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E-flow
ENERGY • DEMAND • CONTROL

Differential Energy Variable Flow Control for Hydronic Heating and Cooling Systems

Intelligent On-Demand Pumping with Closed Loop Hydronic Energy Supply Control

Patent No.: 9,519,297

EPAct of 1992 and Energy Incentives

Energy incentives were given for the installation of VSD's in order to reduce pumping costs, because:

Reduced flow = slower motor speed = reduced power use

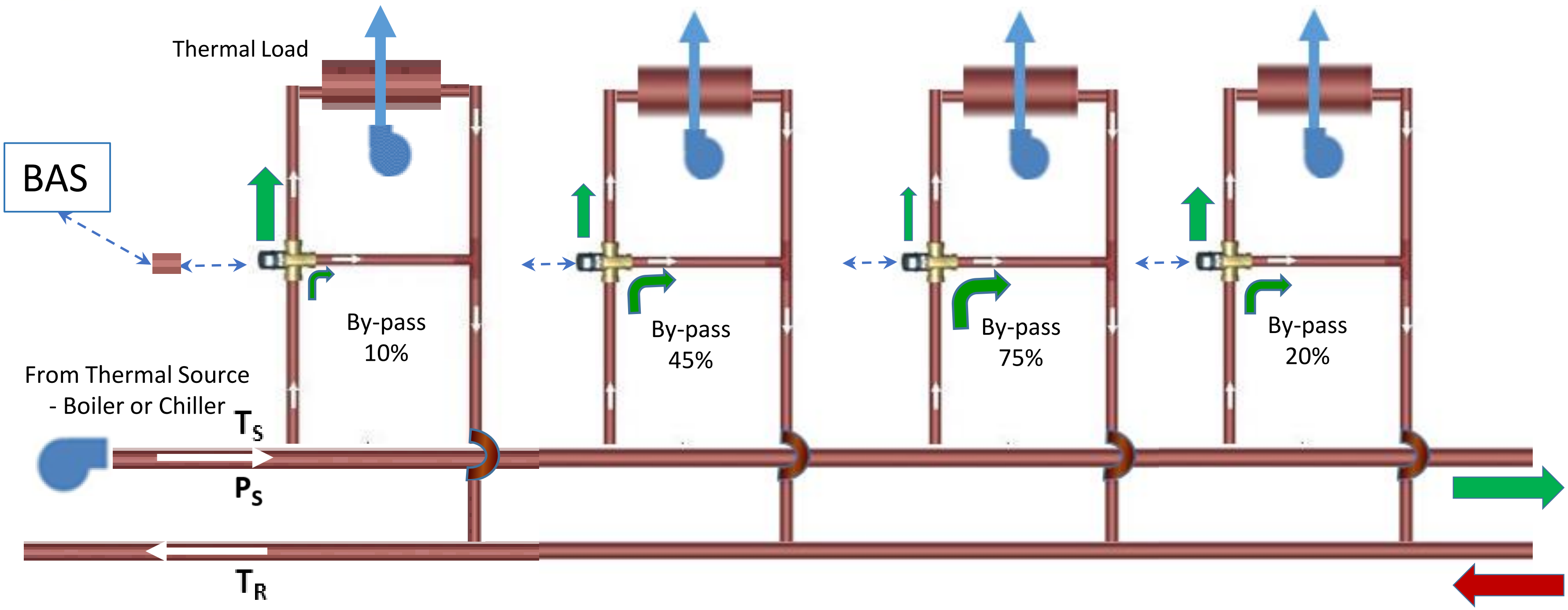
for a <u>20% reduction in motor speed, the power draw was reduced by ~50%.</u>

Hot water heating pumps operate 24/7 for 6 months during the heating season, so a 10 HP motor can save approximately $ 1,600 in 1 heating season.

The Problem: ***How can the pump speed and flow be made*** **variable** ***in a system that is designed as a constant volume flow system,*** which:

- does not have valves that can shut off the flow, such as a system that has only 3-way valves which only *divert* the flow; or,
- has no valves, such as in a condensing loop, or other type of heating/cooling system.

Typical 3-Way Valve Loads = Constant Volume System



In a ***<u>Constant Volume</u>*** System the Sum of the flows:

1) <u>To the thermal</u> loads **+**
2) Bypass flow of 3-way valve **+**
3) Remaining flow to other loads

Remains Constant at all times

$$\textbf{Volume}_{S\ t\text{-}1} = \textbf{Volume}_{S\ t\text{-}2}$$

Therefore: $$\textbf{Pressure}_{S\ t\text{-}1} = \textbf{Pressure}_{S\ t\text{-}2}$$

Where:
S = Supply
R = Return
V = Volume Flow
P = Pressure
T = Temperature
t = time

Since the Pressure in the pipe does not change in a 3-way valve system, <u>pressure cannot be used</u> as a control input to manage flow by controlling pump speed.

The Relationship of Pressure and Flow

- Classical mechanical theory states that the *rate of flow* in a pipe is dependent on some element of static or differential *pressure*.

- When attempting to maintain constant static pressure, in a hydronic supply system for example, if the pressure in the pipe begins to increase due to valves closing downstream, the pressure controller can be used to keep the pressure constant by reducing the speed of a pump motor through a VSD.

According to the *affinity laws*, pressure is proportional to the square of the shaft speed of a motor-driven pump.

For a relatively small change in pressure on the downstream side of a pump, it requires a relatively large change in pump rotation.

Using <u>pressure</u> as the *input control variable* assumes that there is an actual <u>change in pressure</u> in the supply pipe due to system mechanical dynamics.

