Using Hydronic HVAC Systems to Further Decarbonization Goals

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As the commercial building industry continues to seek guidance on mitigating the negative carbon impact of buildings on the environment, a growing focus exists on resource-efficient decarbonization: an incremental methodology, coupled with integrated design and strategic capital planning, to create a path toward efficiently decarbonizing buildings. According to the International Energy Agency (IEA), commercial buildings are the fourth-largest emitters of CO_2 globally, and taking a holistic approach to decarbonization in existing structures makes it more technically and economically feasible to create a decarbonization path. By reconfiguring HVAC systems to address both operational and embodied carbon emissions, significant energy savings can be achieved while contributing to a greener, more sustainable future. This article looks at the use of hydronic systems to help meet these goals.

Because of their benefits, commercial building owners pursuing improvements to achieve carbon-neutral buildings are eager to retain hydronic systems in their portfolio of properties. Existing hydronic systems can easily integrate with any new heat source, particularly when a building's use and its loads remain unchanged.

The Advent of Hydronic System Design

Hydronic HVAC systems have an illustrious history. From an 1953 ASHRAE paper titled "Compression Tank Selection for Hot Water Heating Systems" that presented breakthrough thinking in the science of hydronic heating to the advent of modern hydronic technology in residential and commercial building applications, the global hydronic systems market is positioned to grow to $16.19 billion by 2028.[1]

While the fundamental concepts of hydronic system designs are well-defined, how to apply them isn't always straightforward. Different building types may dictate different expectations for comfort conditions and energy requirements. This means it is key to identify the building type and expected energy use early in the design process. Without this information, system capacity, space conditioning needs, equipment

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selections and overall system control strategies cannot be determined.

For instance, consider the heating and cooling load requirements for a hospital versus a multifamily complex. While a hospital requires precise temperature and humidity level control to ensure optimum occupant comfort and functionality, a multifamily unit requires much lower load demands. Similarly, larger facilities like schools or office towers require vastly different temperature regulation and energy use.

Modern Hydronic System Design in Commercial Retrofits

Modernizing HVAC systems in existing buildings to ensure occupant comfort and sustain structural integrity presents an increasingly cost-effective option for commercial building owners looking to advance sustainability and carbon neutrality. Roughly 80% of buildings targeted for decarbonization are existing structures; some are a result of adaptive reuse plans, which involves repurposing an existing building for a new use. According to Commercial Building Energy Consumption Survey (CBECS) data, nearly 65% of commercial buildings constructed before 1990 use hydronic heating and cooling systems. When choosing the best solution for electrification of an existing fossil fuel-based hydronic heating system, it's helpful to understand how the original system was designed and the assumptions that went into equipment selection.

For instance, when designing for adaptive reuse, designers need to consider potential limitations of the building's existing infrastructure. In some cases, limited physical space or impassable ceiling obstructions may make it impossible to route piping or place equipment.

Despite challenges and design constraints, retrofits pose a clear advantage for realizing decarbonization and net zero energy targets. Among other things, achieving these goals involves the introduction of renewable energy sources. In most hydronic decarbonization projects, replacing the energy source, either partially or entirely, will be a given. The decision to replace or reuse existing piping and ancillary devices such as coils, pumps, control and balance valves and air management components will depend on how the designer alters the original building operating conditions, with potential building envelope upgrades and ventilation improvement strategies having significant influence.

Once new building conditions are finalized and associated system loads have been identified—whether they are unchanged, modified or entirely new—a detailed assessment of existing hydronic HVAC equipment and distribution piping should be completed. To determine what should be reused or replaced, several factors should be considered:

Age and Condition.

- Will service be required? (parts and labor cost).
- Parts availability (has the product been obsoleted by the manufacturer?).
- Efficiency compared to a newer model (simple return on investment, impact on carbon footprint).

Capacity and Performance Within New Operating Parameters.

- Modifications required to achieve new desired capacity (increase or decrease).
- Concessions needed for acceptable performance (gpm/cfm, pressure drop, etc.).
- Will supplemental components be required to manage deficiencies?

