Leveraging Radiant and Hydronics to Help Achieve Decarbonization Goals

Discovering how thoughtful design for radiant heating and cooling, hydronic hot-water heating, and chilled-water systems can provide a compelling solution for comfort, efficiency, air quality, and other IEQ benefits while helping projects meet construction schedules and budgets and also supporting a low-carbon economy that can benefit carbon neutrality efforts

Authored by Hailey Mick

Contributions from Stephanie Radel and Kim Bliss

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Why Decarbonize?

Decarbonization is the process of reducing the carbon emissions produced by the construction, operation, and maintenance of buildings. This is becoming increasingly important as the built environment is a major contributor to global greenhouse gas emissions.

According to Fatih Birol, Executive Director of the International Energy Agency, "Over the next 40 years, the world is expected to build 230 billion square meters (2.4 trillion square feet) in new construction — adding the equivalent of Paris to the planet every single week. This rapid growth is not without consequences." (unep.org)

The built environment is responsible for an estimated **42% of annual global CO2 emissions** (architecture2030.org) and decarbonizing buildings is a critical step to meeting global climate goals.

When technology is misused and it has a detrimental ecological impact — as is now the case with the excessive burning of fossil fuels for energy — it becomes necessary to implement a cultural response to reinstate a sustainable equilibrium.

There are several solutions for supporting decarbonization efforts in the construction, operation, and maintenance of buildings. However, the focus of this paper will be on indoor climate solutions that provide comfort, efficiency, air quality, and other indoor environmental quality (IEQ) benefits while helping projects meet construction schedules and budgets.

The built environment is responsible for an estimated 42% of annual global CO2 emissions.

System Types

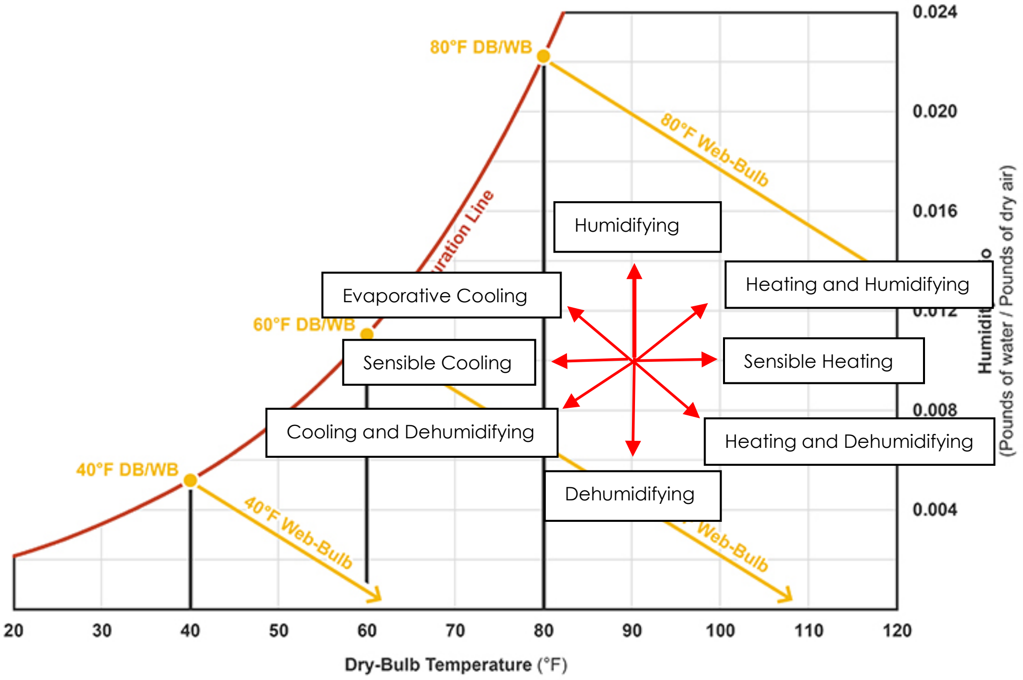
Central vs. Decentralized Design

With air-based systems, there are two design options: central and decentralized, which essentially describe where in the building the heat exchange is happening between the air and the coil carrying the heat-transfer medium. It can happen in one central plant where the air is conditioned and then distributed to various zones through ductwork. This is sometimes called an air-side or forced-air system.

Then, there are also systems that pipe water or refrigerant to the zone with the exchange happening on a local level. Regardless of which option has been chosen, the goal is to heat the air, cool the air, and address humidity in the air by means of having the air come in contact with hydronic or evaporator coils, commonly referred to as direct expansion (DX) coils. And whether using an air distribution model with conditioned air being delivered to zones through ductwork or a hydronic or refrigerant-based distribution system, the issue of ventilation still must be addressed.

Ventilation is about providing fresh air and dealing with toxins that might be building up in the space. ASHRAE published Standard 62.1 to specify minimum ventilation rates and other measures intended to provide indoor air quality (IAQ) that is acceptable to human occupants and also minimizes adverse health effects. (ashrae.org)

So, with a decentralized design, most large commercial applications will still require some amount of ductwork to deliver ventilation and a dedicated outdoor air system, also known as DOAS unit.



Psychrometric chart source: https://www.theengineeringconcepts.com/psychrometric-chart/

Central, forced-air systems often attempt to handle both comfort and ventilation simultaneously, whereas a decentralized system uses separate, dedicated systems to address comfort and ventilation.

ASHRAE even addresses these two different systems with two different standards. Standard 55 addresses thermal comfort and Standard 62.1 addresses ventilation, as mentioned previously.

Because there are many variables that need to be addressed for thermal comfort and many other variables that need to be addressed for ventilation, building these central station air handlers can become quite cumbersome and quite expensive rather quickly.

Furthermore, the operation of these units becomes quite complex and results in a system that uses more energy than necessary.

Temperature, humidity, contaminants, and oxygen levels do not fluctuate in proportion to one another. And thermostats and sensors need to monitor each of these details and react accordingly.

If the temperature is sufficient but the CO2 levels are high, the central air handler controlling it all must turn on, bring in, and condition outside air, which in turn will have an impact on the space temperature.

Conversely, when the systems are separate, the heating and cooling equipment can now focus solely on comfort and a separate ventilation system can focus solely on air quality without overtaxing either system.

Central systems tend to be more expensive to install, more expensive to operate, and fail faster than decentralized systems. And when they fail, the entire building is down compared to a single zone having a failure in a decentralized system.

Plus, water has the capacity to transfer energy 3,500 times greater than air, so it takes significantly more energy to move air than it does to move water.

So, for the purpose of this paper, the assumption will be that comfort and ventilation will be handled separately and continue down the path of comparisons by discussing the heat-transfer medium options.

Heat-Transfer Medium

Refrigerant vs. Water-Based Systems

As previously stated, there are several options when it comes to HVAC systems in commercial construction, and there are no set rules for when to use which solution. It is often a function of building space, location, purpose, budget, timeline, engineer preference, owner preference, and even goals of the project itself.

The concept behind the design options here are similar in that they all distribute fluid to a zone to condition the air locally. But the amount of refrigerant needed in the hydronic system is negligible and is typically contained compared to a VRF system, which sends refrigerant-filled piping all throughout the building.

Global Warming Potential, or GWP, is a measure of how destructive a climate pollutant is to our environment. Specifically, it is a measure of how much energy the emissions of one ton of a gas will absorb over a given period of time, relative to the emissions of one ton of carbon dioxide (CO_2). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time period. (epa.gov)

The GWP of a gas refers to the total contribution to global warming resulting from the emission of one unit of that gas relative to one unit of the reference gas, carbon dioxide, which is assigned a value of 1.

Refrigerants today are often thousands of times more polluting than carbon dioxide. In fact, the two most common refrigerants currently being used are R-134a and R-410a, which have a GWP of 1,430 and 2,088, respectively.

Meanwhile, **water has a GWP of 0**.

Granted, there is research currently underway for refrigerants with much lower GWPs, but today, these are the choices. And while instances of refrigerant leakage are few, the risks posed by VRF systems are nonetheless concerning.

VRF systems have hundreds (if not thousands) of feet of piping, filled with hundreds of pounds of pressurized refrigerant. At the very least, it is important to note that when the decision is made to use a refrigerant-based system, like a VRF system, there are several additional safety measures that need to be put in place to prevent further harm to the occupants and the environment.

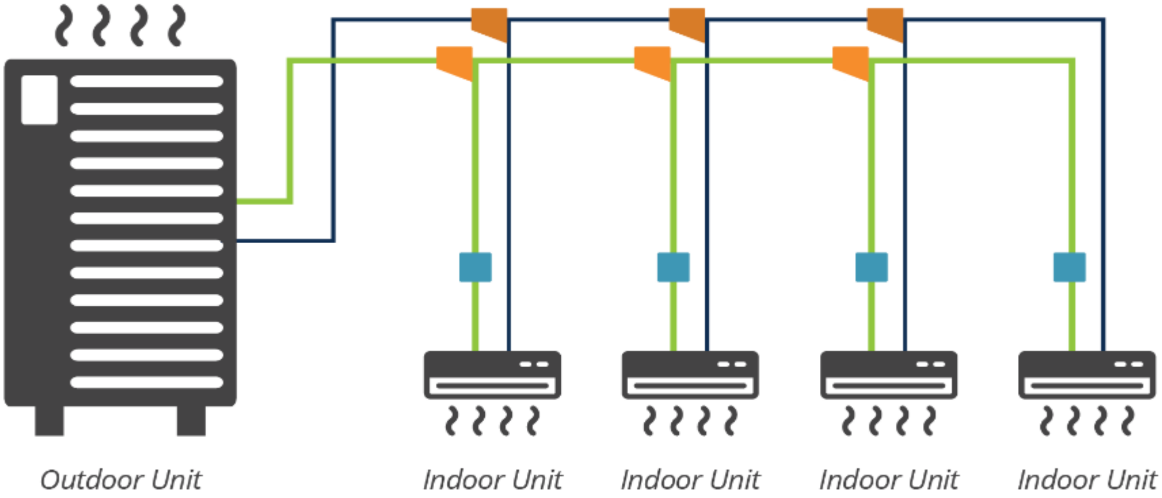
ASHRAE Standard 15 (requirements for the safe design, construction, installation, and operation of refrigeration systems), Standard 34 (naming refrigerants and assigning safety classifications based on toxicity and flammability data), and Standard 147 (Reducing the Release of Halogenated Refrigerants from Refrigerating and Air -Conditioning Equipment and Systems) all address these concerns when designing refrigerant-based systems.

