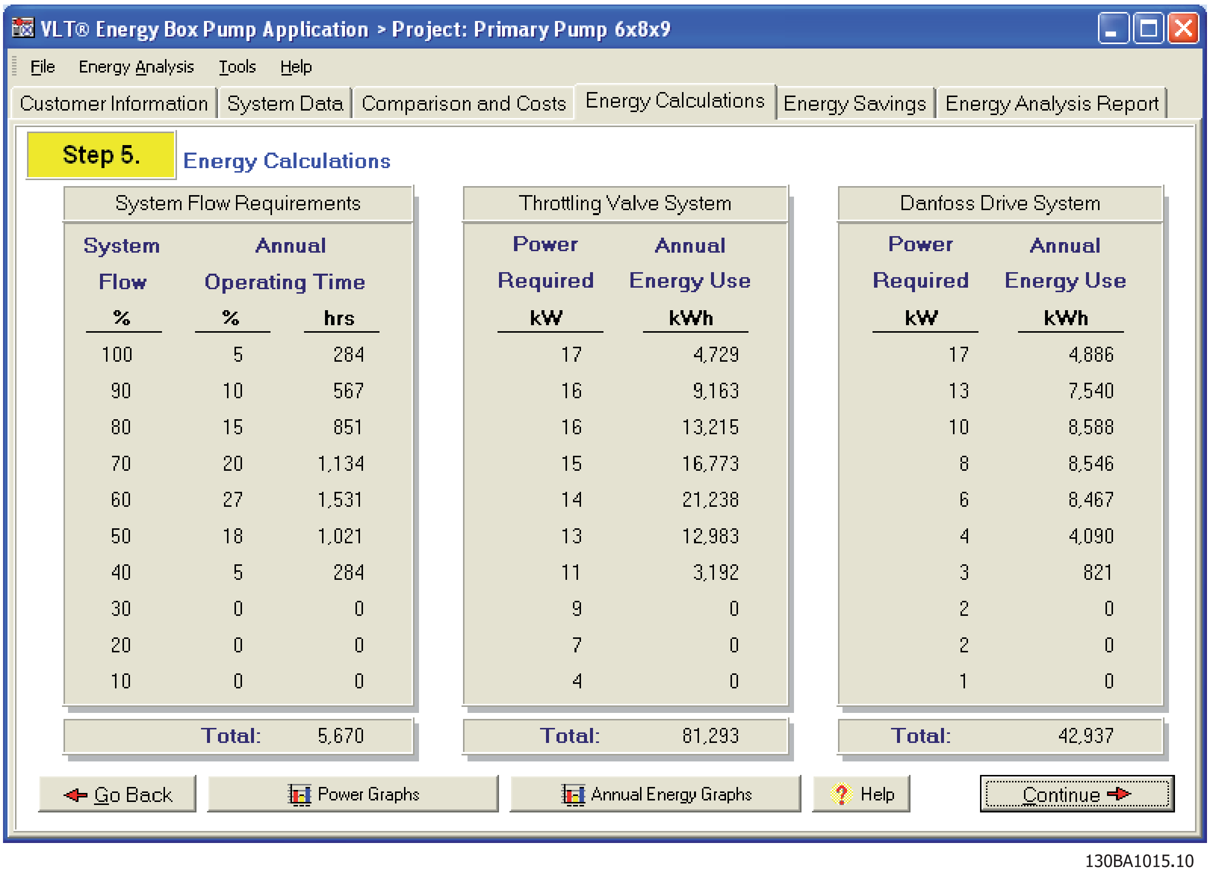


Illustration 8.4: Energy Box Input Data

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.



System Flow Requirements			Throttling Valve System		Danfoss Drive System	
System Flow %	Annual Operating Time %	Annual Operating Time hrs	Power Required kW	Annual Energy Use kWh	Power Required kW	Annual Energy Use kWh
100	5	284	17	4,729	17	4,886
90	10	567	16	9,163	13	7,540
80	15	851	16	13,215	10	8,588
70	20	1,134	15	16,773	8	8,546
60	27	1,531	14	21,238	6	8,467
50	18	1,021	13	12,983	4	4,090
40	5	284	11	3,192	3	821
30	0	0	9	0	2	0
20	0	0	7	0	2	0
10	0	0	4	0	1	0
Total:		5,670	Total:	81,293	Total:	42,937

Illustration 8.5: Annual Energy Consumption

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The program also calculates the simple payback period for the frequency converter including cost data for the drive, installation, wiring and other control components such as sensors. The illustration below shows a payback of 1.28 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