Pipe Size or Design Layout Adjustments.

- Corrections to keep fluid velocity and friction loss rates within industry standards.
- Changes to manage total pressure drops so existing pumps can be reused.
- Isolation of high pressure drop zones to reduce size and quantity of new pumps needed.
- Separation of zones requiring different supply water temperatures.

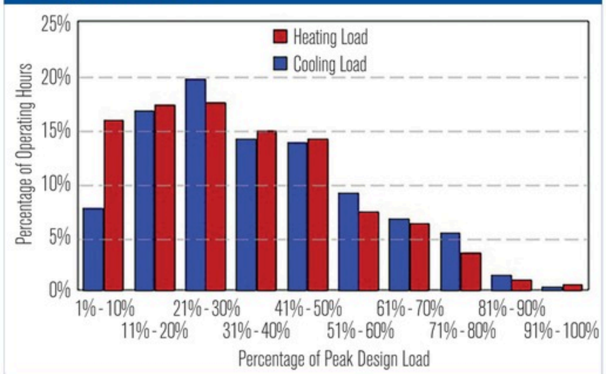
Adhering to Key Engineering Principles

With the objective of reusing as much existing equipment and piping as possible, designers should consider the following established engineering principles of performance applied in hydronic system design and operation during their analysis.

Starting with the overall building load profile, *Figure 1* shows a comparison of the percentage of peak design load to the percentage of expected operating hours at each load for a typical commercial building in North America. Realizing that 70% to 100% of peak load occurs during less than 10% of regular operating hours, the application of diversity in the required capacities of heat transfer terminal units and pumps can be advantageous in maximizing the reuse of existing equipment.

The required flow rate for each load can be calculated using *Equation 1* or obtained from the equipment

FIGURE 1 Average comfort heating and cooling load profiles for commercial buildings in North America.



manufacturers' selection software, if available. Review of current pipe sizes for fluid velocity and friction loss rates, existing control and balance valves for acceptable coefficients (C_v) and overall branch authority percentages and any required capacity modifications to installed pumps are dependent on these results.

$$\text{gpm} = \frac{Q}{(500 \times \Delta T)(C_p)(SG)} \quad (1)$$

where

Q = heat load, Btu/h

500 = 8.34 lb/gallon* × 60 min/h (*weight of 68°F [20°C] water)

ΔT = system fluid design temperature drop, °F

C_p = specific heat of system fluid, Btu/lb°F

SG = specific gravity of system fluid

Replacing just the energy source in an existing hydronic system may offer the most economical solution in applications where building use will not change. When selecting the new energy source, the design system supply water temperature may be lower than the temperature used for the original coil selections. Should design load remain unchanged, the required flow rate will increase, potentially creating limitations to reusing existing piping and other components.

To evaluate potential coil reuse, *Equation 2* can be applied once the log mean temperature difference (LMTD) between the air and system fluid has been calculated to determine the impact of the lower supply water temperature on the coil heat load capacity with the existing coil surface area. A closer look at supply water reset schedules is also suggested.