Defining a VRF System

A VRF system is one that uses refrigerant as the working fluid to distribute heat within a building. The system output is regulated based on system load, and the refrigerant flow is regulated by electronic expansion valves and variable-speed compressors.

First developed in Japan in the 1980s and first appearing on the North American market in the early 2000s, VRF systems are a relatively new technology. In general, they consist of a central outdoor unit and multiple indoor units of different types and capacities.

The following image shows the outdoor unit, indoor units, and refrigerant piping layout in a VRF system.



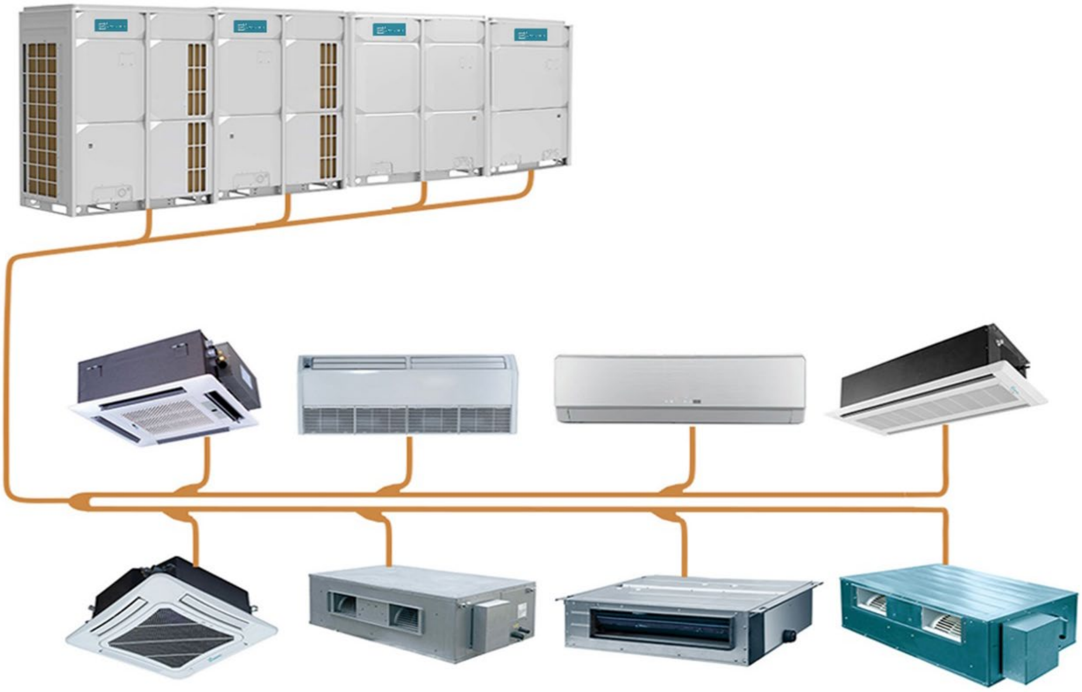
Small systems (i.e., 40 to 50 tons of refrigeration and below) are often designed as air-cooled systems because they are less expensive. However, the energy consumption of air-cooled systems is usually significantly higher, especially as the systems get larger. In addition, the space required for large air-cooled systems becomes impractical in many applications.

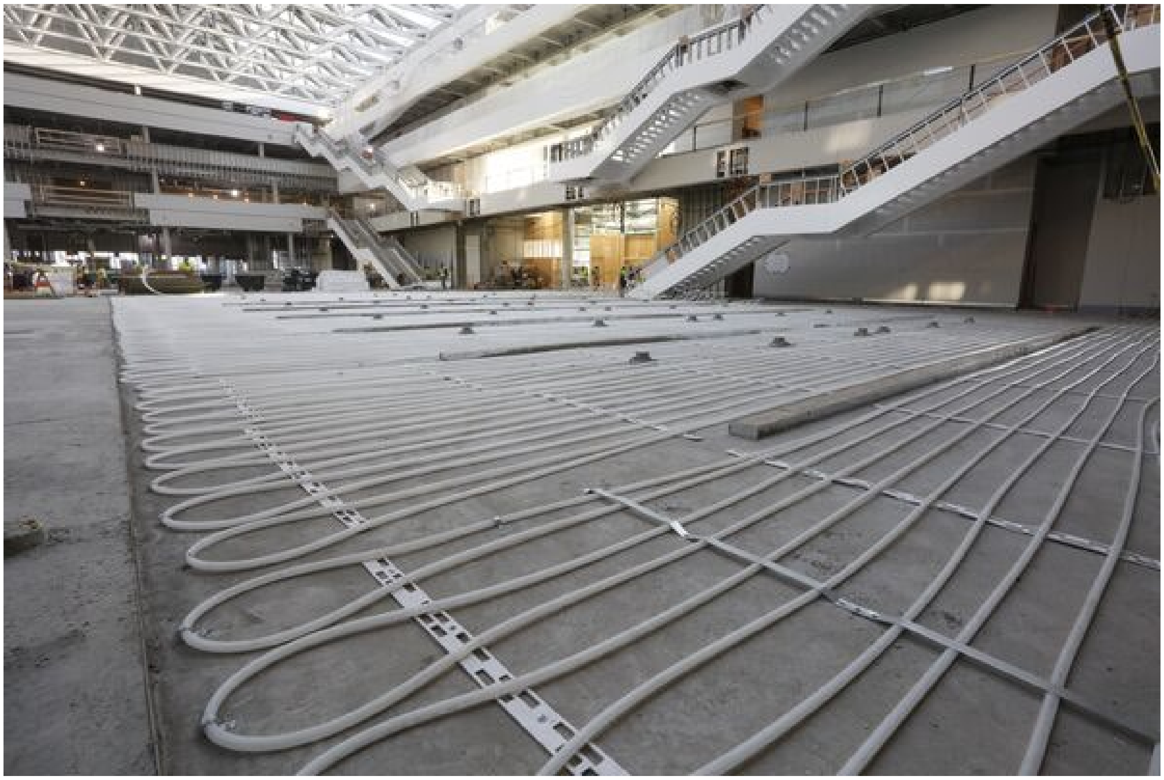
Since air-cooled systems are used in limited applications and use air instead of water as the cooling mechanism, they are not the focus of this paper.

Water-cooled units tend to be more energy-efficient than air-cooled units, particularly in larger facility applications.

So, considering the topics previously discussed, this paper will examine three systems — a VRF system, a hydronic-based system using fan coils, and a hydronic radiant heating and cooling system.

Below are examples of what these systems would look like on a very basic level. The first image is a VRF setup, and the second is a hydronic radiant heating and cooling system. The goal is to represent the distribution model of a design with a central plant, piping, and coils located in remote zones throughout the building.





Definitions — Carbon vs. Electricity

Now that system design and heat-transfer mediums are covered, it is important to define a few terms.

For starters, what is net zero? Is it energy and electricity or carbon and emissions? Is one more important than the other, or do they both matter?

The answer is yes!

The goal is to get to net zero carbon, but it is necessary to minimize energy use and change it to clean energy sources in order to achieve this goal.

Decarbonization refers to the goal of ending our dependence on oil and gas as power sources to reduce the carbon dioxide emissions that raise global temperatures.

Electrification refers to using technologies such as vehicles or heat pumps that operate with electricity instead of burning fossil fuels such as oil, gas, and coal.

Electricity generated through clean resources, such as wind and solar power, is considered a decarbonization strategy.

In order to reach net zero, it is necessary to reduce and balance emissions from our commercial buildings. There are many strategies that help offset carbon through planting trees or using technology like carbon capture and storage.

However, it is vital to start the process with intentional designs that use clean energy sources, maximize energy efficiency, minimize transportation cost, and conserve our most precious resource — water.

The ASHRAE Position Document on Building Decarbonization states, "As society faces the challenge of mitigating climate change, ASHRAE's position is that decarbonization of buildings and their systems must be based on a holistic analysis including healthy, safe, and comfortable environments, energy efficiency, environmental impact, sustainability, operational security, and economics." (ashrae.org)

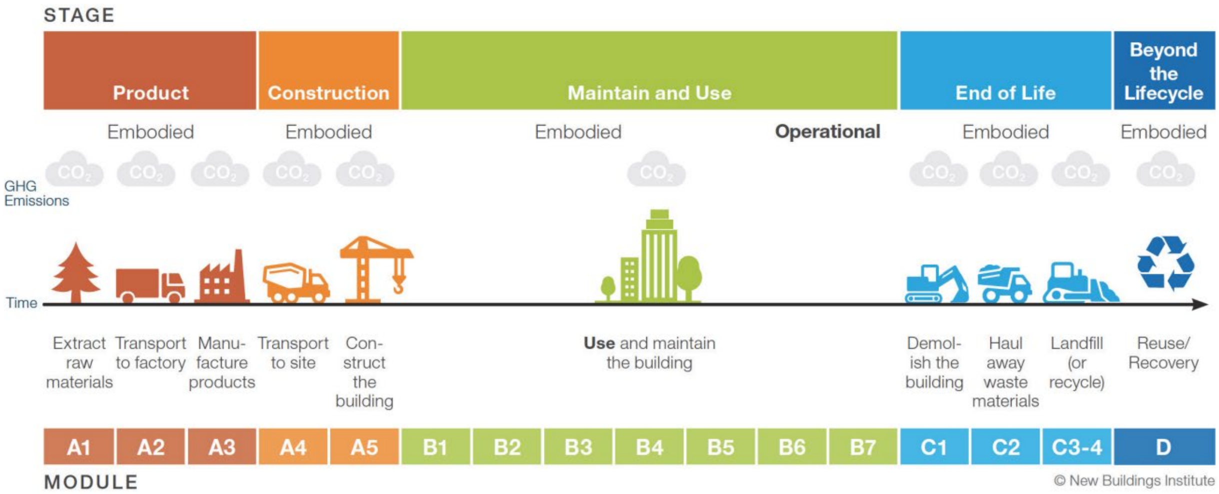
Hence, a comprehensive approach is needed that addresses every stage of a building's lifecycle, including design, construction, operation, occupancy, and decommissioning.