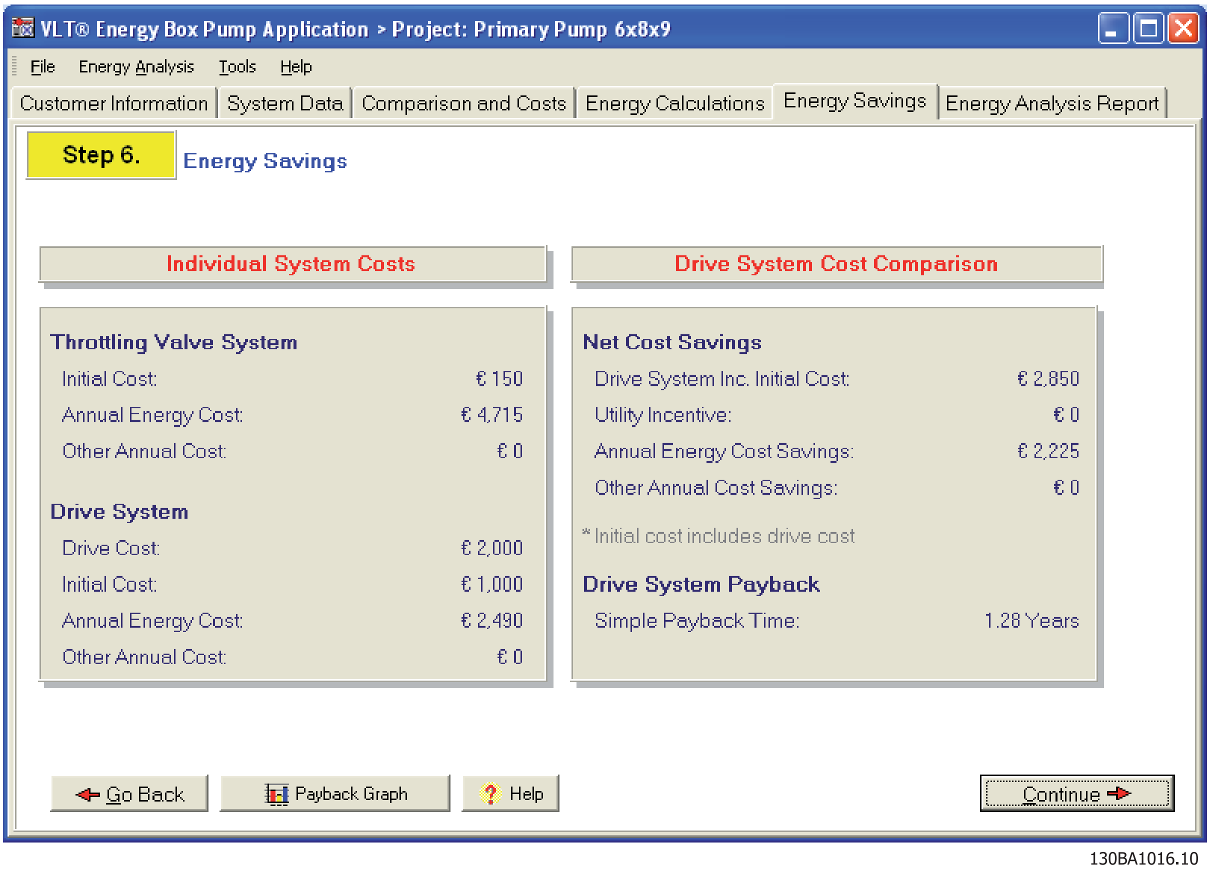


Illustration 8.6: Energy Box Financial Calculation

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 frequency converter 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 frequency converter 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 frequency converter 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 frequency converter 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 that 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 frequency converter 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 frequency converter 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 frequency converter speed increases to maximum speed to attempt to produce the full pressure. If the frequency converter 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 frequency converter continuously accumulates the consumption of the actual power from the frequency converter 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 frequency converters, reducing or eliminating the need for external devices.

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

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.