$$Q = U \times A \times LMTD \quad (2)$$

where

A = surface area, ft^2

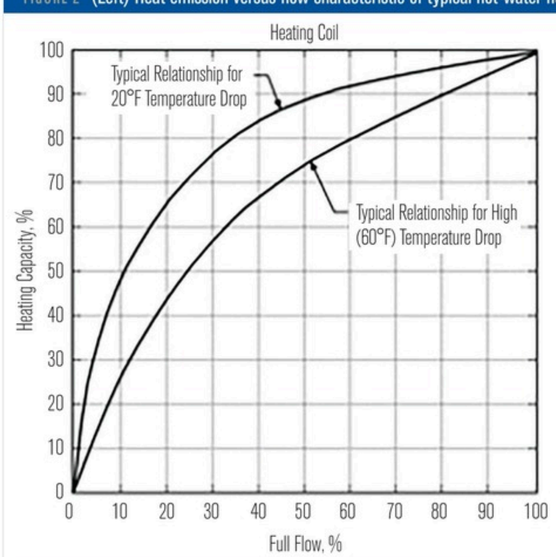
Q = heat load, Btu/h

U = heat transfer coefficient, Btu/h·ft^2·°F

LMTD = log mean temperature difference, °F

Additionally, *Figure 2* and *Figure 3* outline the typical nonlinear relationship of coil heat transfer capacity and percentage of design flow. For example, heating coils with a constant supply water temperature and airflow, designed for a 20°F (11°C) waterside temperature

FIGURE 2 (Left) Heat emission versus flow characteristic of typical hot-water heating coil. (Right) Generic chilled-water heat transfer characteristic.



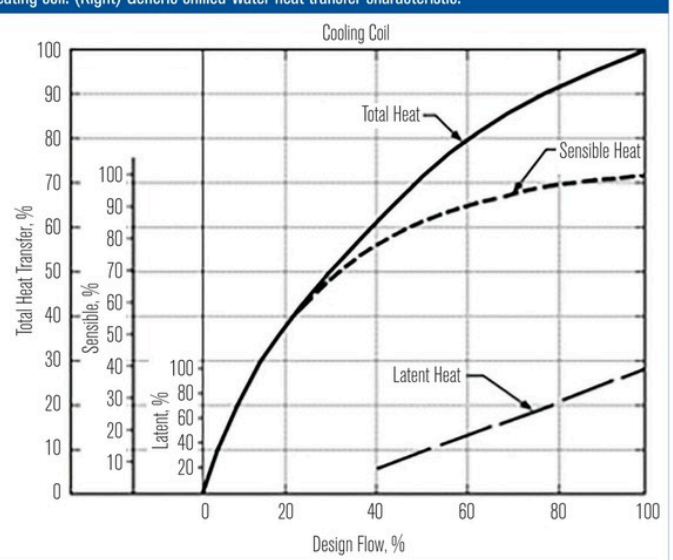
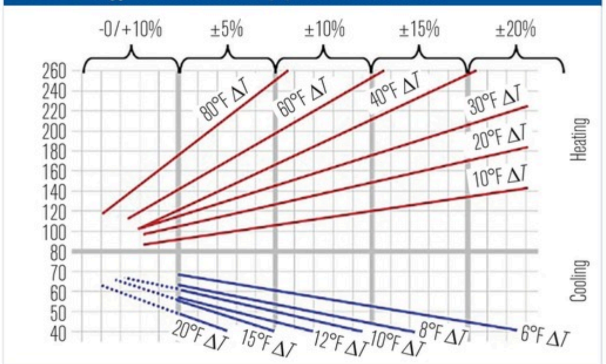


FIGURE 3 Suggested flow tolerance (%) for 97% heat transfer.



difference, will deliver 97% of the rated coil heat capacity at just 80% of design flow. Supply water temperature and design temperature drop will define acceptable flow tolerance. Application of these relationships can prove beneficial to evaluate current hydronic system components and their potential reuse.

For some applications, changing the energy source inherently alters the system pumping strategy, which subsequently impacts the piping layout required for the correct proportional distribution of system fluid throughout the building. A possible consequence, especially in a centralized pumping design, is the creation of an individual piping circuit whose combined friction losses at design flow for pipe, valves, fittings and heat transfer coils is exceptionally higher than any other circuit within the system. This is known as the critical circuit and will dictate the total differential head the main pump must create at total system design flow. *Figure 4* offers a simple example of a variable-primary centralized pump design that highlights an important takeaway from this scenario; the pump is extremely oversized for a majority of the remaining circuits within the building, making the control and balance valve sizing and the final hydronic proportional balance of the entire system more challenging.