This could occur due to some restriction of flow as a result of <u>closing downstream valves</u> to create back-pressure. For this special case, pressure *can be used* as the input signal to reduce pump speed in order to keep the pressure constant in the pipe…*but*

<u>*…Only if*</u> the downstream valves are 2-way valves, which are capable of closing off completely in order to create a <u>measurable</u> and <u>proportional</u> pressure change.

The problem…Most older buildings have 3-way or diverting valves, resulting in constant flow, and virtually no pressure change as valves respond to thermal load conditions.

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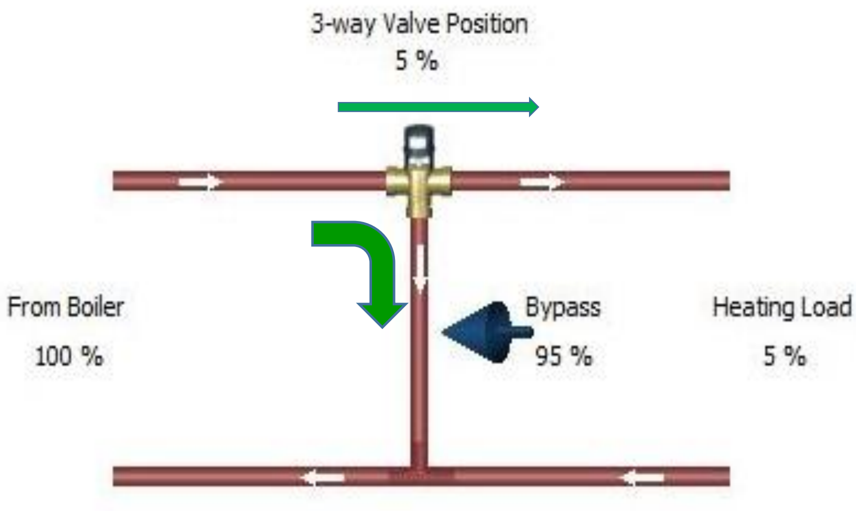
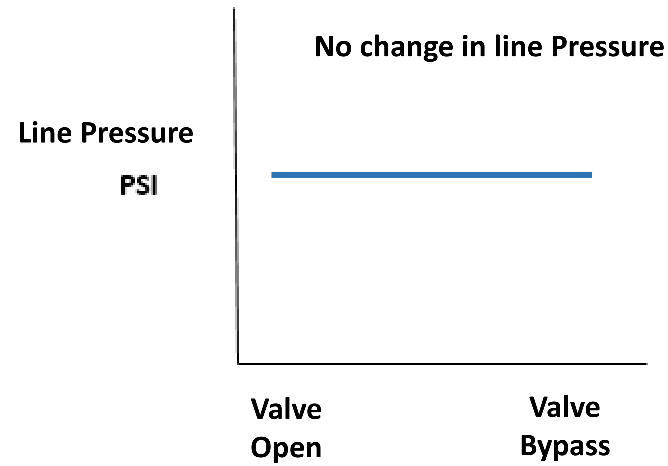
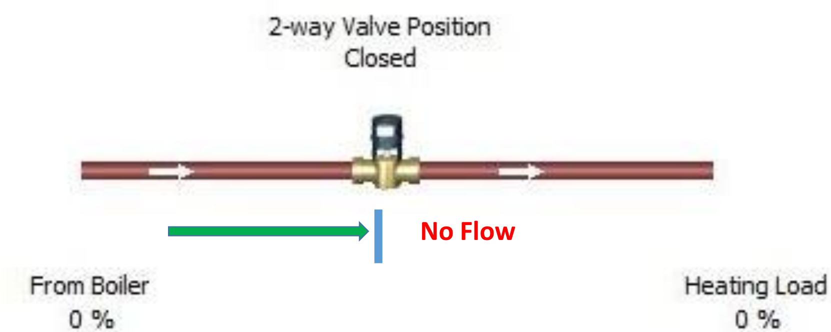
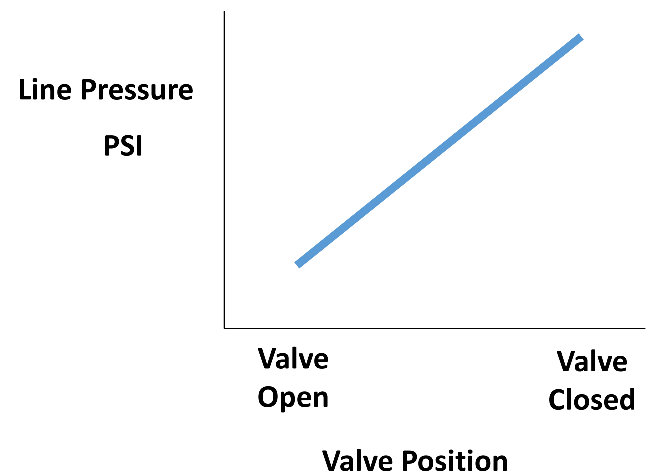
3-way valve = Constant flow = No pressure Change