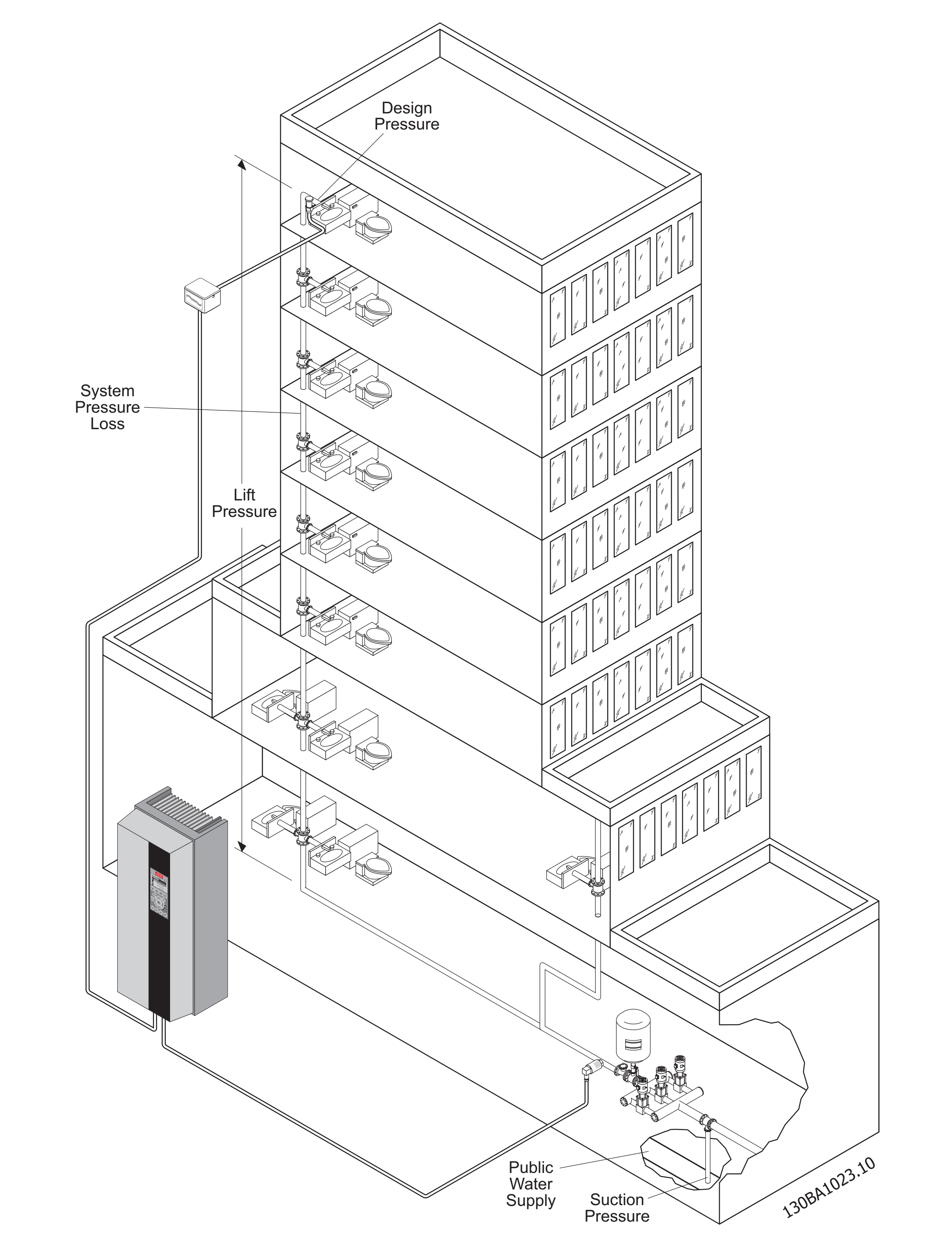


Illustration 9.1: Typical Building Pressure Booster System

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.

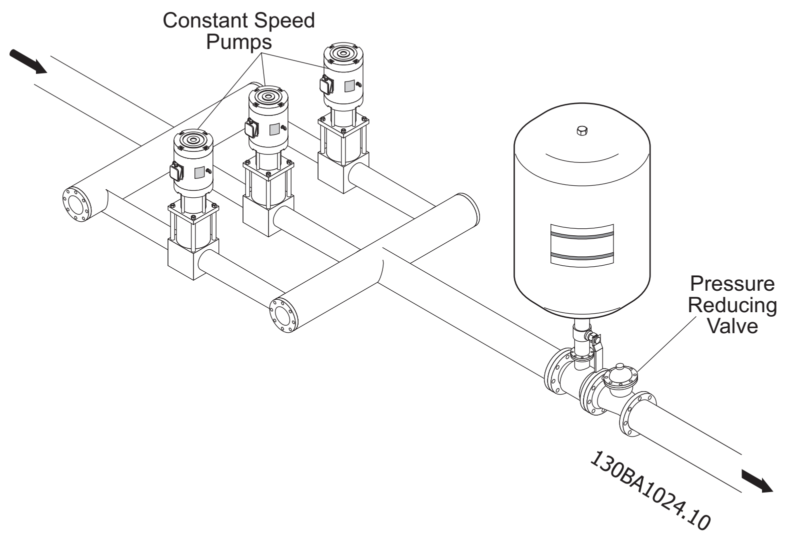


Illustration 9.2: Pressure Booster System

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.

