

Consider the Designing and

Environmental and economic issues are driving projects to use greener piping systems. In addition, some of the most energy-efficient mechanical systems are based on hydronics, such as ground source heat pumps, active solar with storage, radiant heating and cooling, cogeneration, and district heating and cooling. The efficiency of hydronics is driven by the fact that it takes less than one-tenth the amount of energy to move a British thermal unit (Btu) 1 foot using water than using air.

Plumbing system engineers will play a pivotal role in solving the energy challenges facing our country and the environmental issues threatening our planet. Engineers are being pushed to design piping systems that use fewer resources—in both construction and operation—and that have minimal cradle-to-cradle impact on our planet. Of course, the opposing forces of low first cost and avoiding liability never go away.

This article presents some concepts that can improve the performance and reduce the environmental impact of piping systems. Items addressed include decisions that affect the energy consumption of the piping systems and the environmental and health impacts of the materials that make up the piping systems. This article does not attempt to cover other important items that are external to the pipes themselves, such as using reclaimed water, dual flush-toilets, or high-efficiency chillers.

DISTRIBUTION ENERGY

Because pumping systems often run continuously and unnoticed, they can consume many times their initial cost in energy. A small improvement in performance can result in significant lifelong reductions in electrical consumption and the associated costs and negative environmental impacts. Care given by the plumbing engineer from design through commissioning can reduce pump power demand by as much as 50 percent or more.

Following are some tips to make your systems run more effectively.

Dual Pumps

In many systems, both the main heating pump and the backup pump (both sized for 100 percent of the worst-case scenario) are running full bore in the middle of the summer. Instead of this energy-wasting setup, select two pumps at 50 percent flow and full head. If one goes down, typically the single pump will ride the pump curve up to 80 percent or more

flow, enough to handle the emergency. This reduces first cost and operating costs.

Controls

Engineer automatic controls to sense when the pump is not needed and shut it off. Instead of an OFF-ON-AUTO switch that can remain in the ON position, specify an override timer that resets to AUTO after 24 hours of being in the ON position.

Plant Placement

Architects tend to banish mechanical equipment to remote areas, so you should meet with your architect upfront to discuss a central mechanical plant location. Explain that by cutting the distance of the longest run in half, one reduces the distribution energy in half. Heating or cooling fluid makes the round trip from plant to load dozens of times per hour. Give the architect an analogy they understand: Distancing the plant from its loads is like locating the serving kitchen remotely from the dining room it serves. For domestic systems where booster pumps are needed, zone the building with separate booster pump stations serving each zone, and feed the lowest floors directly, without a booster pump.

Delta T Selection

Sometimes rules of thumb should be ignored, such as 10°F delta T for chilled water. By specifying slightly more effective cooling coils, a temperature differential of 12.5°F is possible, which requires 20 percent less flow. If you leave the critical run pipe size unchanged, the distribution head loss can be reduced by as much as 36 percent, and the distribution energy can be reduced by nearly 50 percent.

Variable-flow Rates

Variable-frequency drives (VFDs) have become less expensive and pay for themselves in energy savings over time. They also may increase the life of the system and should be used whenever budgets allow.

Piping Layout

Determine the most direct route to the most hydronically remote location, and work with the design team to get there with the least amount of pipe and fittings. Consider alternative strategies that use one pipe instead of two. Engineers always should investigate new strategies that could save energy over the life of the building.

Environment Before Specifying Piping Systems

By Steven J. Clark, PE

Critical Pipe Sizing

Once you have determined the critical pipe run, spend a lot of time optimizing it. Look at the pressure drop of each section, and determine how much head could be saved by increasing the pipe size or specifying long-radius elbows. However, oversizing pipe often requires larger-diameter insulation and more space above ceilings. Pipe hanger size and spacing also may be affected, so all of these items should be considered in the design process.

Pipe Friction

Can you imagine a jet plane with an outside finish of sandpaper? The extra drag would increase the cost to operate it and may affect its performance adversely. Similarly, drag is produced when water flows through a pipe. This affects the energy consumption of the system every moment it is operating, yet little thought or effort is spent considering the hydrodynamics inside a pipe.