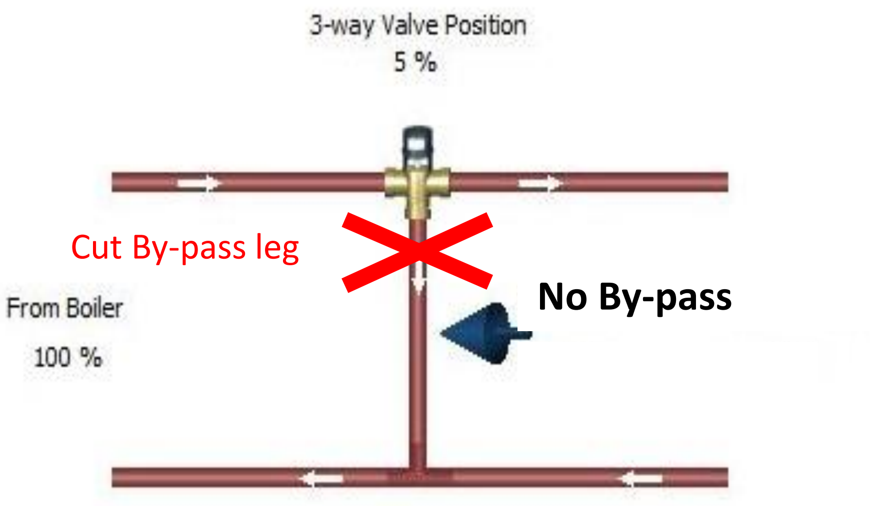




2-way valve – back-pressure increases until valve is fully closed

Engineers recognize that a hydronic system that uses 3-way valves <u>cannot be effectively controlled with a pressure control scheme</u> because the systems are by definition *Constant Volume* and *constant pressure*.

3-Way Valve converted to a 2-Way Valve



For these systems, the <u>3-way valves must be cut and capped</u>, or the 3-way valves must be replaced with 2-way valves, before the utility will offer any monetary incentives for the installation.

This often makes it too expensive $$$ i.e. the payback is too long, to make converting hydronic systems to variable flow attractive.

BTU and Flow Metering too expensive…

It has been too expensive $$ or too complicated to determine "exactly" <u>how much thermal hydronic flow is enough</u> in any given instant, because it required expensive flow/BTU meters and complex programming.

If…changes in *instantaneous energy demand* could be indexed cheaply and accurately,

then…electric and thermal energy supply could be managed by calculating a control input to reduce the flow in hydronic systems during low energy demand conditions,

…thereby reducing pumping energy and thermal energy consumption.

The Solution to Flow Control in Constant Volume and Hybrid Flow Systems

- Eliminates over-pumping in order to prevent excess pumping and the resulting wasted energy costs,

- Optimizes instantaneous energy delivery to a system or load,

- Minimizes incremental electric and/or thermal energy waste in building secondary systems or loads.

- <u>NO expensive flow meters </u>or devices are required.

E-flow is based on the recognition that hydronic thermal energy delivered to a building load is dependent on *both* the *volume flow and temperature* of the fluid.

Because *Energy is a function of both flow and temperature*, if the *differential energy* between supply and return is optimized, then the flow can be varied in order to satisfy the system’s total energy demand.

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What is E-flow

E-flow is a series of related calculations (the *algorithm)*, that uses differential energy in order to manage and optimize the hydronic *flow* in a system.

E-flow is based on the energy actually used by the building (thermal demand), which is equal to the difference between the energy supplied to the building and the remaining energy in the fluid returning to the central heating/cooling plant.

The *instantaneous* energy delivered to the system:

$\boldsymbol{\Delta E_{S\text{-}R} = |E_S - E_R|}$ or simply ($\boldsymbol{\Delta E}$)

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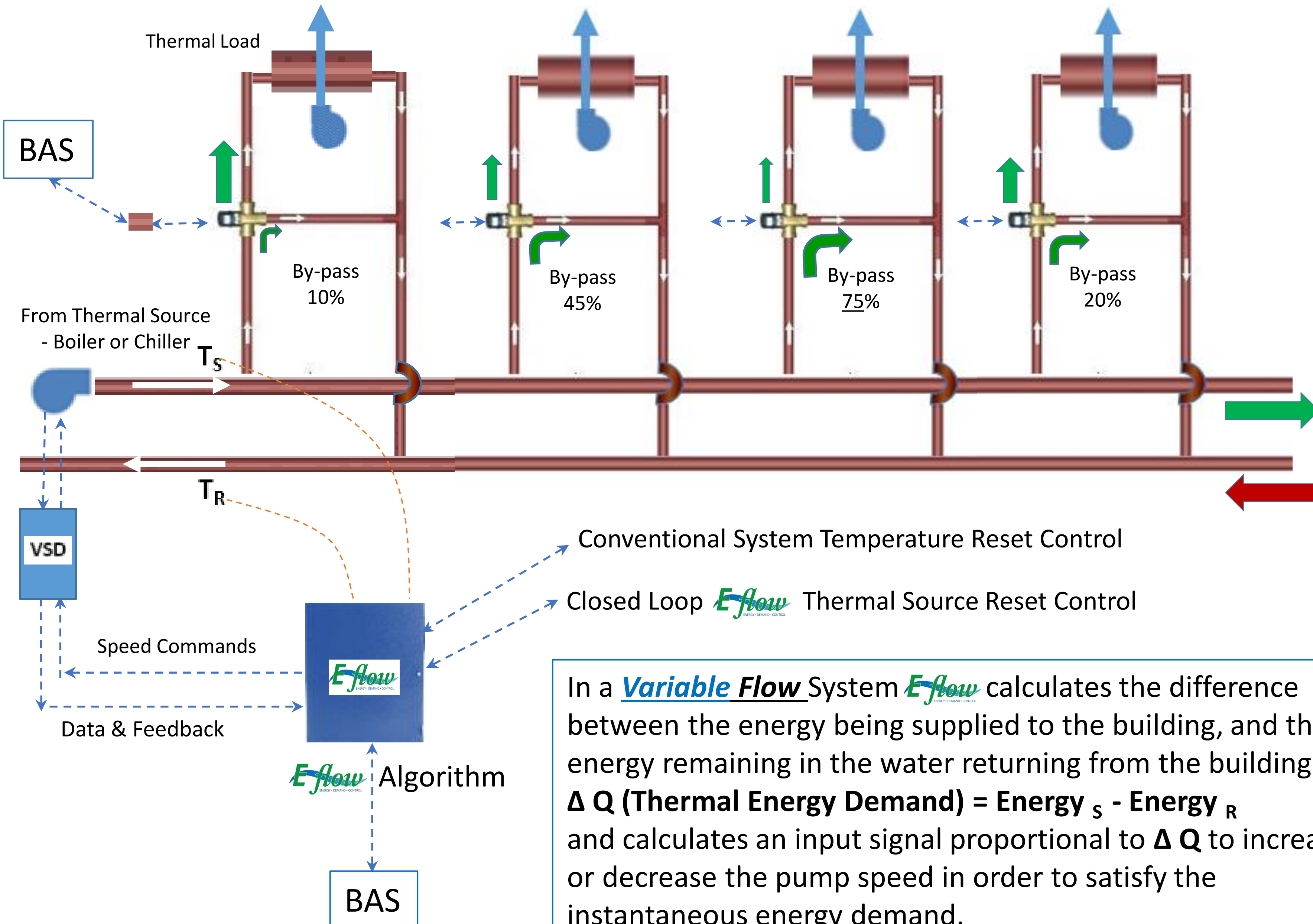
Typical 3-Way Valve Loads = ***Variable*** Flow System