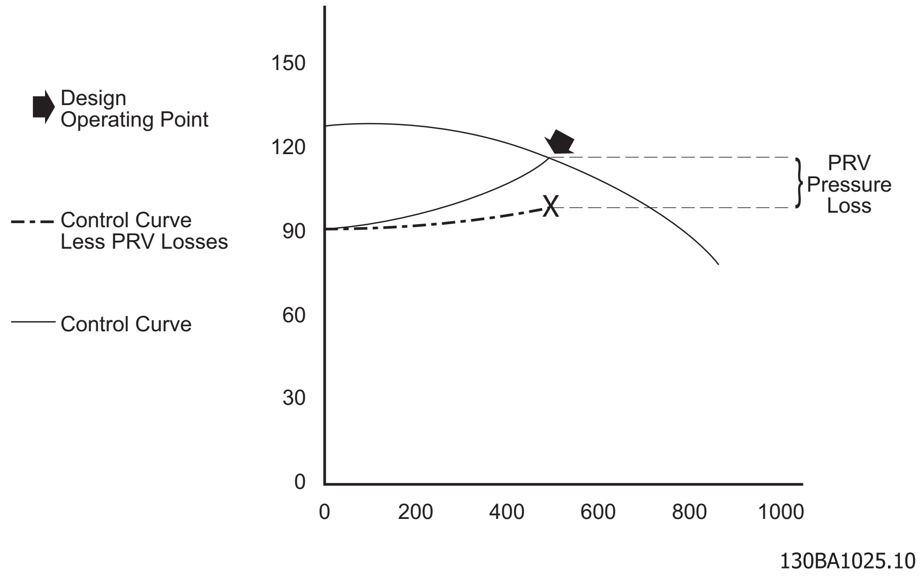


Illustration 9.3: Constant Speed Control Curves

9.2.2 Variable speed booster pump control

Variable Speed Pressure booster systems offer several benefits which make installing a frequency converter 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 frequency converter from three additional factors: pump over-sizing, PRV head losses and changing suction pressure.

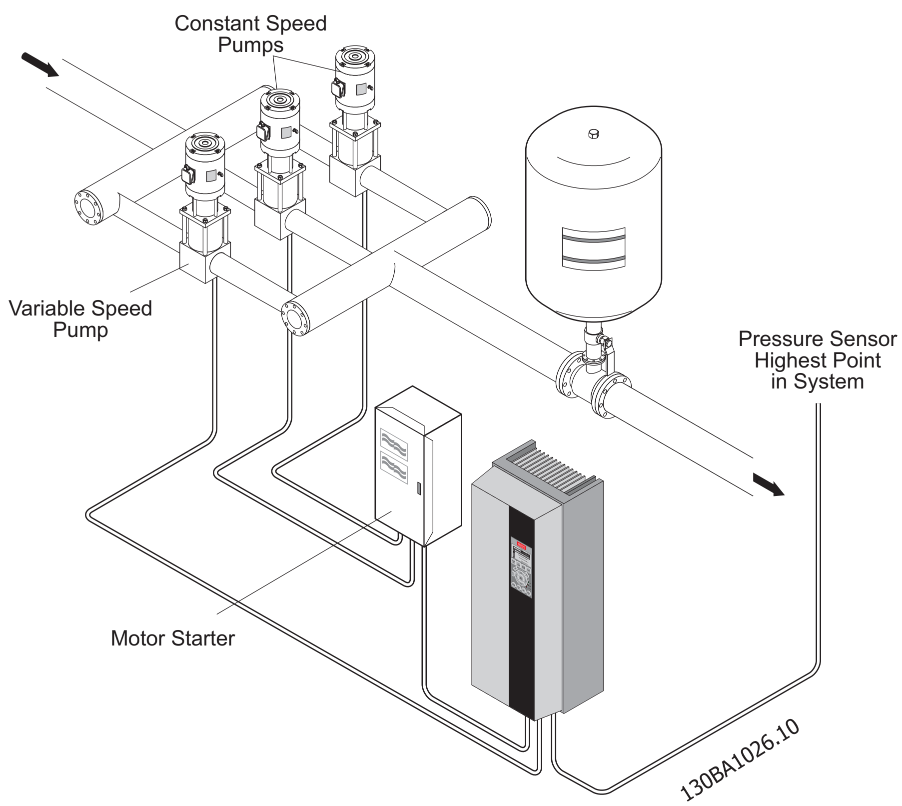


Illustration 9.4: Standard Cascade Controller

A pressure transducer located at the highest point in the system sends a signal to the frequency converter 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.