Even when relatively new, some piping materials have nearly twice the friction of others. This becomes much worse over the years as scale develops. Pipe roughness is measured in terms of the Hazen-Williams coefficient. For instance, seamless steel pipe has a coefficient of 100, while very smooth materials (e.g., PE, PEX) have a coefficient of 150. In calculating the actual pipe friction, the coefficient is raised to the 1.85 power, meaning smooth materials can generate less than half of the pipe friction of common materials at the same water velocity. Thus, engineers should consider specifying pipe materials or linings with a Hazen-Williams coefficient friction of 140 or higher, which can provide a surface that prevents scale from bonding to it over time (see Table 1).

This is based on the empirical head loss calculation known as the Hazen-Williams formula:

$$f = 0.2083 (100/c)^{1.852} q^{1.852} / d_h^{4.8655}$$

where

f = Friction head loss in feet of water per 100 feet of pipe (ft_{h2o}/100 ft pipe)

c = Hazen-Williams roughness constant

q = Volume flow (gallons per minute)

d_h = Inside hydraulic diameter (inches)

Note that the Hazen-Williams formula is empirical and lacks a theoretical basis. Be aware that the roughness constants are based on "normal" conditions with approximately 1 meter/second (3 feet/second).

Table 1 Hazen-Williams coefficients of common pipe materials

Material	Hazen-Williams Coefficient	Relative Resistance
Copper and brass	135	122%
Ductile iron pipe (DIP)	140	114%
Fiberglass pipe (FRP)	150	100%
Galvanized iron	120	151%
Glass	130	130%
Lead	135	122%
Metal pipes (very to extremely smooth)	135	122%
Plastic	140	114%
Polyethylene, PE, PEX	150	100%
PP, PVC, CPVC	150	100%
Smooth pipes	140	114%
Steel, welded and seamless	100	212%

Other Losses

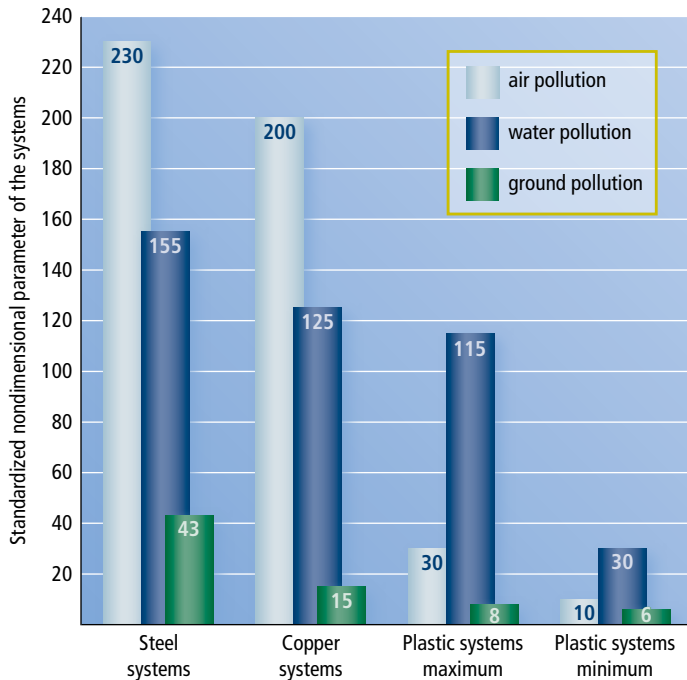
Control and balancing valves, coil losses, etc. on the critical run also should be assessed to determine if sizing increases are beneficial.

Right Size vs. Oversize

While I favor oversizing a pipe in the critical run, in my opinion possibly the single most wasteful practice in HVAC engineering is the tendency to oversize central plant equipment. To avoid complaints that a space is too hot or too cold, heat gain and loss calculations are conservative and then include a safety factor and are rounded up. I have seen heating and cooling plants that never reach 50 percent of their design capacity. This is wasteful upfront, and these oversized plants continually waste energy as long as they run. Oversized equipment generally never operates at its peak efficiency. Design teams should work with owners upfront to reach a more acceptable mutual understanding of the benefits and potential risks of more accurate system sizing. Buildings, systems, and equipment should be modeled to facilitate accurate loads and



Figure 1 Standardized nondimensional air, water, and ground pollution parameter of the systems



optimize equipment selection. ASHRAE 90.1, the U.S. Department of Energy, and others have modeling requirements and recommended software for modeling. One option may be to not include safety factors or morning warmup loads, and instead control the lights to come on to assist with morning warmup during extreme cold snaps.