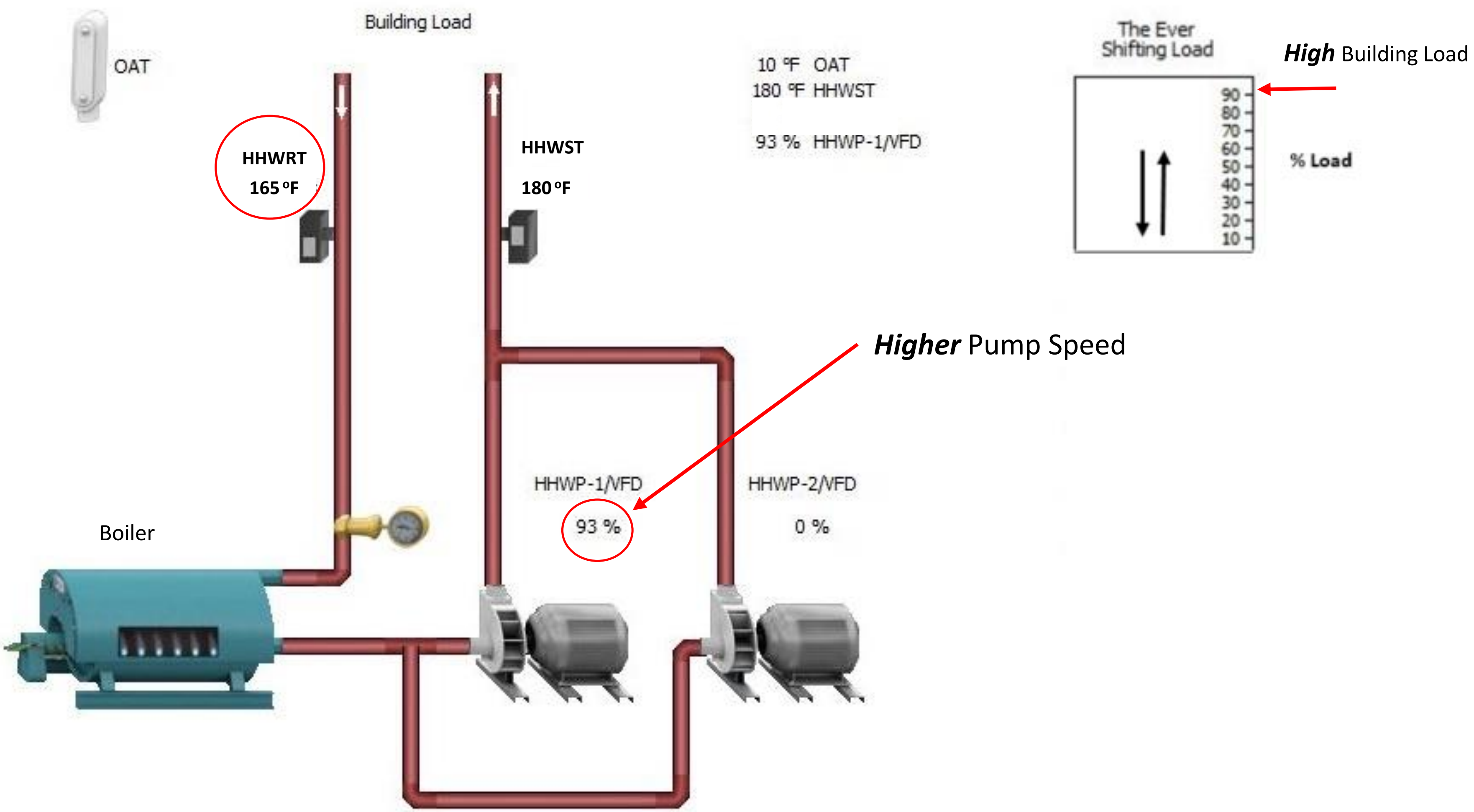
In a ***Variable Flow*** System E-flow calculates the difference between the energy being supplied to the building, and the energy remaining in the water returning from the building:

Δ Q (Thermal Energy Demand) = Energy $_S$ - Energy $_R$

and calculates an input signal proportional to **Δ Q** to increase or decrease the pump speed in order to satisfy the instantaneous energy demand.