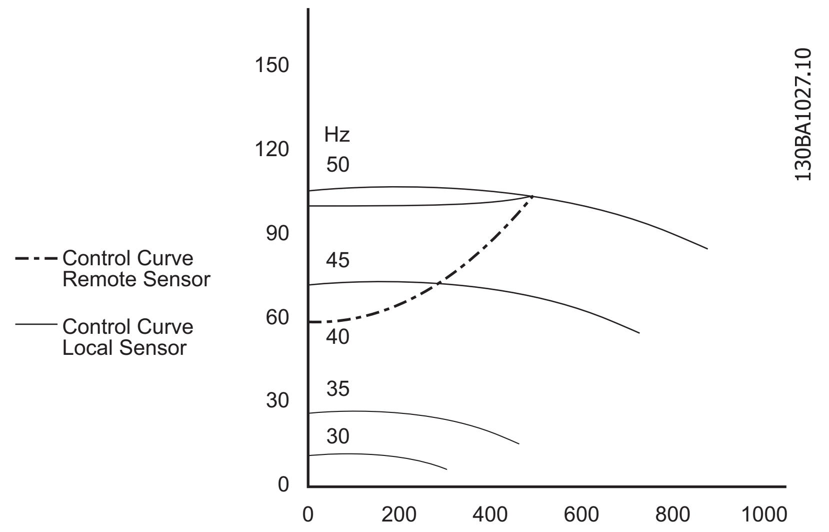


Illustration 9.5: Variable Speed Control Curve

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 simultaneous. 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 frequency converter 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 frequency converter 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 frequency converters 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 frequency converter 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 frequency converter provides only a small reduction in pump speed, which can occur with a flat control curve.