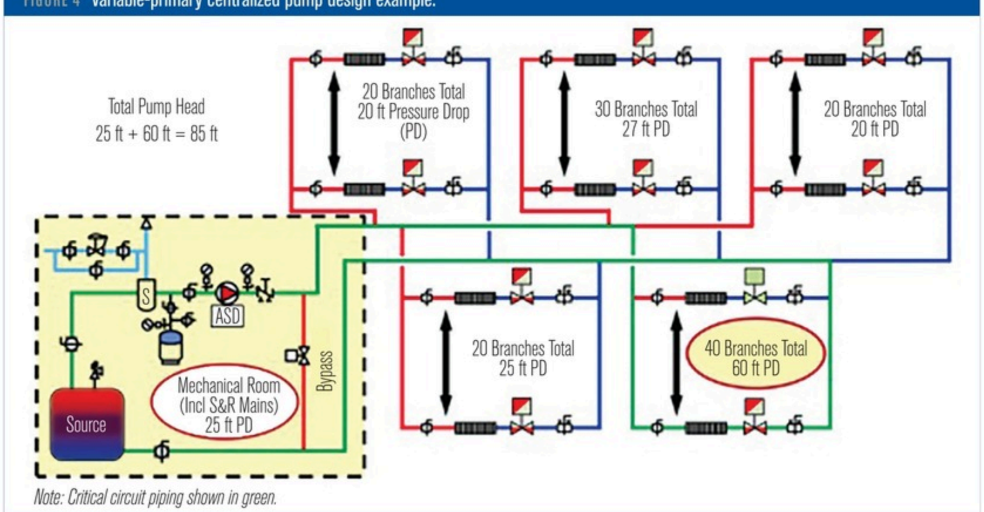
Another potential scenario is if this new head loss value complicates reuse of the existing pump or requires a new pump that is larger than expected, the designer has the option to integrate primary-secondary pumping as a problem-solving strategy. First conceived in 1954, the primary-secondary pumping method can be used to break up the existing HVAC system into more manageable subzones. This is done by adding a low pressure drop "common" pipe across the supply and return main to create hydraulic separation of specific circuits in the system. Because flow in one circuit cannot create flow in the other, smaller energy-saving pumps are used with flow and differential head capacities specific to the zone they serve.

Figure 5 shows the basic application of primary-secondary to the system shown in *Figure 4*, where the heat source and associated mechanical room piping and accessories are a zone, and the high pressure drop area that formed the critical circuit is now a separate zone. Notice the secondary distribution pump is rightsized to manage the other zones, as their pressure drops are very similar.

Primary-secondary pumping offers two important advantages:

- Less energy is required to move water through the entire system (rather than one large circulator, small energy-efficient circulators can be used to overcome the friction and inertia—or pressure drop—of their respective loops).
- More control can be taken over zones (and each zone can operate at its own optimum temperature).

FIGURE 4 Variable-primary centralized pump design example.



Note: Critical circuit piping shown in green.


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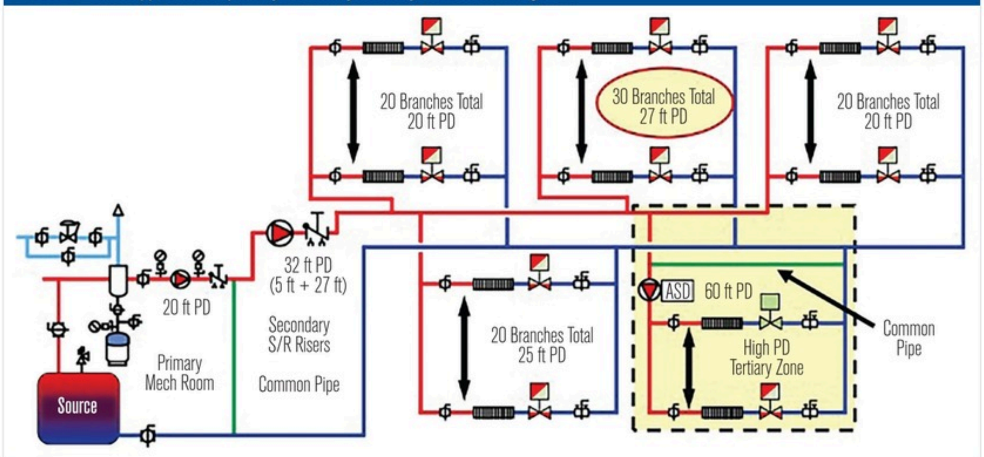
FIGURE 5 Basic application of primary-secondary to the system shown in *Figure 4*.