How does ***E~flow*** *Work?*

The algorithm senses the temperature of the supply water temperature and the return water temperature, and *increases or decreases* the pump speed to *satisfy building heating demand*.



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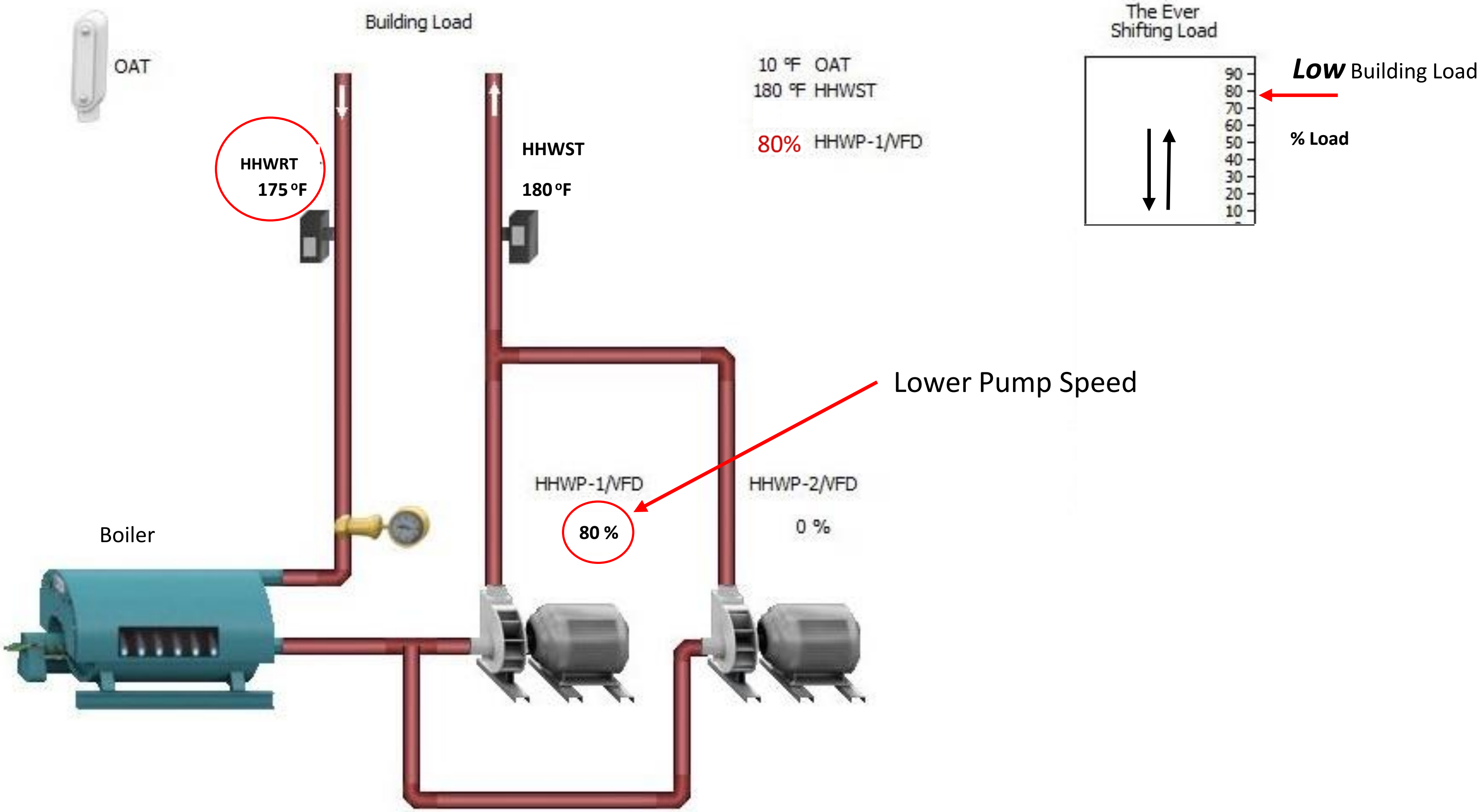
How does ***E~flow*** *Work?*

If the building thermal load de*creases or decreases* the pump speed to *satisfy building heating demand*.



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How does the E~flow Dynamic Flow Control Algorithm Work?

An *instantaneous* measurement is made across the entire system that is used by the E flow ENERGY • DEMAND • CONTROL algorithm to generate a *relational control input signal* to control a VSD on a pump motor.

The E flow ENERGY • DEMAND • CONTROL algorithm performs this calculation continuously and generates an input variable to a pump VSD to controlling the volume flow of any hydronic system.

How is E-flow applied to control an entire building hydronic Heating or Cooling System?

System *Thermal Response Elasticity* (*TRE*)

TRE is manifested by the dynamic re-positioning of the valves of each *n*-load as the temperature controls in the system function to maintain constant temperatures delivered to spaces. ΔE across the entire system can be maintained by varying the macro volume flow to the system.