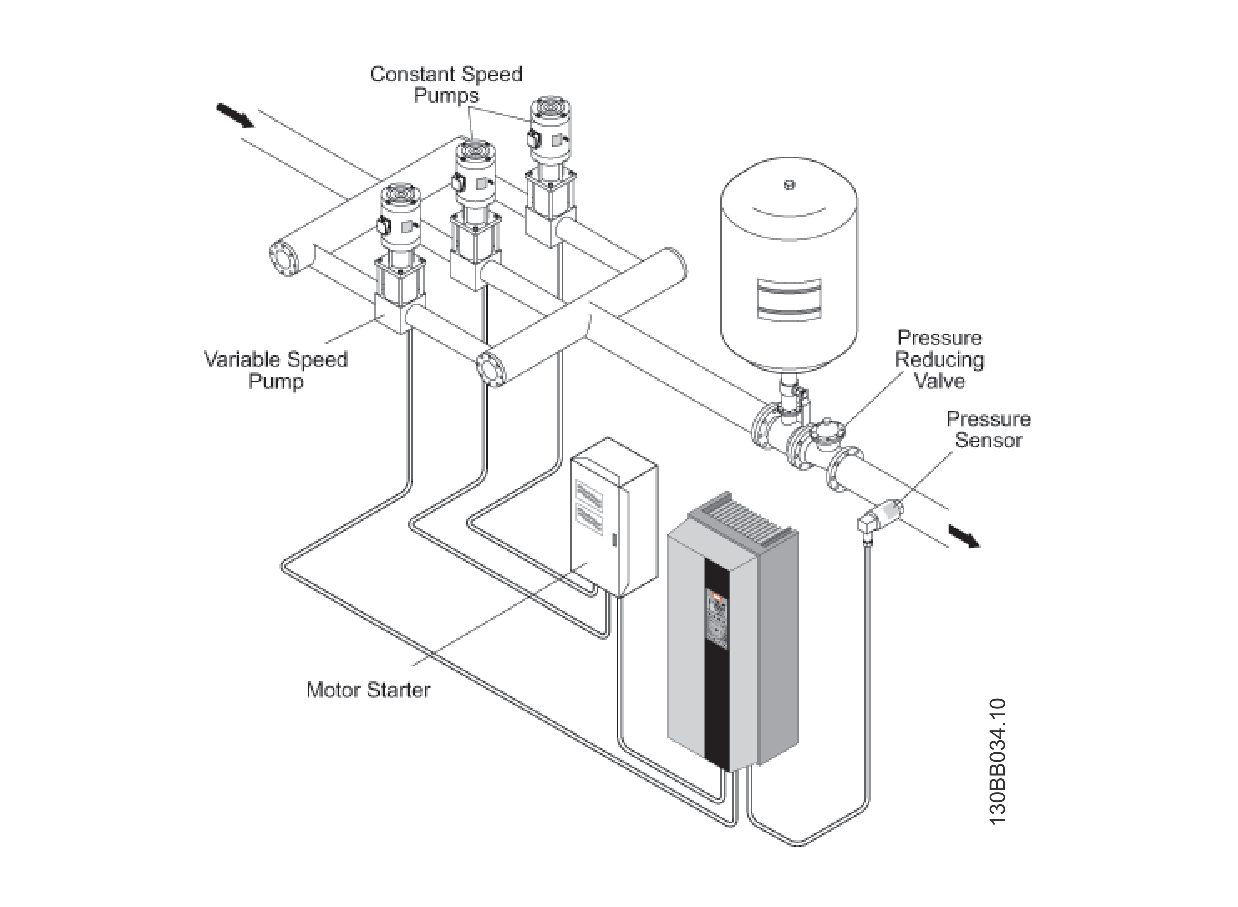


Illustration 9.6: Local sensor placement

By placing the sensor at the highest point in the system (see Standard Cascade Controller, chapter 9.2.2), the frequency converter 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.