The main contributors to greenhouse gas emissions include construction processes, energy consumption, methane emissions, and refrigerant use.

A thorough lifecycle assessment must account for both operational and embodied emissions. Operational carbon is the amount of carbon emitted during the operation of a building. This includes both energy and water-related emissions. Embodied carbon is the amount of carbon emitted from the extraction of raw materials for the building to the building's end of life, including refrigerant emissions. It is everything in the life of the building that is not covered by operational carbon.

Operational emissions largely stem from energy use during the building's functional lifespan. In contrast, embodied emissions cover the greenhouse gases emitted from raw material extraction to manufacturing, transport, and installation of building components.

These emissions also extend to the building's maintenance, repair, and eventual decommissioning, including refrigerant leakages throughout its lifecycle. The graphic below from the New Buildings Institute and referenced in the ASHRAE Position Document on Building Decarbonization shows the various stages and modules for a building's lifecycle.



Source: https://newbuildings.org/code_policy/embodied-carbon/

It is also imperative to start thinking and talking about **whole life carbon** — not just for buildings and the architectural building materials but also specifically about MEP equipment.

Early incorporation of design elements aimed at carbon reduction needs to be a priority. Assessing the building's life-cycle emissions — during the design phase — enables designers to make data-driven decisions that minimize long-term greenhouse gas emissions.

MEP systems are made largely from high embodied carbon metals. For instance, aluminum for motors, copper for piping, and steel for enclosure and support rails. And due to low recyclability to most of these equipment types, virgin metals need to be mined, treated, processed, and transported over long distances — a highly energy-intensive endeavor — to create new equipment at the end of its short useful life.

Supporting Decarbonization Efforts via Radiant and Hydronics Systems

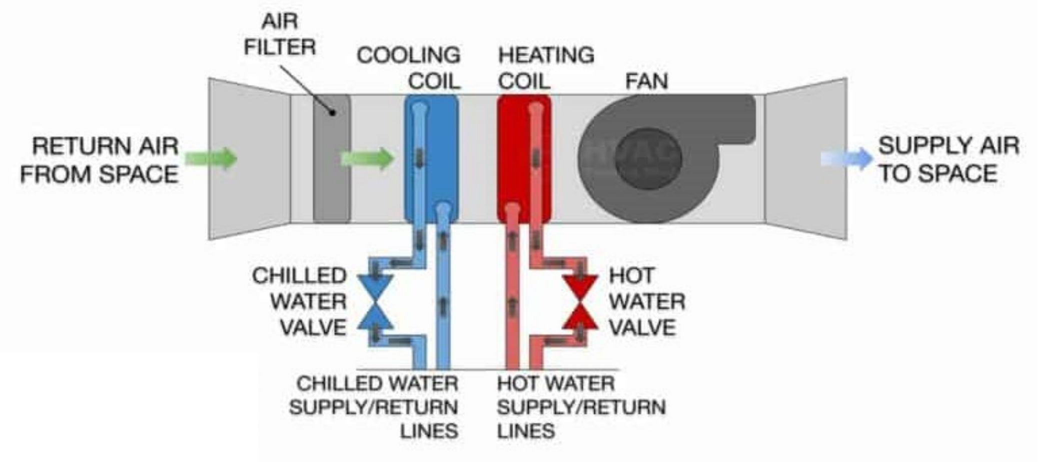
While there is still a lot of unknown information regarding building construction and decarbonization efforts, it is important to take the current existing knowledge and start the process of moving in the right direction by making comparisons through a system evaluation.

In an attempt to create a like-for-like comparison, the assumption will be made that ventilation is being handled through a dedicated system. The following pages will evaluate a VRF system, a fan coil system, and a hydronic radiant system, and compare the impacts on health and safety, occupant comfort, energy efficiency, embodied carbon, and economics.

Health and Safety

It is important to note that for each of these categories, there are a lot of similarities between a VRF design and a hydronic fan coil design. However, the biggest difference is, of course, the heat-transfer medium.

Generally speaking, these systems have a central plant generating hot or cold fluid (hydronic or DX) and distributing that fluid to zones where the air is then circulated over a coil to be conditioned. Inherent to this design is the need to constantly move the air around in the space. The image below shows a general illustration of this concept.



Unfortunately, with this design, all the dust, germs, and microbes are also constantly moving. Now, one might question, "If the air is constantly being returned to a fan coil or cassette, it is constantly being filtered and cleaned?"

The reality is that changing out filters is most likely not happening as often as it should, and ultra-high levels of filtration come at a premium price and significantly increase the air-side pressure drop and energy required to move the air across the coil.

Hydronic radiant systems, on the other hand, provide improved air quality by allowing the particles in the air to settle so they can be removed through the cleaning of surfaces. The only air being moved with a hydronic radiant system is the fresh, ventilated air that is being filtered at a location more likely to be regularly monitored and maintained. And maintenance is simplified, primarily requiring visual checks.

The illustration at right shows how forced air circulates dust and infectious aerosols throughout a space while a radiant system radiates warmth up from the floor without the use of fans or blowers.

Additionally, a VRF system leak is a serious issue due to the large refrigerant volume it contains. A single leak can result in a complete refrigerant loss and even require building evacuation and intervention of hazmat teams.

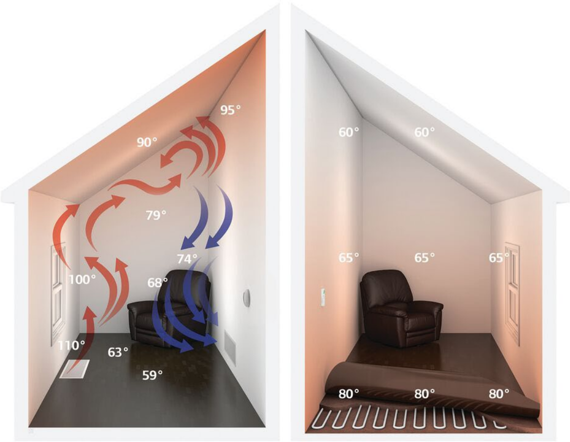


Image courtesy of Uponor

R-410a and similar refrigerants can displace the air in a room. In spaces with minimal ventilation, it is possible for refrigerant concentrations to reach values that could render occupants unconscious and ultimately lead to suffocation.

For this reason, ASHRAE Standard 15 limits refrigerant volume based on the smallest space served. Properly addressing the risk of refrigerant leakage requires extensive design considerations and added costs, such as refrigerant detectors, separate systems for smaller spaces, piping rearrangement, etc.

Based on the appropriate air movement needed and ensuring the ability to clean surfaces easily, the minimal amount of maintenance required, and lack of excessive amounts of refrigerants used, hydronic radiant systems are the best option for health and safety.

Category	VRF	FCU	Hydronic Radiant
Air quality/air movement	✗	✗	✓
Unit maintenance	✗	✗	✓
Refrigerants	✗	✓	✓

Indoor Environmental Quality (IEQ)

Now on to occupant comfort, which is generally measured by IEQ or indoor environmental quality. IEQ plays a key role in the design of high-performance, sustainable buildings.

IEQ is a broader term that encompasses IAQ, or Indoor Air Quality, and other physical and psychological aspects of the indoor environment. While IAQ focuses on the quality of the air inside a building, IEQ considers overall conditions of the building.

Good IAQ is necessary for good IEQ, but it is not sufficient on its own. IEQ includes several factors unrelated to the HVAC system, however sound, smell, thermal comfort, and design flexibility are all factors that can be affected.

Starting with sound, with a VRF or fan coil unit design, the space temperature fluctuates and that is what controls the operation of the fan and motor in the zone. The nonstop sound of the fan turning on and off and back on again can become intrusive. In fact, the noise from most VRF and fan coil units when operating is in the range of 50-70 decibels, which, while not harmful, can be annoying and distracting.

Next is the topic of odor. When temperatures begin to drop at the beginning of fall, people start to turn on the heat for the first time that season, and everyone experiences the same familiar smell — the burning off of dust and other microparticles that have accumulated on the coil. Again, when the air in the space is constantly being moved, it is difficult to truly clean the space.

Now, on to the topic of comfort. A large portion of a body's heat loss is caused by radiation to cooler surfaces. The cooler the surfaces around a human body, the faster heat is "pulled" from the body, resulting in a feeling of chill and discomfort. By warming the interior surfaces of floors, walls, ceilings, windows, and doors, radiant heating reduces radiant heat loss from the body, providing a more consistent and comfortable experience.

Radiant systems eliminate the familiar — but uncomfortable — reality of warm air blanketing the ceiling while cool air and surfaces remain at floor level. Not only does this improve comfort, but it also reduces heat transfer through the ceiling and upper portions of the walls, making radiant heating and cooling a highly energy-efficient solution. The greater the height of the interior space, the greater benefit this characteristic provides.

The need for fans to push warm air back down to the occupied zone of the room is eliminated in most cases when radiant heating and cooling systems are installed. Radiant systems allow the conditioning of a space very close to the ideal temperature curve for human comfort.

The images on the following page illustrate how radiant systems more closely align with the ideal heating curve of the human body while forced-air systems vary widely from the curve.