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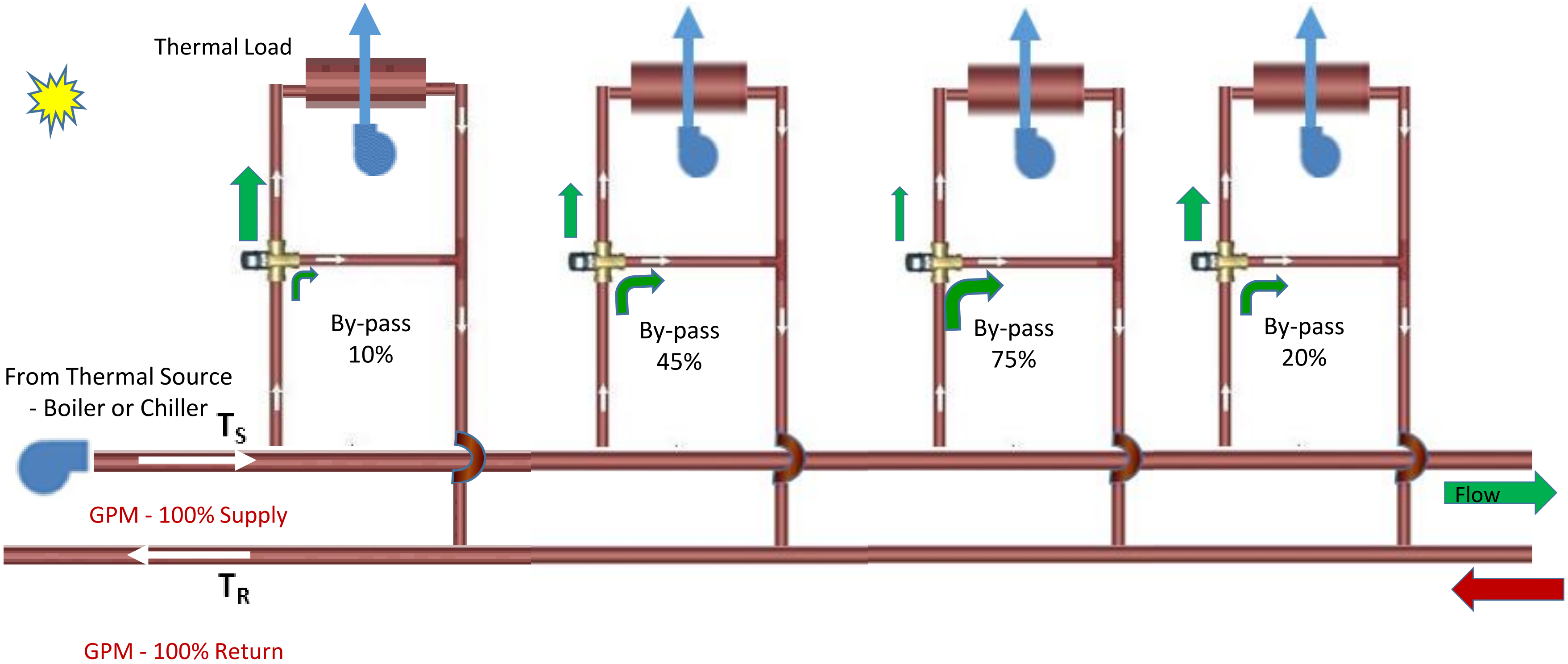
Typical 3-Way Valve Loads - With E-flow



Virtually no pressure change in the system

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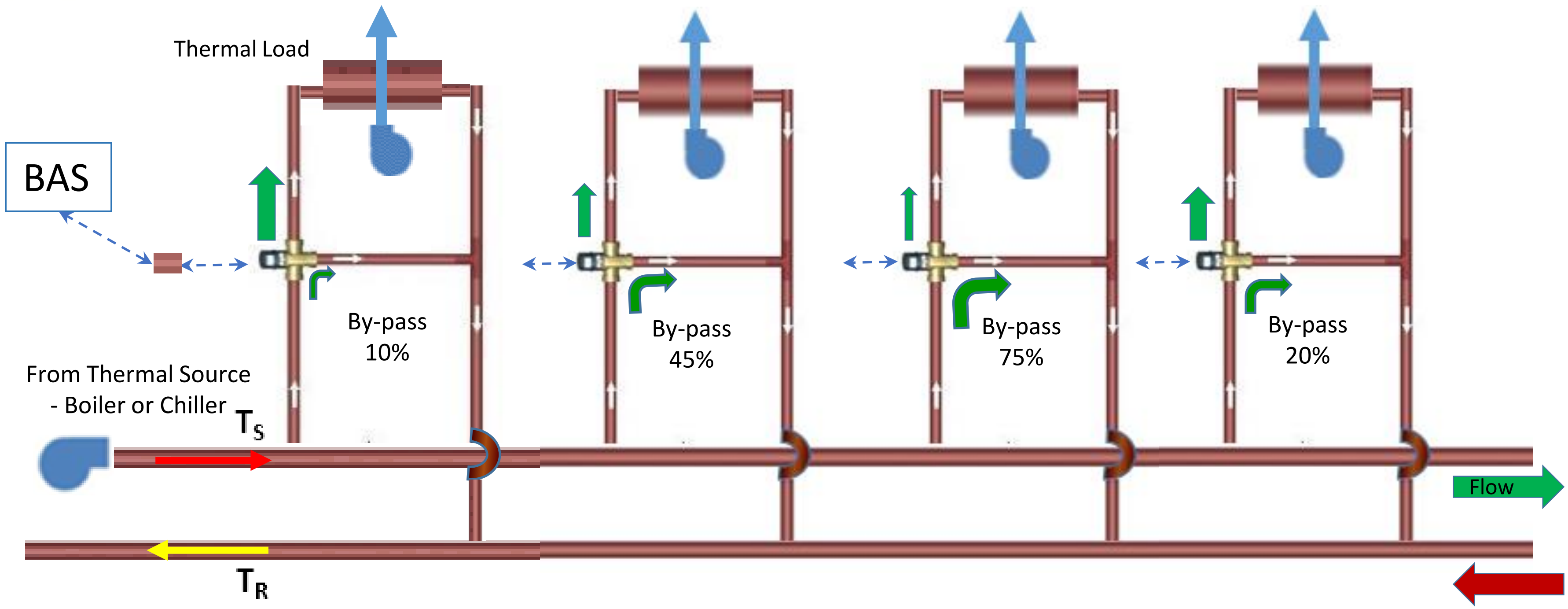