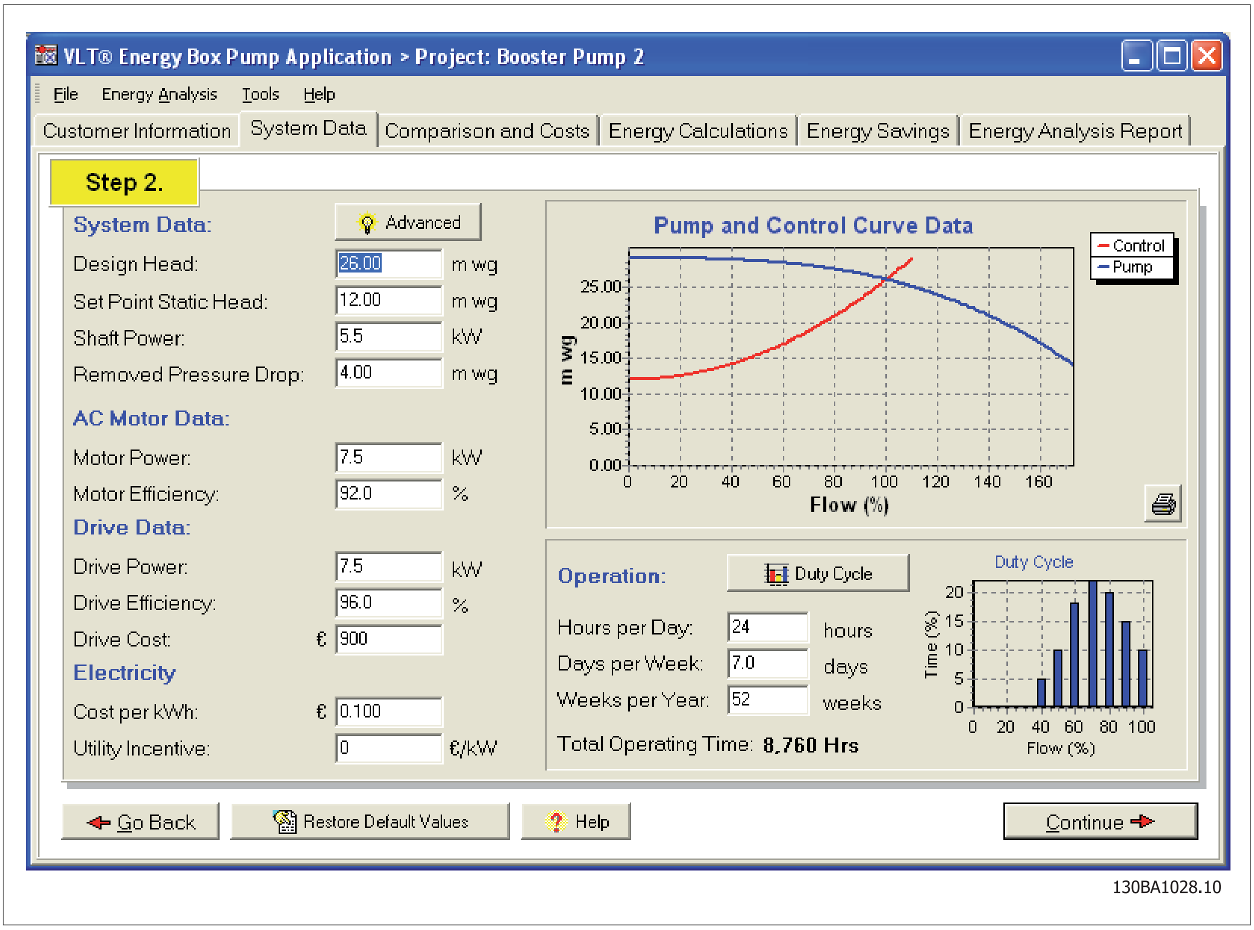
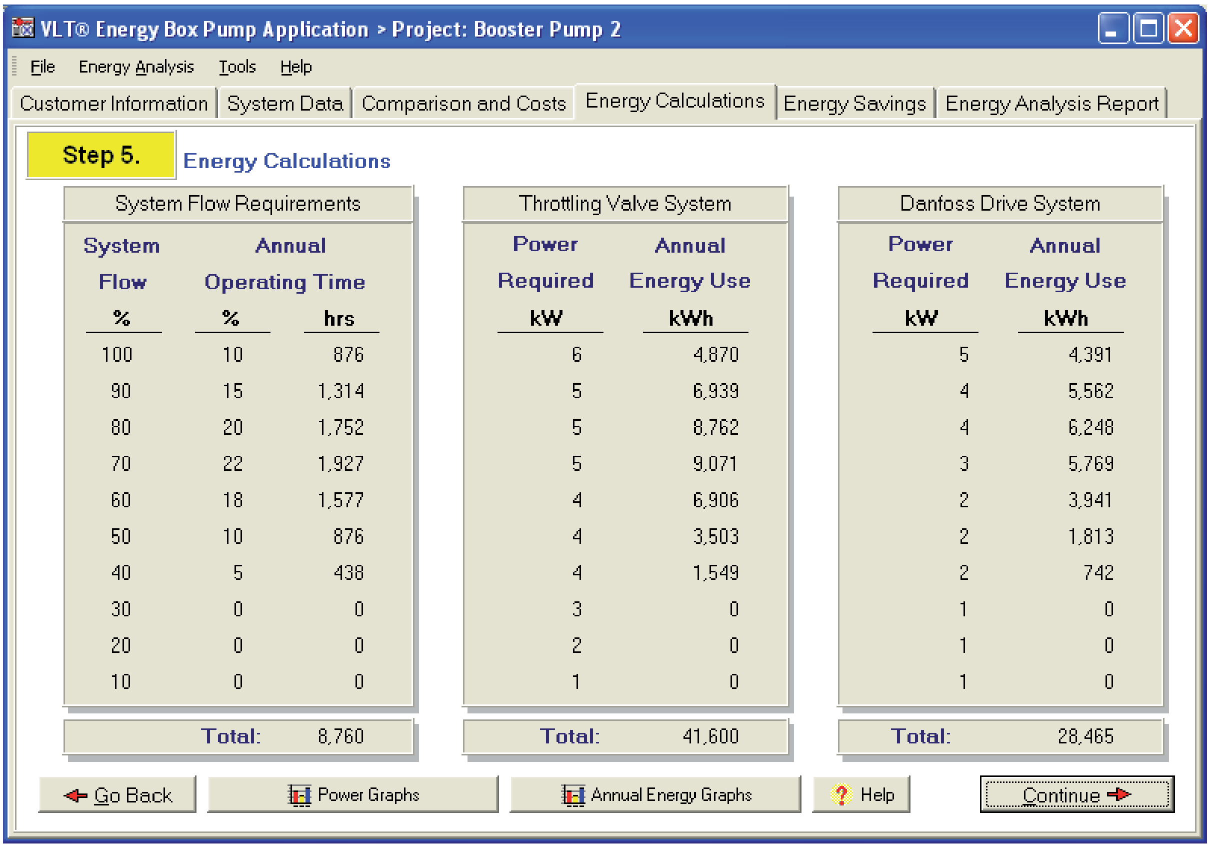


Illustration 9.7: Energy Box Input Data

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.