Avoiding Common Pitfalls to Ensure Responsible System Design

With the expectation that low site energy use intensity (EUI) building design will become mandatory, balancing first-cost and the cost of lowering energy use is an obstacle designers face in this emerging era of decarbonization, electrification and sustainability.

Design errors and improper system control strategy setup can erode the potential operating efficiency of hydronic HVAC systems. Taking the following proactive steps can help avoid common system design mistakes:

1. Take full advantage of a manufacturer's knowledge base. While water is one of the most efficient fluids for the transfer of Btus, many applications require the use of other fluids, such as propylene and ethylene glycol. As more and more design professionals use manufacturer's equipment selection programs on their own, assigning incorrect or extreme fluid properties when selecting equipment such as pumps, heat exchangers and heat transfer coils has led to system performance issues that may not be identified until the equipment has been installed. Having a manufacturer's representative validate selections prior to being placed in an equipment schedule is a good practice to catch oversights at no cost.

2. Follow proper maintenance. Design professionals must evaluate routine maintenance requirements based on the operating environment the equipment will be subjected to, as well as the level of expertise of the maintenance staff tasked with system and equipment upkeep. System fluid quality must be considered to maintain performance, prevent fouling and minimize early failure of components known as "normal wear items." Therefore, a thorough water treatment and filtration program should be established.

3. Use industry tools. HVAC tools like equipment selection and system design software are necessary to ensure proper piping system design.

4. Embrace industry education and training opportunities. Learning about new and emerging technologies and how to effectively embrace hydronic HVAC system design is vital. This is especially apparent as HVAC contractors struggle to attract young professionals to address the growing skilled technician shortage, making robust industry education and training opportunities essential to retain and prepare the next generation.

Making the Case for Hydronics

When it comes to achieving decarbonization goals through retrofitting, hydronic systems can deftly accommodate energy source upgrades due to their flexibility and long system life. Installing hydronic-friendly energy sources like water source heat pumps allow for easy building upgrades and future additions without replacing all existing equipment because of the mandatory changes to new refrigerants on all new equipment manufactured after Jan. 1, 2025.

As the building sector moves away from gas-fired boilers toward water-source heat pumps, hydronic systems provide an adaptable, efficient delivery of heating and cooling, regardless of the source, and are already compatible with a wide range of energy sources, including refrigerant-based, thermal and electric heating and cooling sources. What's more, water can transfer heat 24.17 times faster than air, proving itself as a far superior heat absorbing material. Water is a natural refrigerant with a zero or near-zero global warming potential (GWP). Additionally, water's thermal properties allow for efficient heat transfer through building distribution systems.[1]

All this said, making the case for hydronics as the sustainable system of choice still requires an understanding of its pros and cons over other HVAC system designs. With HVAC systems dictating a substantial amount of the overall energy use of commercial buildings, it is critical to evaluate varying system-to-system costs before installation.

Because it can be difficult to accurately compare systems as they are applied in an actual building, industry professionals have developed standards, tools and other resources to help evaluate the efficiency of different HVAC system styles. One such resource is the Hydronic Industry Alliance's Building Efficiency System Tool (BEST), a free interactive commercial building system efficiency comparison application that evaluates energy performance, first cost, life-cycle cost and more for all major types of HVAC systems. The latest release enables comparing projected costs and energy use for different systems before selection and installation.