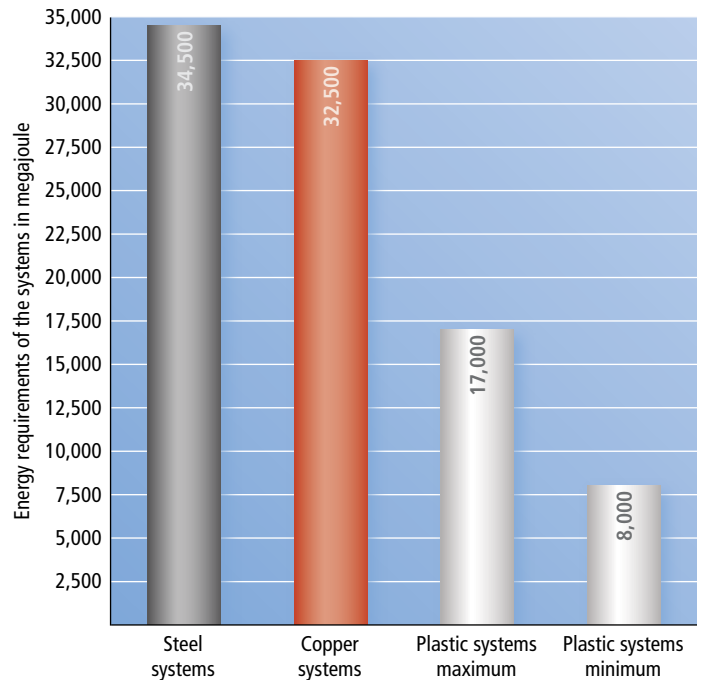
Don't Over-insulate

Pipe heat loss wastes energy, so specifying the correct level of insulation is important. However, don't fall into the trap of thinking if a little is good, a lot would be better. Due to the law of diminishing returns, over-insulating pipes is extremely wasteful. I have seen insulation levels that would not pay back in hundreds of years. I suspect the incremental energy savings from these high levels of insulation would not offset the energy required to produce the extra insulation. All the model energy codes have minimum insulation thickness requirements. Insulation optimization can be achieved using modeling software. For example, the North American Insulation Manufacturers Association makes software that calculates optimal economic insulation thickness. It can be downloaded at no cost at www.pipe-insulation.org. Calculations may well show that even the minimum code levels are excessive and beyond reasonable economic justification. In your role as a steward over our natural resources, as well as over your client's financial resources, it is your duty to determine a truly reasonable insulation level, and if it is less than code requirements, to work with your state and local code officials to correct this misallocation of resources.

Commissioning and Verifying

Require an independent balancing contractor to verify that the actual flow rates and pressure drops correspond to the design. If they don't, the design engineer may need to work with the mechanical contractor to determine why.

Figure 2 Energy requirements of the systems in megajoules



Measure and Compare Results

As an engineering community, we need to develop metrics that define distribution system efficiency, such as connected distribution power per area (full-load watts for all pumps and fans divided by the area in square feet). Knowledgeable owners know their chiller and boiler efficiencies. What if they knew their distribution efficiency? What if design firms used this to promote their services?

MATERIALS SELECTION

Energy-efficient design is only half the story. The other half is how the materials used will have a lasting impact on building occupants and the planet. To do their part, plumbing engineers should consider the environment when specifying or purchasing pipe, fittings, glues, solvents, solder, gaskets, sealants, tapes, and lubricants.

Some items to consider follow.

Toxicity

A system designed to deliver potable water for human consumption should avoid exposing the water to any potentially toxic materials. Currently, we settle for testing where water is left in contact with piping materials, and if certain selected toxin levels are below acceptable levels, the pipe is okay. A greener and healthier method is specifying nontoxic materials for pipe and systems that come in contact with potable water. Lead, heavy metals, phthalates, dioxins, and other toxins should be avoided. Any piping to be used for drinking (potable) water always should bear the NSF-PW stamp, per code.

Life of System

An important but often-overlooked factor of environmental friendliness is how long something will last. Our planned obsolescence mentality is extremely shortsighted. If you build something using



half the resources, but its useful life is half as long, the net benefit is zero—except for piping systems, where the net benefit is much less than zero. This is because piping system failures almost always result in collateral damage such as water damage, mold, and structural damage. Matters often are made worse by concealed pipes that allow damage to progress unnoticed for years, ultimately requiring substantial additional cost for repair or replacement. Thus, you should know the longevity of the pipe material specified for the product conveyed in it.