System Flow Requirements			Throttling Valve System		Danfoss Drive System	
System Flow	Annual Operating Time		Power Required	Annual Energy Use	Power Required	Annual Energy Use
%	%	hrs	kW	kWh	kW	kWh
100	10	876	6	4,870	5	4,391
90	15	1,314	5	6,939	4	5,562
80	20	1,752	5	8,762	4	6,248
70	22	1,927	5	9,071	3	5,769
60	18	1,577	4	6,906	2	3,941
50	10	876	4	3,503	2	1,813
40	5	438	4	1,549	2	742
30	0	0	3	0	1	0
20	0	0	2	0	1	0
10	0	0	1	0	1	0
	Total:	8,760	Total:	41,600	Total:	28,465

Illustration 9.8: Annual Energy Consumption

The program also calculates the simple payback period for the frequency converter including cost data for the drive, installation, wiring and other control components such as sensors. The illustration below shows a payback of 1.29 years to use a VLT® HVAC Drive for a booster pump application. The Energy Box Analysis and report can be printed, faxed or emailed.

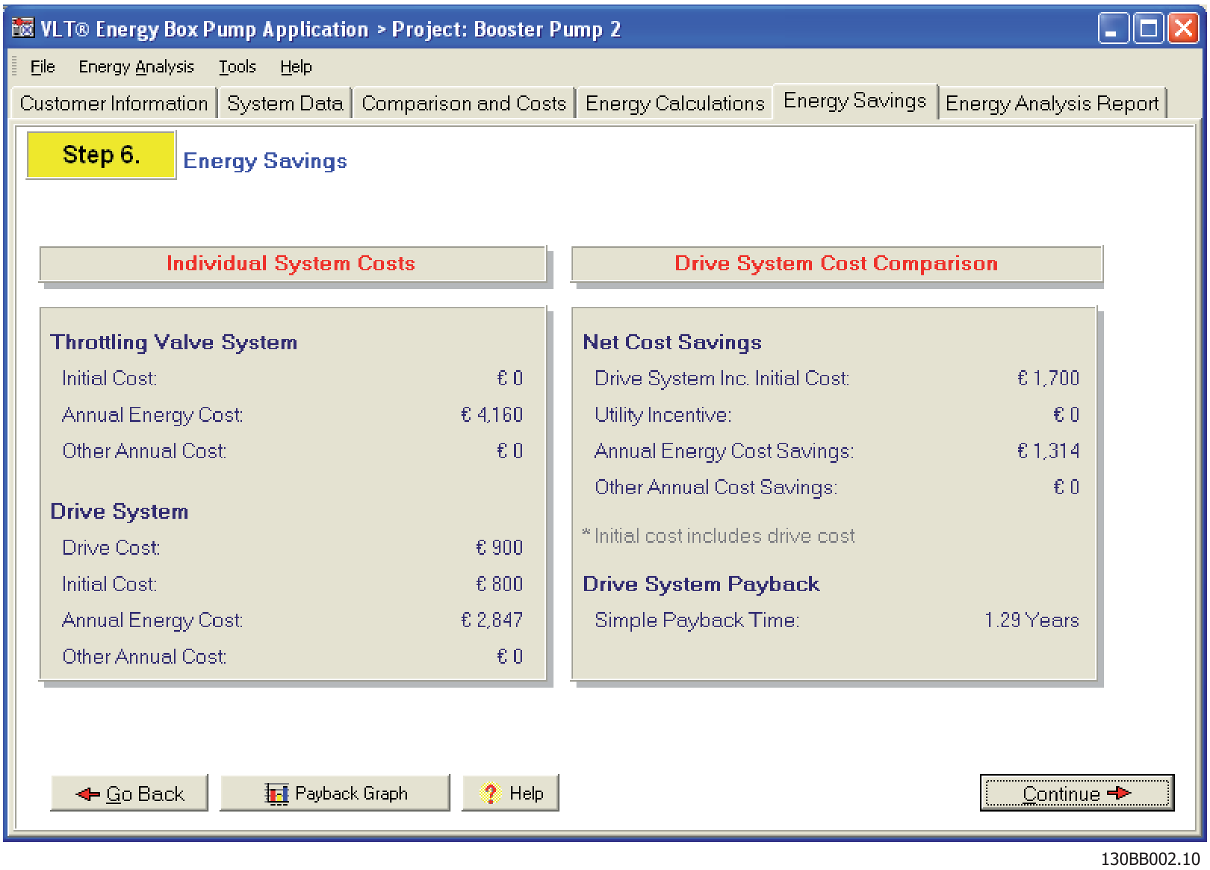


Illustration 9.9: Energy Box Financial Calculation

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 frequency converter 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 frequency converter is always available to run, when the preset "wakeup" 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 frequency converter 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 that 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 frequency converter 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 frequency converter 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.

9.6.6 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 frequency converter speed increases to maximum speed to attempt to produce the full pressure. If the frequency converter 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 frequency converter continuously accumulates the consumption of the actual power from the frequency converter 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 frequency converters, reducing or eliminating the need for external devices.

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

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