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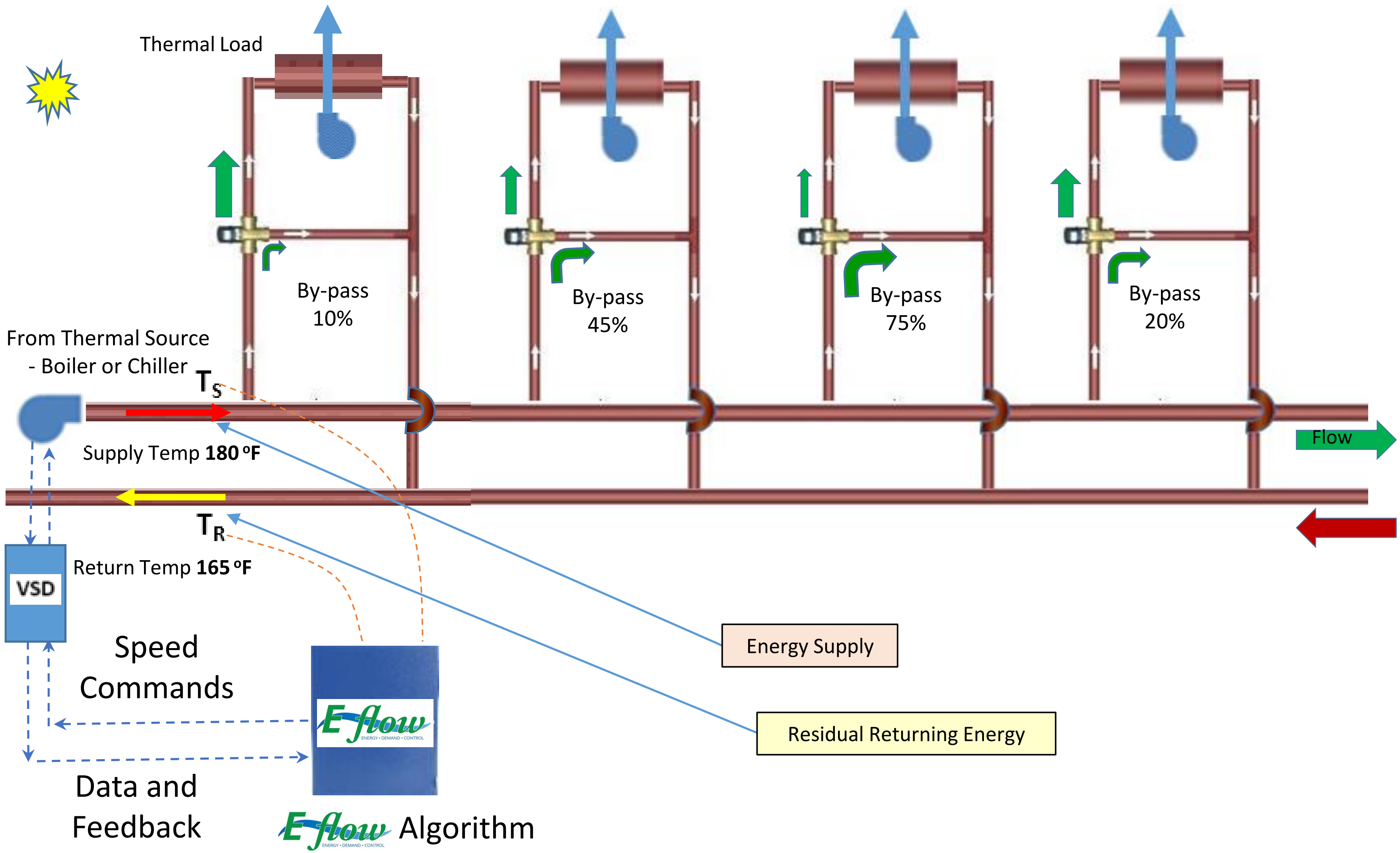