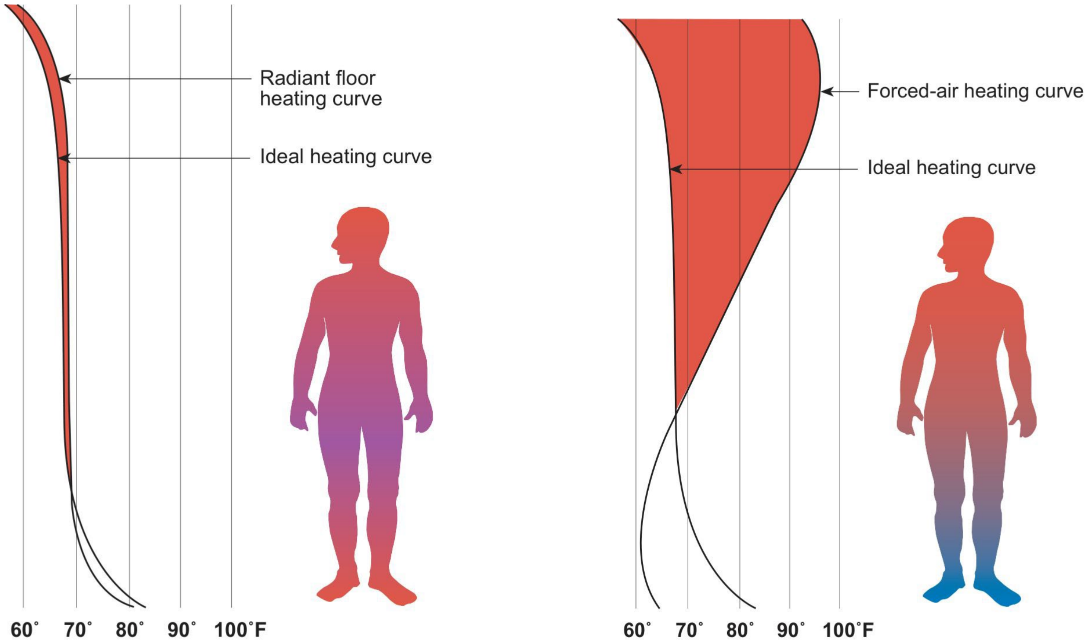


Image courtesy of Uponor

Comfort, however, is highly individual and related to a multitude of factors such as clothing and metabolic rate. Thankfully, most radiant systems are designed for room-by-room zoning. Not only does this offer the potential for energy savings by reducing temperature in unoccupied rooms, but it also allows different occupants to adjust rooms to their own desired comfort level.

When people have more control over their spaces, they tend to feel more comfortable, which leads to the final topic for this section: design flexibility.

The built environment should be able to change to meet shifting needs, whether social or environmental. Flexible architecture considers how occupants' needs may change and requires design of those spaces with these changes in mind.

Theoretically, this reduces the need for redesigns, especially in MEP systems. As the world changes and occupant needs evolve at a faster pace, the built environment must be designed in consideration of these future changes.

Architects and designers are challenged to meet and exceed these developing demands. By adopting an agile approach, they are creating truly innovative, configurable spaces that are fundamentally practical.

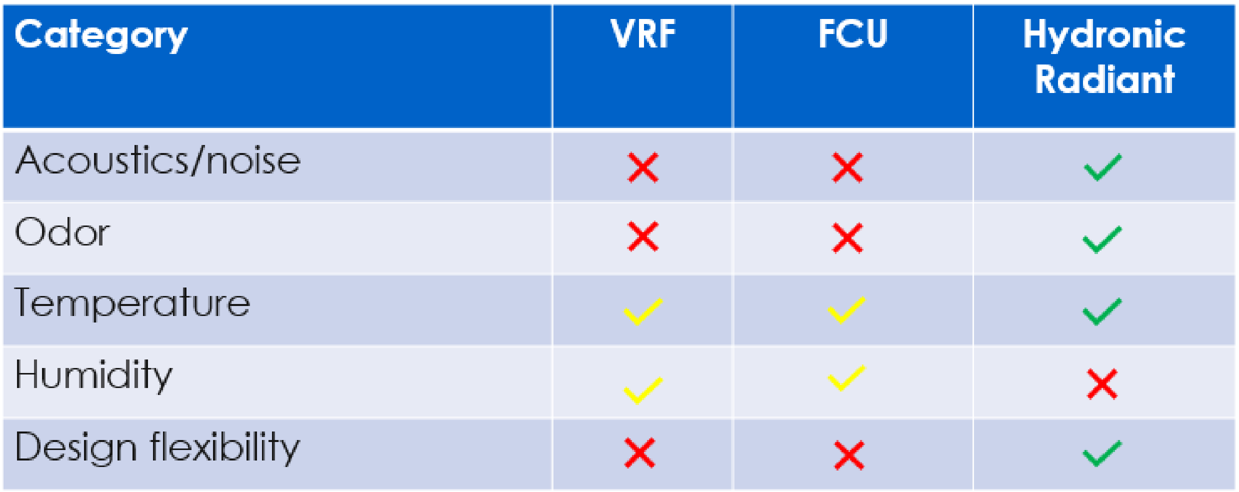
When radiant heating and cooling is used to condition the space, the opportunity to reconfigure the space is optimized. Because the floor is the "unit", there is no relocation of equipment, grilles, or piping.

IEQ Scorecard

Now for the ranking in this category. Due to the fact that both VRF and fan coil systems essentially require temperature fluctuations to operate, and humans can recognize temperature variances as small as one degree, these two systems will get a half point in this category because, despite that fluctuation, they do a decent job of maintaining the space temperature, albeit very inefficiently. And to be fair, both VRF and fan coil systems score higher than a radiant system for humidity.

When discussing heat, a radiant system can certainly handle the entire load, but in cooling mode, the hydronic radiant system can only address the sensible load. The latent load will need to be handled by the dedicated outdoor air unit, which could require a decent amount of upsizing on that unit to handle the load.

However, radiant heating and cooling systems are certainly the better solution for noise and odor mitigation as well as design flexibility.



Category	VRF	FCU	Hydronic Radiant
Acoustics/noise	✗	✗	✓
Odor	✗	✗	✓
Temperature	✓	✓	✓
Humidity	✓	✓	✗
Design flexibility	✗	✗	✓

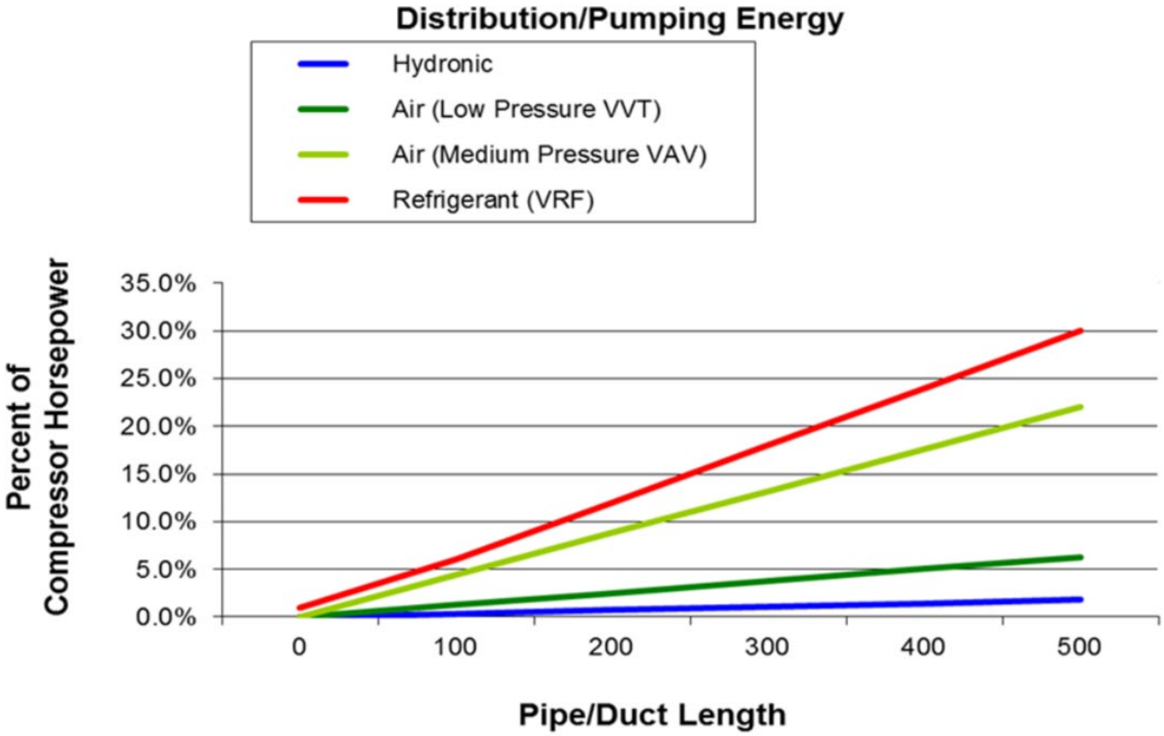
Energy Efficiency

Now on to energy efficiency. Several studies have shown that the farther the piping distance, the less efficient a refrigerant-based system becomes.

Although proponents of VRF systems point out no circulators are needed to move refrigerant throughout a building, electrical energy still is required just to move refrigerant gas and liquid through piping.

That energy is supplied as electrical input to the system's compressor(s). The electrical energy consumption for moving refrigerant through a VRF system, per unit of heat or cooling energy delivered, is significantly higher than that required for a well-designed hydronic system.

This graph compares the energy required to move the cooling medium through a building. It assumes the thermal energy is supplied by a vapor/compression source, such as is used in a VRF system.



Source: https://www.iapmo.org/hiac/energy_efficient

The vertical axis represents the percentage of the compressor power required to move the cooling medium throughout the space, and the horizontal axis represents the distance from the thermal energy source to the load.

The VRF system uses about 6% per 100 ft. of refrigerant line set compared to the hydronic system, which uses only about 0.3 % per 100 ft. of distribution distance.