Recyclable

After the piping system has served its purpose, the building and its piping systems should be disassembled and made into other useful items or recycled so that they do not contribute to the landfill issue.

Recycled Content

On the other hand, in my opinion, the recycled material should never be made into new pipes. Recycling by its nature introduces impurities into the pipe. Impurities affect both the toxicity and quality of the pipe. In many regions, building owners are finding that piping systems do not last as long as they used to, resulting in very expensive replacement costs. One possible source of this problem may be the increasing use of recycled content in pipes.

Avoid Bad Chemistry

Water can be a very aggressive chemical. To make it even more challenging, water varies considerably in its makeup by geographic location, in pH level, oxygen level, minerals, microbiological content, and more. Chemical interactions between the fluid and the piping material have negative consequences for both, resulting in premature failures of the piping system and contamination of the water. For example, the mountain-fresh water in the Pacific Northwest is high in entrained oxygen and low in pH and attacks copper pipe, resulting in system failures in as little as 10 years and concerns about copper toxicity for those who drink the water.

Historically, we have tried to protect piping systems from the fluids they carry by adding inhibitors, but this means we are adding many chemicals to the mix. More chemicals mean a greater chance for unintended consequences, such as chemical incompatibility or environmental contamination. When a pipe leaks, consider what effect the inhibitors have on groundwater.

For example, polyolester oil, commonly called POE oil, is a type of synthetic oil used in refrigeration compressors that is compatible with new, environmentally friendly refrigerants. The use of this type of oil is being phased in by manufacturers who use compressors in their products. However, a LEED engineer recently warned me against the presence of POE oil in CPVC piping. A CPVC manufacturer confirmed that the presence of even the minutest amount of

POE in their piping causes stress fractures. I have encountered several projects where entire new piping systems failed due to incompatibility with common jobsite chemicals. To protect ourselves, our customers, and the environment, we must strive to select the appropriate material for the application.

Effects on Land, Air, and Water Pollution

In a European study called *Comparative Ecological Analysis of Drinking Water Installation Systems*,¹ a detailed analysis of drinking water pipe installations was conducted at the Technical University in Berlin. This study quantified emission values for common piping materials from the raw materials and the production. In conducting this complete environmental analysis, all aspects of the ecological impact of each piping material from raw material sourcing through manufacture of the finished product, installation, and finally disposal were considered. Figure 1 summarizes their findings for the air, water, and land pollution effects for steel, copper, and plastic pipes.

The study also evaluated the relative energy requirements to produce the competing piping systems, as shown in Figure 2. According to the study, “The results clearly show more intensive ecological pollution loads associated with the use of metal pipe systems. Differences can also be seen between the individual plastic pipe systems. The use of drinking water pipe systems manufactured from the plastics under review of PP (polypropylene), PEX, PB, and PVC-C represents a more ecologically beneficial solution than the use of metal systems. There are also differences between the individual plastic pipe systems in view of their energy balance, recycling, and waste disposal; on the whole, PP and PB present the most environmental beneficial alternative compared to metallic pipe systems.”¹

THE PLUMBING ENGINEER'S ROLE

Plumbing engineers are in the position of being stewards over vital natural resources, and we make decisions every day that have long-term effects on the health of people and our planet. Current trends and environmental necessity likely will drive even more buildings to use hydronics. The systems will need to have minimum negative environmental effects. Plumbing engineers are being called on more than ever to consider the environment before designing and specifying piping systems. **PSD**

REFERENCES

1. Kauter H., Weinlein R., Jokel C.: *Final report: Comparative analysis of drinking water systems*, Technical University Berlin, Berlin, 12. 1994.



STEVE CLARK is a Professional Engineer in the U.S. and Canada. He worked as a development and applications engineer for the Trane Company and as an HVAC and energy engineer for consulting engineering companies, including his own firms. His building system designs have won energy efficiency awards in both the U.S. and in Canada, including first place for commercial building from ASHRAE. He holds several international patents on HVAC and piping systems. His 30 years of experience in building energy optimization have led him to the conclusion that hydronics are a key component to efficient building design and that selecting the right pipes is key to an efficient and reliable piping system design. To help fill this need in North America, he now serves as president for North America for the German-made plastic piping manufacturer Aquatherm Inc. For more information or to comment on this article, e-mail articles@psdmagazine.org.