Along with tools like BEST that enable efficient HVAC system design, equipment manufacturers are committed to establishing the highest industry standards to demonstrate hydronic HVAC efficiency. For instance, part-load efficiency value (PLEV) is a criterion that helps HVAC designers select pumps based on real-world system demands to ensure the most efficient hydronic system performance. Standards like AHRI Standard 550/590-2023 for rating water chilling packages and AHRI/ASHRAE ISO Standard 13256-1: 1998 (RA 2012) for rating water source heat pumps also provide methods to compare equipment efficiencies, including part-load performance.

Industry studies that compare a range of HVAC systems to determine the most efficient heating and cooling method are another resource that routinely demonstrate hydronic system effectiveness.[2] Hydronic system efficiency is well documented in thousands of real-world installations, with an estimated 25-year operation life cycle, compared to 15 years for other heating and cooling methods.[2]

Regulations Impact Modern Hydronic System Design

Even as decarbonization and electrification initiatives in commercial buildings take hold, many industry professionals don't yet fully comprehend the unprecedented revolution taking place in the commercial HVAC system market. Bringing awareness to what's driving this market disruption is a pivotal place to start.

ASHRAE standards have long been integral to any HVAC system designer's process when selecting the appropriate systems for a given building type. For instance, when designing a new building, it is nearly impossible not to factor in ASHRAE/IES Standard 90.1, which sets minimum energy efficiency requirements for hydronic systems. Other standards impacting future HVAC system design include ASHRAE Standards 15 and 34's refrigerant requirements that restrict refrigerant amounts in occupied spaces, the elimination of refrigerant R-410A in all new equipment and the ASHRAE Board approved "ASHRAE Position Document on Building Decarbonization."

In recent years, ASHRAE has set out to improve the overall efficiency of commercial buildings through sensible equipment selection and system sizing. Designers must select appropriate equipment such as boilers, pumps and controls to adhere to these guidelines and ensure effective system performance.

According to industry experts, by 2050 all new and existing assets will need to have net zero greenhouse gas (GHG) emissions across their entire life cycles. Therefore, hydronic systems are being applied to more efficient designs with higher delta temperature equipment and lower approach temperatures making balancing and commissioning even more critical.

With these pressures in mind, many state and local codes are beginning to shift focus to comply with electrification and decarbonization mandates as they are increasingly passed into law. Often, state and local governments adopt Standard 90.1 as the primary source that comprises these codes, demonstrating their commitment to energy conservation. As demand grows for reduced energy use and carbon emissions, Standard 90.1 is routinely evaluated. The latest update includes expanded scope for building sites, a minimum prescriptive requirement for on-site renewable energy and new requirements to improve the efficiency of HVAC equipment and processes.

The Future of Hydronic System Design

Many advancements in hydronic system design and operational methods have transpired because of increased focus on indoor air quality (IAQ) and humidity control due to major human health-related events, as well as the current movement away from combustion heat sources. With the recent release of ASHRAE Standard 241-2023, *Control of Infectious Aerosols*, designers, facility managers, engineers and building owners have new guidance to make informed decisions regarding indoor air quality (IAQ) protocols in new and existing buildings. Based on ASHRAE's existing ventilation and IAQ standards, Standard 241 highlights the importance of operational control, balancing and maintenance of HVAC systems to provide desired clean airflow rates. While core design principles for hydronic systems have not changed, the applications for these systems have expanded well beyond traditional HVAC comfort cooling and heating.

Growing commitment to decarbonization and electrification with the goal of zero GHG emissions by 2050 or earlier will put stress on the United States' existing electrical grid as the switch is made from coal and gas for source production. As a result, using thermal energy storage to reduce demand electrical peaks will become an essential HVAC design requirement. By storing excess heat, hydronic systems with advanced thermal storage reduce the need for continuous operation of heating sources. This translates into energy savings and lower utility bills.

Today's hydronic system design allows for its relevance well into the future. Basic thermodynamics cannot be challenged, and pumping practices such as primary-secondary, zone pumping and variable-primary are well suited for high and low temperature systems regardless of the heating or cooling source.

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