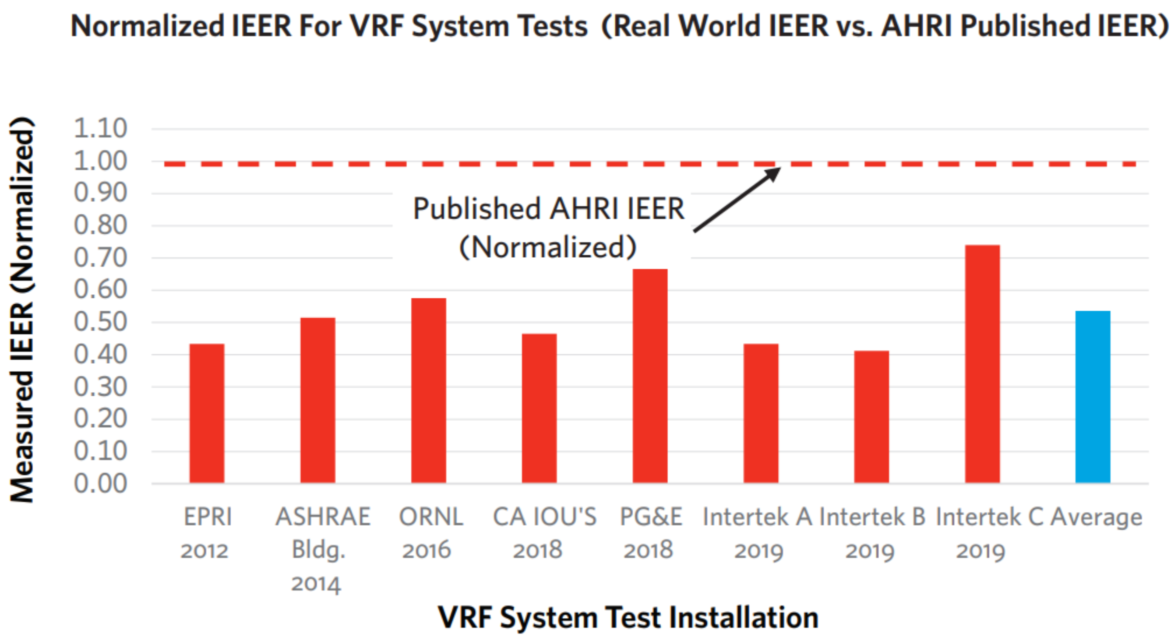
The more piping that is required, the more difficult it becomes to justify a refrigerant-based system over a hydronic system from an energy consumption standpoint.

According to IAPMO, many VRF systems are conservatively measured at 50% below published energy efficiencies. The reason is simple, a real building requires multiple de-rates to the rated efficiency based on actual operation.

Variables in a real building include: outdoor air temperature, length of refrigerant lines, elevation change between the condensing unit and indoor split units, indoor room temperature when cycling, actual airflow, constant verses variable room loads, and multiple other real world operating differences from prescribed laboratory test points. Even oil migration in the refrigerant charge impacts efficiency (armstrongfluidtechnology.com).

When VRF systems are lab tested to find published IEERs (or Integrated Energy Efficiency Ratings), a 12.5-foot separation between the indoor and outdoor unit is used.

In a building, there’s likely to be hundreds of feet of copper refrigerant line installed, and for refrigerant, distance is the number-one energy hog.

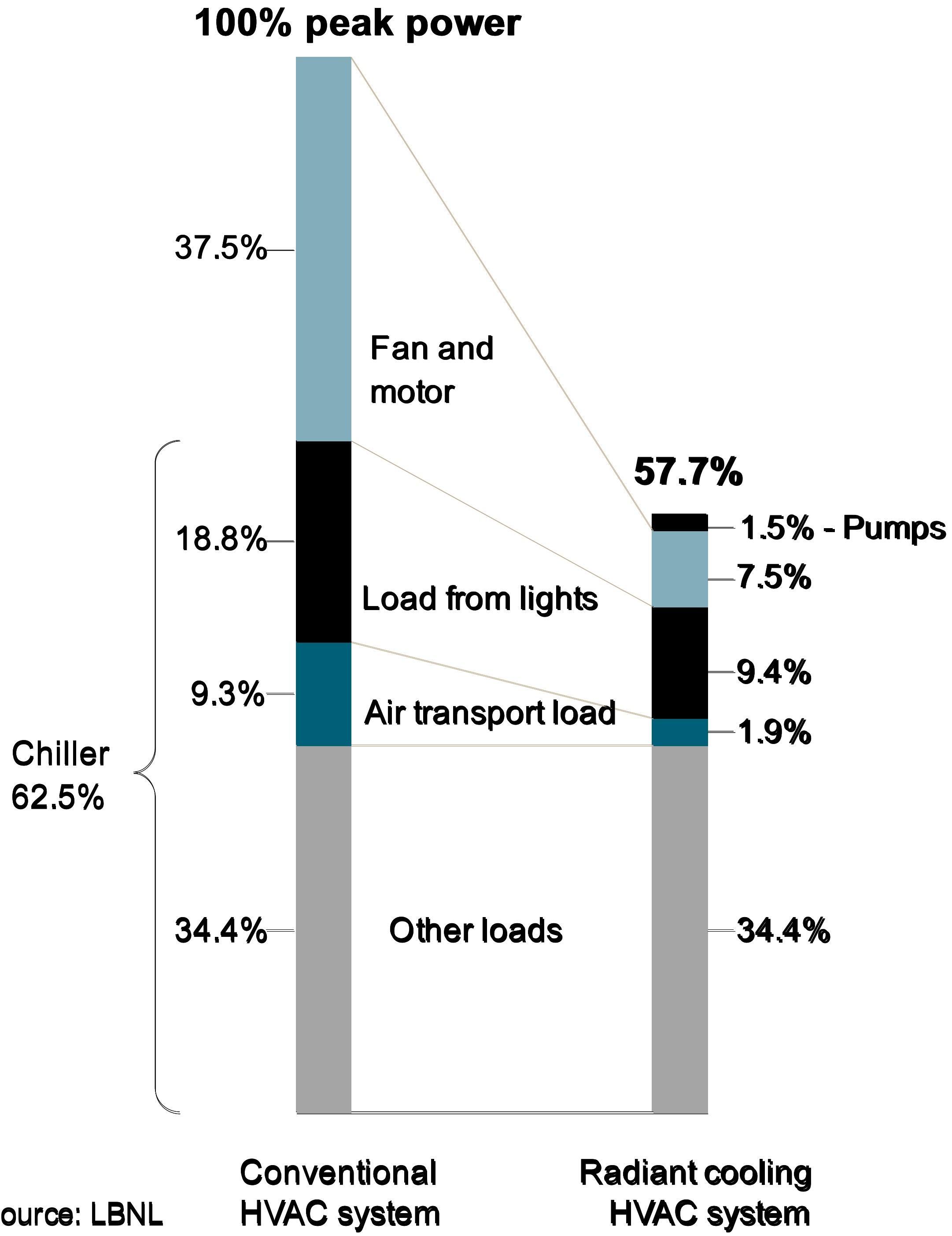


Source: https://armstrongfluidtechnology.com/~/media/documents/sales-and-marketing/white-papers/9-884_the_advantages_of_hydronic_systems_vs_vrf_a_critical_analysis_whitepaper.pdf?la=en

Additionally, according to the Lawrence Berkley National Laboratory (LBNL), radiant cooling systems, which use cooled surfaces such as floors or ceilings to absorb heat from a room, can help cut energy use and lower and shift peak electricity demand in buildings. (flexlab.lbl.gov)

As a matter of fact, depending on the climate, a radiant cooling system in conjunction with a dedicated outside air system could save between 17% to 42% over the baseline VAV system. (radiantprofessionalsalliance.org)

Simply stated, for maximum efficiency, water is the best option.

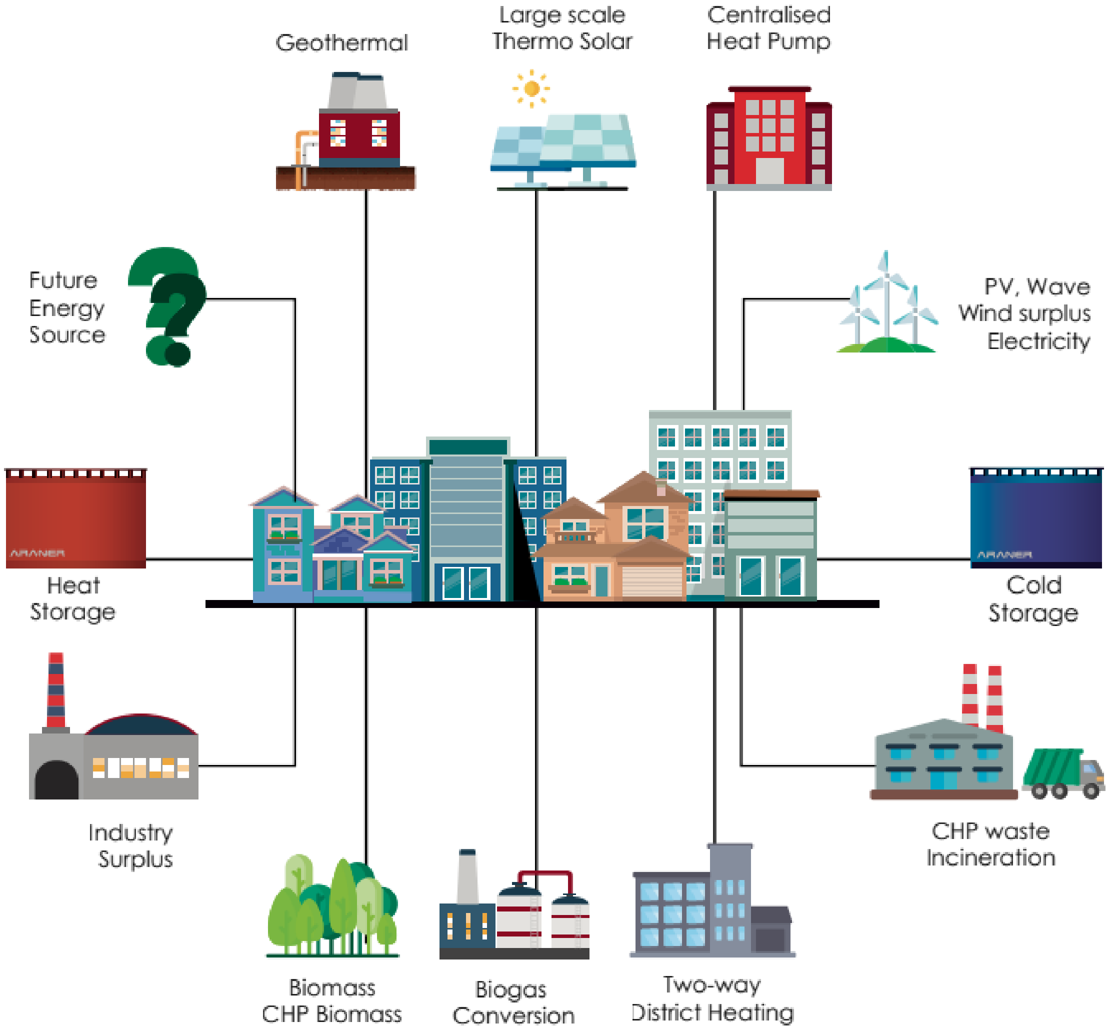


Source: LBNL

Energy Sources

Nothing demonstrates the versatility of a hydronic system like the ability to integrate sustainable technology. Radiant systems can efficiently utilize various energy sources, such as geothermal and solar energy, for everything from space heating and cooling to snow melting to hot water supply. Additionally, they support waste-heat recovery and thermal energy storage during off-peak times.