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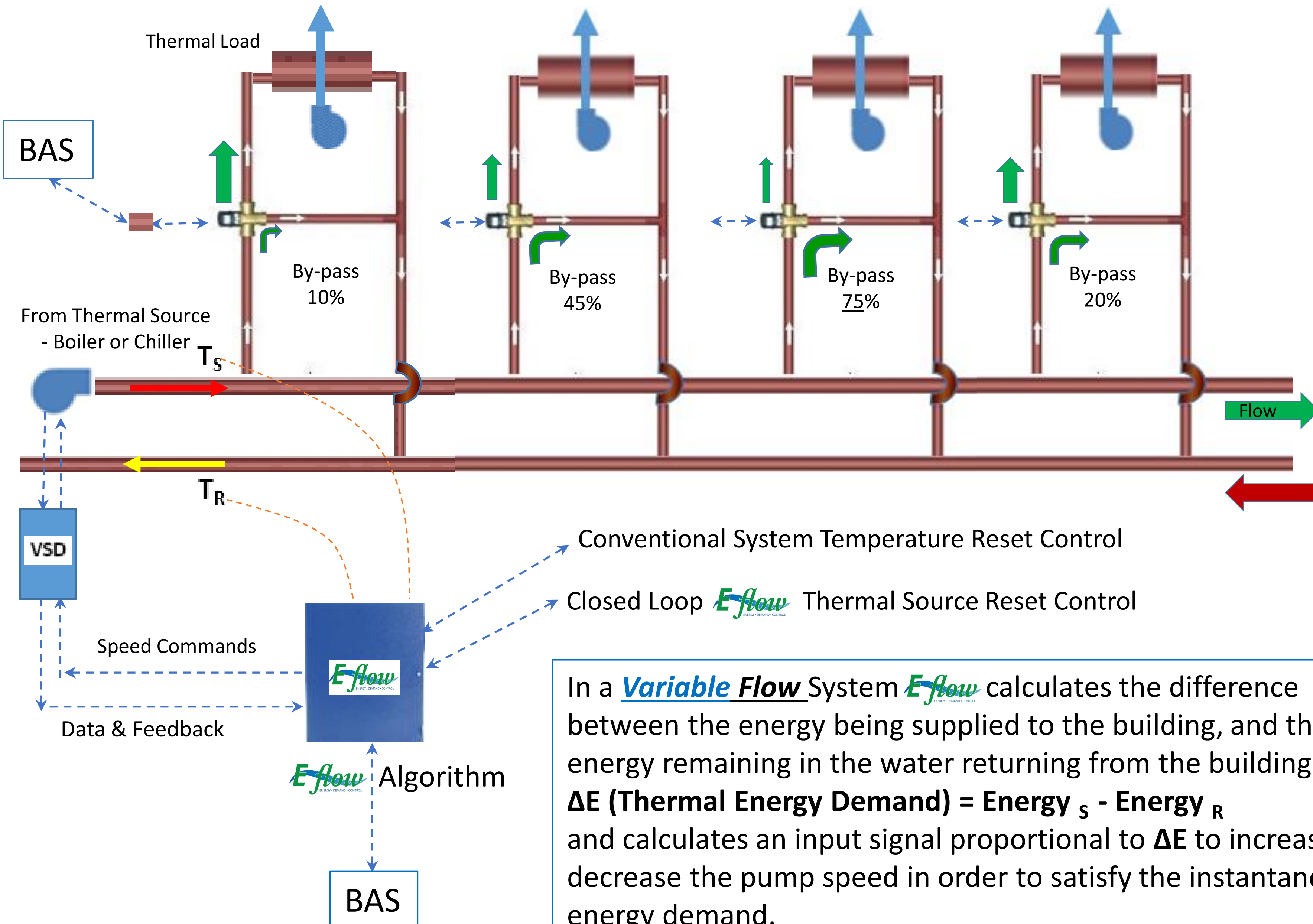
Typical 3-Way Valve Loads = *Variable* Flow System



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Benefits of E flow

E flow provides a number of beneficial effects over controlling flow based on hydronic pressure, including:

a. The E~flow energy control process is not dependent on an indirect variable like pressure, but it responds directly to the energy the building is actually using—i.e. the energy demand.

b. The E~flow control process does not require expensive flow meters, or pressure sensing devices or installations.

c. E flow does not require replacing 3-way valves with expensive *pressure compensated 2-way valving* for the variable flow system to function properly.

d. Direct sensing of the building energy demand provides a more universal, and more precise control of the energy delivered.

e. The pumping energy used can be reduced to the minimum energy needed, on a real time basis, in *direct response* to the actual building/system demand.

e. *E-flow* is a direct response algorithm to the <u>cumulative effects of numerous thermal variables</u>. This is not universally possible with other control schemes, such as OAR control. A building heating load, for example, changes as a result of many variables that cannot be individually accounted for in a building automation hydronic temperature control sequence.

A building heating/cooling load includes:

- *Occupancy, lighting, and equipment ("plug") loads;*
- *Outside temperature, solar, wind, and other weather loads;*
- *Equipment status (on/off), ventilation damper adjustment and position, variations in motor speeds;*
- *Dynamic valve positioning in the chilled or heating hydronic distribution systems.*
- Building occupancy and schedule.

Added Benefits of E-flow

f. E-flow is programmed into a stand-alone electronic controller or PLC, which can communicate directly to a building automation system.

g. The process is eminently scalable since pump motors from 100+ horsepower, all the way down to a fractional hp pump can be effectively controlled to achieve greater system efficiency, as well as efficacy.

Proven Control Concept

- The mathematics of E flow theory of control have been developed, and the concepts of controlling hydronic boilers, pumps, and circulating loops have now been well established.
- E flow is operating in over 4 million square feet of facilities of various types. The efficacy of the system has been proven, both for variable volume pumping of heating water systems, as well as, chilled water systems and chiller sequencing control.

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Controller

Primary Features

<u>REAL-TIME CONTROL STRATEGIES</u>

- No programming required
- Simple analytics data model
- Multi-variable trending
- Normalized energy use
- Real-time energy optimization
- Actual closed loop feedback control
- Tracking operational response in real time
- Real-time trending diagnostics
- Energy use logging and trending analytics

<u>Remote Access Tools</u>

<u>Helpful Visualization</u>

- User-specific dashboards
- Concise exportable trend logs

- E-flow ENERGY • DEMAND • CONTROL provides a technically sophisticated, accurate, and energy efficient method of variable flow heating & cooling demand control.

the implementation of E-flow ENERGY • DEMAND • CONTROL is very simple, inexpensive, and very effective.

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Questions