Combining multiple heat sources in a single system optimizes efficiency, while various cooling options, such as standard chillers or water from large lakes, enhance adaptability.



Source: araner.com

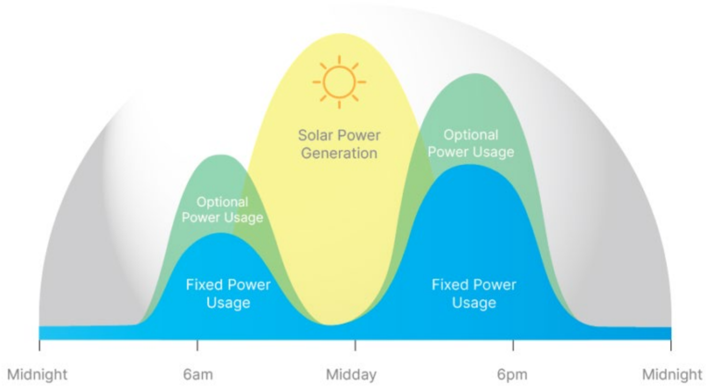
Thermal Energy Storage (TES) and Load Shifting

Thermal energy storage (or TES) is a versatile technology that stores heat or cold for later use, and it is ideal for hydronic systems. It saves energy and costs by producing hot or cold water during off-peak times, a practice known as "load shifting".

Load shifting involves adjusting energy consumption patterns to use energy during low-demand periods, helping to maintain a stable energy grid. TES and load shifting are compatible with renewables like solar and work seamlessly with hydronic heating and cooling systems.

While heat can be transferred from refrigerant to water, it is impractical to recover it for direct-space heating or cooling. In heat-recovery VRF systems, some indoor units can be in cooling mode while others are in heating mode, reducing energy consumption. Although this balance doesn't occur frequently, it significantly improves energy efficiency when it does.

VRF systems offer zoned comfort by transferring heat between zones, but they lack thermal energy storage capabilities. Water-based hydronic systems, like water-source heat pumps, extract heat or cold from a room and return it to the system, reducing energy use and costs.



Source: powerpal.com

Energy Efficiency Scorecard

So, in the category of Energy Efficiency, hydronic based radiant systems are still the clear winner.

Category	VRF	FCU	Hydronic Radiant
Efficiency capabilities	✗	✗	✓
Thermal storage	✗	✓	✓
Load shifting	✓	✓	✓

Embodied Carbon

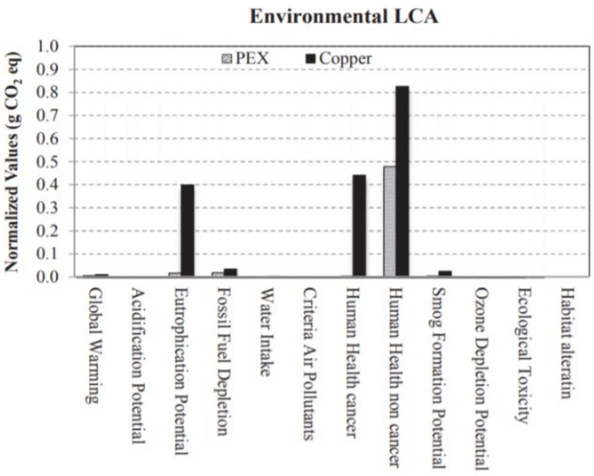
Now, moving on to embodied carbon. When using a refrigerant-based design, metallic piping is the only acceptable option. However, when hydronic-based systems are chosen, there is the option to use polymer piping solutions.

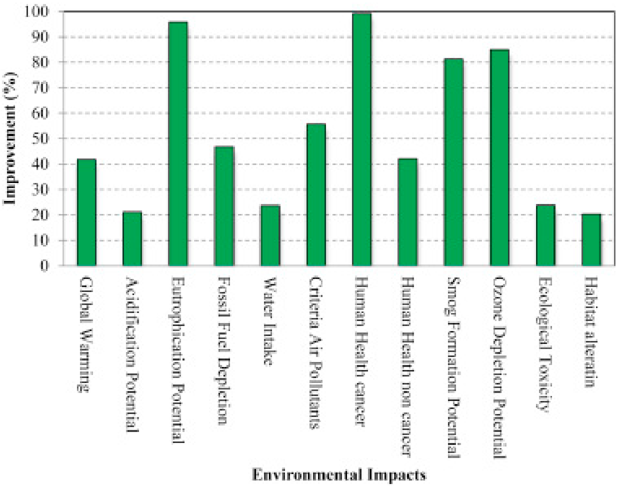
As mentioned earlier, embodied carbon is the amount of carbon emitted from the extraction of raw materials for the building to the building's end of life. The USEPA has defined a lifecycle assessment, or LCA, as a comprehensive method for measuring environmental impacts associated with a product's lifecycle.

Studies have shown that when compared to copper, the production of PEX uses 42% less CO2 emissions and that PEX has 47% less embodied carbon than copper. (sciencedirect.com)

Similar studies are well underway for PP-RCT for larger-diameter systems, and results are in alignment with what the industry has historically seen for PEX.

Design concepts that incorporate environmentally responsible materials, intelligent installation plans, minimal construction waste, and avoid potential contaminants are the standard to build towards.





Source: sciencedirect.com

Materials, Labor, and Transportation

Since polymer piping solutions can be up to 80% lighter than copper or steel, there is a direct relationship between the product and a reduction in transportation costs and emissions. And because polymers outlive metallic systems, with life expectancies of 50 to 100 years, there is a reduced need for replacement. This is another benefit for not only building owners but the environment as well.

Environmental Product Declarations (EPDs)

To make real progress toward a more sustainable construction industry requires transparency about the products being used. Environmental Product Declarations (EPDs) use LCA calculations to comprehensively evaluate a product's environmental impact along its entire lifecycle.

These official declarations contain comprehensive information about the environmental impact of specific products. They include details about a product’s consumption of raw materials and energy, waste generation, and air, soil, and water emissions throughout its lifecycle.

They follow a strictly determined methodology — the ISO series 14,025 standards — and are validated as an official document by a third party.

EPDs contribute to greater product transparency and traceability in the construction sector and allow comparisons between products that fulfil the same function.

These resources allow engineers to influence the carbon footprint of buildings and projects by selecting the most sustainable solutions and also help manufacturers constantly review and reduce the environmental impact of their own production and supply chains.

EPD Hub

ENVIRONMENTAL PRODUCT DECLARATION

IN ACCORDANCE WITH EN 15804+A2 & ISO 14025 / ISO 21930

Wirsbo hePEX
Uponor Corporation

EPD HUB, HUB-0484
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Created with One Click LCA

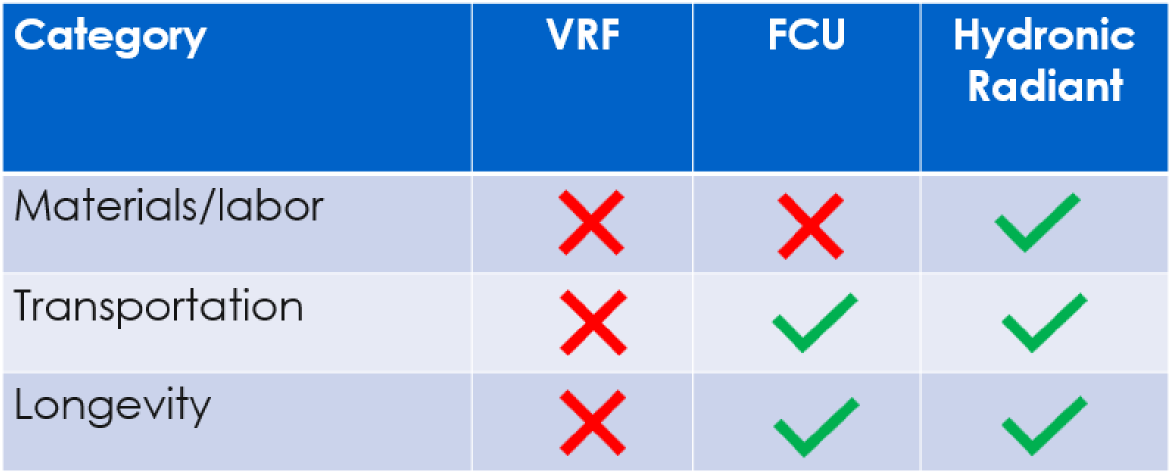
Image courtesy of Uponor

Embodied Carbon Scorecard

Along with high embodied carbon material for both the equipment and piping system needed to be used, VRF systems have a shorter life expectancy. Hydronic systems have been known to last 25 years or more.

However, because the compressor in a VRF system must operate during both heating and cooling cycles, reducing its product life, VRF systems could need replacing after only 10 to 15 years.

VRF systems are more difficult to install, have more components, and have heavier transportation costs, so once again, hydronic radiant systems are the winner in this category.



Category	VRF	FCU	Hydronic Radiant
Materials/labor	✗	✗	✓
Transportation	✗	✓	✓
Longevity	✗	✓	✓

Economics

VRF systems have a place in the market, yet some industry claims of system cost savings relative to other industry standard system designs are based on antiquated comparisons that do not hold up to careful review.

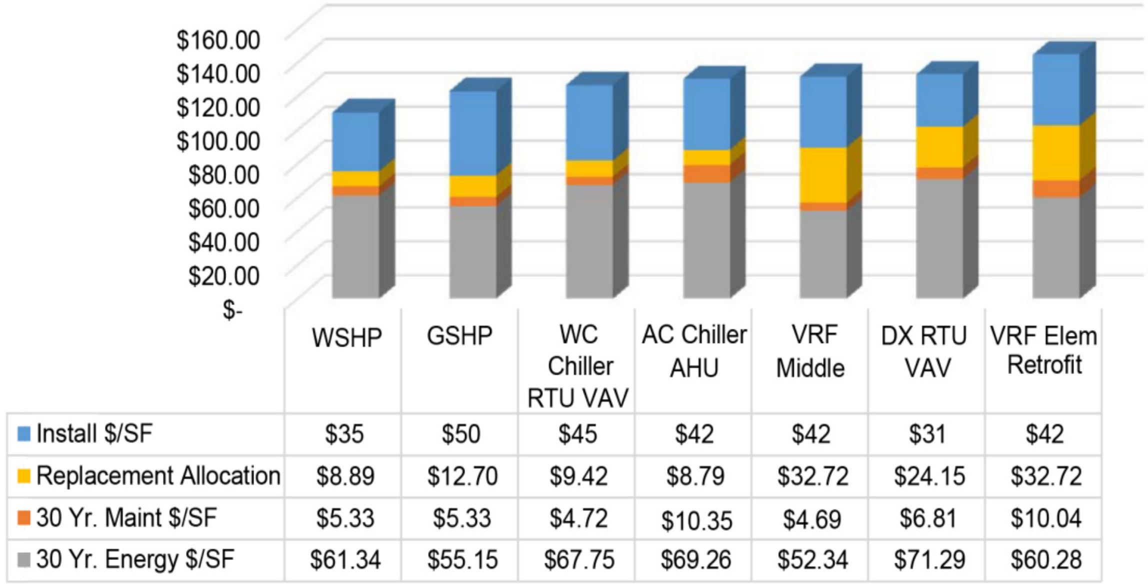
VRF systems are more expensive to install for a handful of reasons, but the main difference is primarily the result of the requirement for more complicated refrigerant management systems and controls and upsizing of the equipment that will be needed for de-rating.

Some of the cost differential comes from the added requirements on labor. Each installation step of VRF systems requires extra care and attention and specialized installers. Again, VRF systems must be installed using copper piping, whereas hydronic piping offers many options.

Due to the high fluid pressures and temperatures of refrigerant in VRF systems, the grade of copper to be used must meet ASTM B280 standards, and metals are traded commodities with constantly fluctuating prices.

In a study commissioned by Xylem Inc. that evaluated HVAC systems in a number of South Carolina school buildings, hydronic systems outperformed all other systems, including VRF, in terms of lower energy use, cost, and life expectancy, by as much as 24% (xylem.com).

The initial cost of a hydronic system is generally lower, and systems offer a much wider range of flexibility for components, operation, and maintenance, both in terms of parts and service.



	WSHP	GSHP	WC Chiller RTU VAV	AC Chiller AHU	VRF Middle	DX RTU VAV	VRF Elem Retrofit
🟦 Install $/SF	$35	$50	$45	$42	$42	$31	$42
🟨 Replacement Allocation	$8.89	$12.70	$9.42	$8.79	$32.72	$24.15	$32.72
🟧 30 Yr. Maint $/SF	$5.33	$5.33	$4.72	$10.35	$4.69	$6.81	$10.04
⬜ 30 Yr. Energy $/SF	$61.34	$55.15	$67.75	$69.26	$52.34	$71.29	$60.28

Source: xylem.com

Prefabricated Radiant Rollout™ Mats

Additionally, to help lower the cost of a radiant system, there are prefabricated mats of radiant piping that provide a fast, efficient, and consistent method for installing radiant heating and cooling systems in large commercial areas. These custom-designed, prefabricated, pre-pressurized solutions can reduce required manifold ports by more than 60%, reduce wire ties and staples by up to 30%, and improve installation time by up to 85% (just for the manifolds).

They are the ideal solution for faster, more consistent radiant installations, resulting in smaller manifolds, less hydronic distribution piping, fewer valves, and less waste in time and materials along with providing worker safety by minimizing knee and back strain as well as offering dependable commissioning with self-balancing circuits.

Image courtesy of Uponor

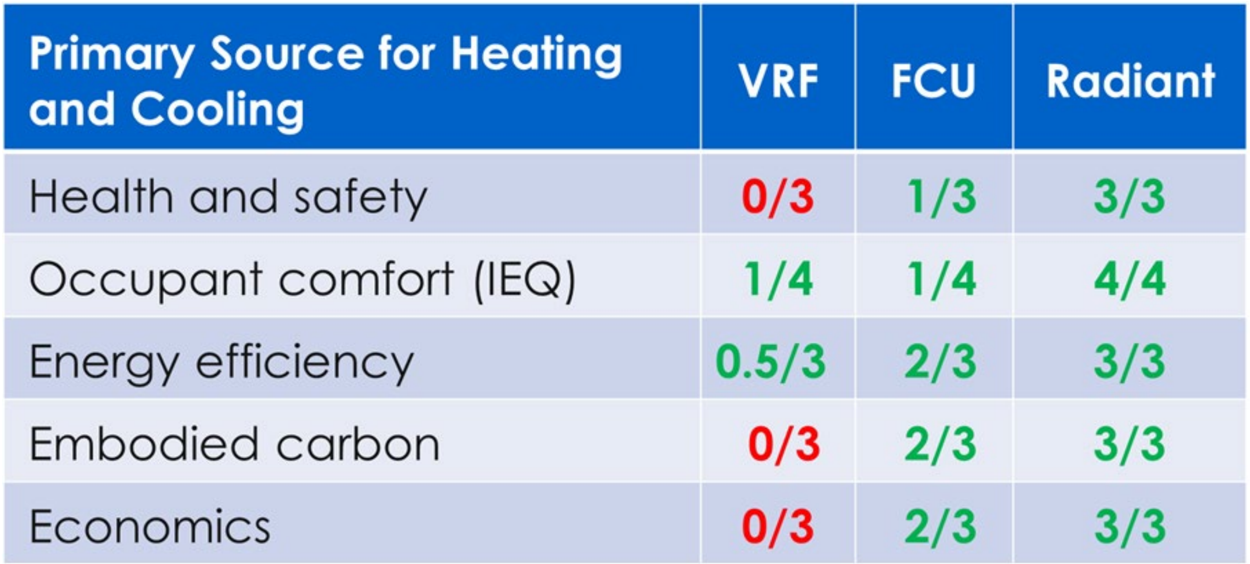
Economics Scorecard

Subsequently, here in the last category, hydronic radiant systems really excel.

Category	VRF	FCU	Hydronic Radiant
Equipment	✗	✓	✓
Installation	✗	✓	✓
ROI (people and space)	✗	✓	✓

System Evaluation Summary

Now that the five areas initially identified at the beginning of the paper are complete, it is clear that hydronics and radiant systems are superior at achieving decarbonization goals compared to VRF and FCU systems.



Primary Source for Heating and Cooling	VRF	FCU	Radiant
Health and safety	0/3	1/3	3/3
Occupant comfort (IEQ)	1/4	1/4	4/4
Energy efficiency	0.5/3	2/3	3/3
Embodied carbon	0/3	2/3	3/3
Economics	0/3	2/3	3/3

Available Resources

Having completed the system evaluation, now it is time to explore some actionable steps to take and resources available. How can the industry mitigate the impact of embodied and operational carbon in MEP systems? It begins with architects taking the lead. Prioritizing design strategies, such as optimizing daylighting and window-to-wall ratios, is essential.

The goal is to align as closely as possible with passive design principles by upgrading building envelopes. Adopting a "less is more" philosophy is key in mechanical system design. This means specifying lighter equipment with economies of scale.

Research demonstrates that selecting a single, higher-capacity unit can result in a lower embodied carbon footprint compared to using multiple units to achieve the same total capacity. Studies have even shown that integrating equipment with architectural design (e.g., using a concrete slab with radiant heating and cooling instead of a typical steel structure with VRF units) can reduce whole-life carbon emissions by at least 40% compared to a standard all-electric building.

Additionally, it is important to address refrigerant leakage due to increasing pollution and temperatures driving greater mechanical cooling demand. As electricity grids shift toward decarbonization, heat pumps and VRF systems become more common. When correctly designed, these systems can help with decarbonization. However, carbon savings during operation can be offset by refrigerant leakage over their lifespan. To mitigate this, it's vital to specify low-GWP refrigerants with minimal leakage.

Reducing refrigerant charge through proper equipment sizing and using factory-sealed equipment during transportation and installation helps minimize leakage. Lastly, it is vital to ensure 100% refrigerant capture and recovery during decommissioning.

Additionally, conduct a whole building LCA early in the design process. Collaborate with an LCA consultant to develop and analyze LCA models to inform better design decisions considering both operational and embodied carbon impacts. Also, advocate for data transparency by requiring product-specific EPDs throughout design, budgeting, bidding, and procurement.

While addressing embodied carbon is crucial, it is important to also remember operational carbon. Adopt a holistic whole life carbon approach that considers both aspects when designing buildings.

Focus on prioritizing higher-efficiency solutions over cost for better building design. Choose to design and install systems that use lower temperatures with larger heat exchangers (i.e., the floor) and fewer chemicals, but still have high heat transfer capability and maximum comfort. And plan for the future by selecting equipment that is fuel agnostic and equipment that has a long life expectancy.

Hydronics Industry Alliance

The Hydronics Industry Alliance is a committee of hydronic equipment manufacturers in North America organized and managed by IAPMO, the International Association of Plumbing & Mechanical Officials.

Operating under the principal that water is the most efficient and greenest energy transfer medium on the planet, the Hydronics Industry Alliance serves as a resource within the HVAC and service water heating industry.

The mission of the Hydronics Industry Alliance is to educate, integrate, and communicate the advantage of hydronic system solutions.

Scan the QR code below to access the website and learn more.

BEST — Building Efficiency System Tool

Among the tools provided by the Hydronics Industry Alliance is the Building Efficiency System Tool (BEST), which is a total commercial building tool that models and compares HVAC systems based on actual system performance data.

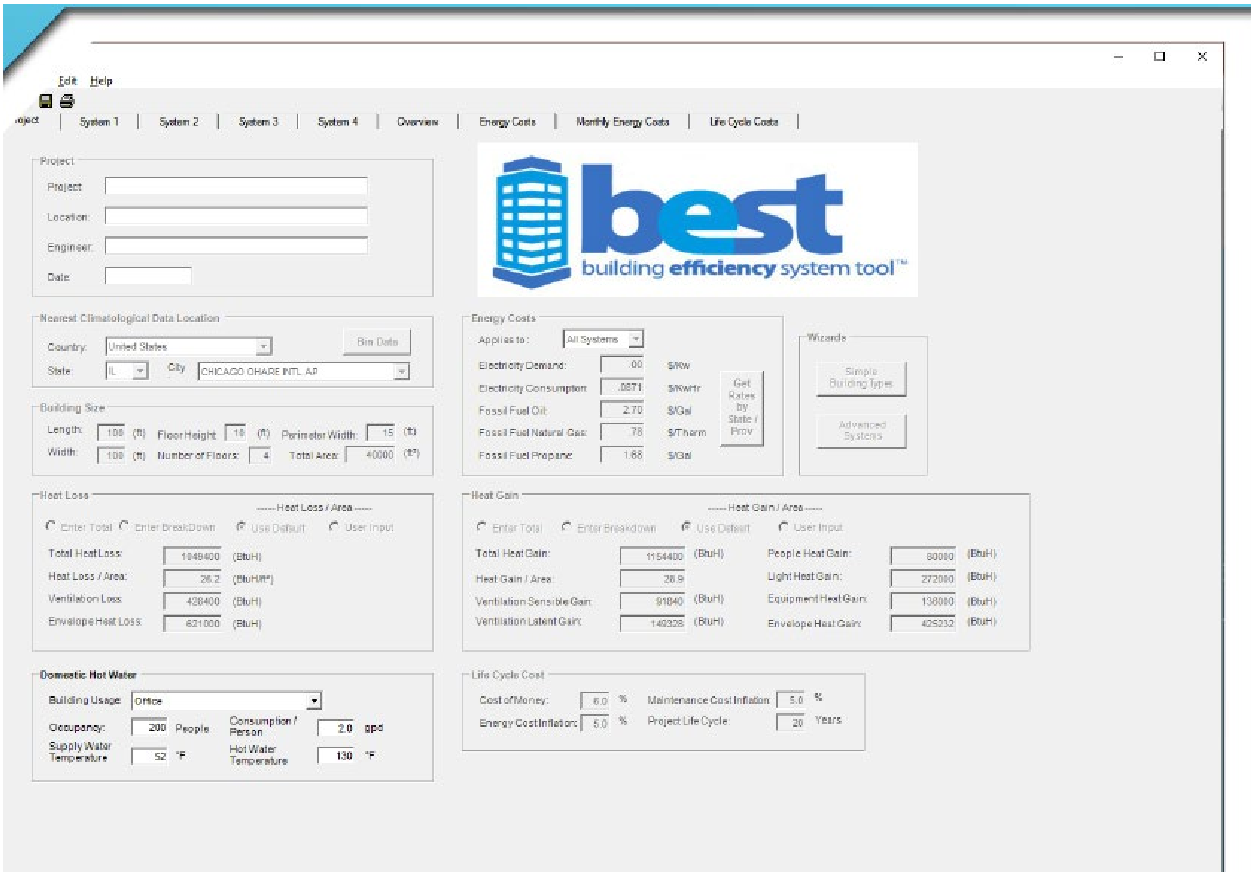
Visiting besthvac.org to access the free tool will save time and money while pointing project teams in the right direction for location, energy needs, and budget.

The tool incorporates default values to help project teams get started and know what questions to ask. The default wizard includes the latest data, equipment types (HP and HR) as well as cutting-edge calculations.

Climatic data is from ASHRAE while the 11 typical building types and square footages as well as fuel costs are from the U.S. Department of Energy.

Equipment costs are provided by a diverse group of manufacturers — for the industry by the industry with no ads or gimmicks.

The information is updated yearly to stay accurate but can be overridden if a project's information varies from standards.



Project

Project:
Location:
Engineer:
Date:

Nearest Climatological Data Location

Country: United States
State: IL
City: CHICAGO OHARE INTL AP

Building Size

Length: 100 (ft)
Width: 100 (ft)
Floor Height: 10 (ft)
Number of Floors: 4
Perimeter Width: 15 (ft)
Total Area: 40000 (ft²)

Energy Costs

Applies to: All Systems
Electricity Demand: .00 $/Kw
Electricity Consumption: .0871 $/KwHr
Fossil Fuel Oil: 2.70 $/Gal
Fossil Fuel Natural Gas: .78 $/Therm
Fossil Fuel Propane: 1.88 $/Gal

Heat Loss

----- Heat Loss / Area -----
○ Enter Total ○ Enter BreakDown ● Use Default ○ User Input

Total Heat Loss: 1049400 (BtuH)
Heat Loss / Area: 26.2 (BtuH/ft²)
Ventilation Loss: 428400 (BtuH)
Envelope Heat Loss: 621000 (BtuH)

Heat Gain

----- Heat Gain / Area -----
○ Enter Total ○ Enter Breakdown ● Use Default ○ User Input

Total Heat Gain: 1154400 (BtuH)
Heat Gain / Area: 28.9
Ventilation Sensible Gain: 91840 (BtuH)
Ventilation Latent Gain: 149328 (BtuH)
People Heat Gain: 80000 (BtuH)
Light Heat Gain: 272000 (BtuH)
Equipment Heat Gain: 136000 (BtuH)
Envelope Heat Gain: 425232 (BtuH)

Domestic Hot Water

Building Usage: Office
Occupancy: 200 People
Consumption / Person: 2.0 gpd
Supply Water Temperature: 52 °F
Hot Water Temperature: 130 °F

Life Cycle Cost

Cost of Money: 6.0 %
Energy Cost Inflation: 5.0 %
Maintenance Cost Inflation: 5.0 %
Project Life Cycle: 20 Years

Source: iapmo.org/hiac

This slide shows the default four systems in the BEST tool, however there are more than 30 preconfigured systems included, which are completely customizable.

The tool can compare costs and provide a clear direction in minutes.

stem Description

ystem 1: Chilled Beam, Hot Water Heat, Chilled Water Cooling, Air Cooled Chiller, 4 Pipe

ystem 2: Heat Pump, Water To Air, Boiler/Tower, 2 Pipe

System 3: VAV, Hot Water Heating, Chilled Water Cooling, Air Coole

System 4: VRF, Air To Air

Source: iapmo.org/hiac

Conclusion

To achieve environmental goals, the industry needs to act now. Decarbonizing buildings is not only vital for the environment, but it represents significant business opportunities for companies, including cost savings, regulatory compliance, risk mitigation, and competitive advantage.

Critical to building decarbonization is the need to start thinking about carbon as equivalent to financial transactions with accountable budgets and acknowledge that when it comes to the environmental impact of buildings, it is not just important to reduce operational carbon emissions.

Significant investments in energy efficiency, green building materials, renewable energy and zero-energy buildings are still needed to effectively decarbonize the buildings sector. Failure to make these types of investments raises the chance that buildings constructed today, which do not consider decarbonization, may become stranded assets in the future and face reduced market value and limited potential for rental income.

Governments and organizations around the world are setting increasingly ambitious targets for reducing greenhouse gas emissions, which will likely lead to stricter regulations on the energy performance of buildings. Additionally, as investors and tenants become increasingly conscious of environmental issues and seek out buildings that are energy-efficient and sustainable, buildings that do not meet these expectations may become less attractive to both groups.

Future-looking market actors are starting to anticipate the risk of “brown discounts” (i.e., the depreciation of buildings that are less energy-efficient), which can be as high as 30%.

Comfort is one issue, but the protection of people, equipment, the building itself, and the services offered may affect the neighborhood and even the city. No one knows what the next great technological breakthrough might be, however it is known that all those identified and emerging as affordable are adaptable to a central hydronic system.

Choosing a hydronic system is the best option for buildings now and in the future.

Simply put, water is safer, cheaper, easier to use, requires less monitoring, has a high thermal capacity, has a low viscosity making it perfect for use in HVAC systems, and is all around better for the environment.

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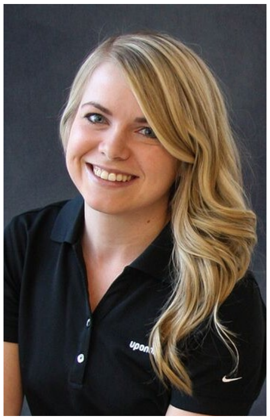
About the Author and Contributors

Hailey Mick, BChE

Hailey Mick is a business development manager for Engineering Services at Uponor North America. She has 17 years of experience in the commercial HVAC industry with roles including engineering applications and technical sales manager, hydronic training manager, product engineer, and sales engineer. She is passionate about educating customers on product functionality and selection, design improvements, and sustainability, while also providing guidance helping industry professionals solve problems. She holds a Bachelor of Chemical Engineering from Auburn University and is a member of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), American Society of Healthcare Engineers (ASHE), American Society of Plumbing Engineers (ASPE), and the Uponor Sustainability Core Team. She can be reached at hailey.mick@uponor.com.

Stephanie Radel, MBA, CPD, GPD, CM-BIM



Stephanie Radel is the sr. product manager of Global Water at Uponor North America. She has more than 15 years of experience in the industry with a focus on innovation and efficiency in plumbing design and construction. Her passion is driving technology solutions and empowering teams to deliver industry solutions that improve water availability, quality, and applications for future generations. She holds a Bachelor of Science in Business Management from the University of Minnesota Crookston, a Certificate of Management in BIM from the Associated General Contractors of America, a Lean Six Sigma Yellow Belt Certification, and is currently working on her MBA from Florida International University. She is a member and certified designer of ASPE and a member of ASHRAE. She can be reached at stephanie.radel@uponor.com.

Kim Bliss

Kim Bliss is the manager of Technical and Marketing Content at Uponor North America. She holds more than 30 years of published writing, editing, and content development experience with a focus in the manufacturing and trades industries. She holds a Bachelor of Arts in Journalism from California State University Sacramento, and her articles and blogs can be found in such publications as *Plumbing & Mechanical*, *PM Engineer*, *Plumber*, *Contractor*, *Mechanical Hub*, and more. She can be reached at kim.bliss@uponor.com.