BHB Industry Insights

Water-Cooled VRF Systems for High-Rise Buildings

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High-Rise Comfort

An introduction to air conditioning systems in multi-level buildings

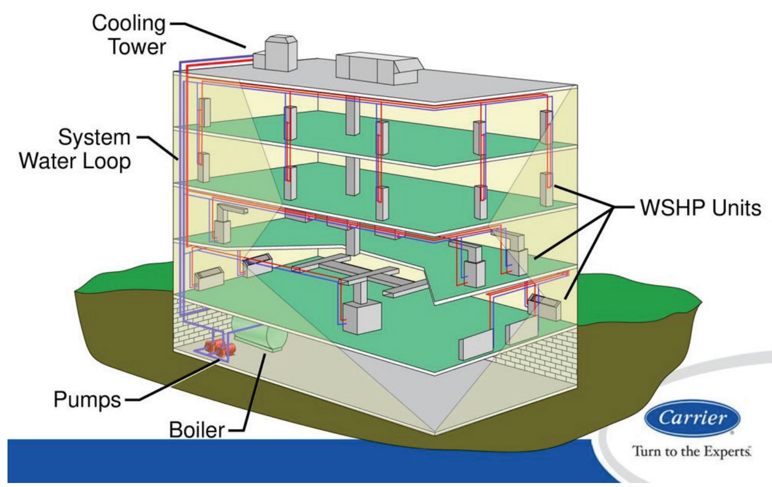
In 1928, the first high-rise air-conditioned office building was introduced to the United States in San Antonio, Texas. A century later, the demand and expectation of climate control through heating, ventilating, and air conditioning (HVAC) has continued to grow, along with the energy consumed by those systems. With HVAC accounting for almost 50 percent of the energy consumed by commercial buildings, the need for energy efficient and space conscious air conditioning designs has become paramount. Pair these environmental and economic concerns with a growing demand for multi-story mixed use buildings across the world, and it is time to revolutionize the way air conditioning systems are designed for high-rise buildings.

High-rise HVAC systems currently come in three main categories:

- Water Source Heat Pump Systems
- Chilled Water Systems
- Variable Refrigerant Flow (VRF) Systems

Water Source Heat Pump Systems

Primarily used in the northeast, water source heat pumps incorporate condenser water piping and pumps, boilers, and individual heat pump air handlers. The system rejects heat at either a cooling tower or geothermal well field. Though this system has a higher efficiency rating than most systems, it is unable to track a building's heating and cooling loads as closely as a VRF system.

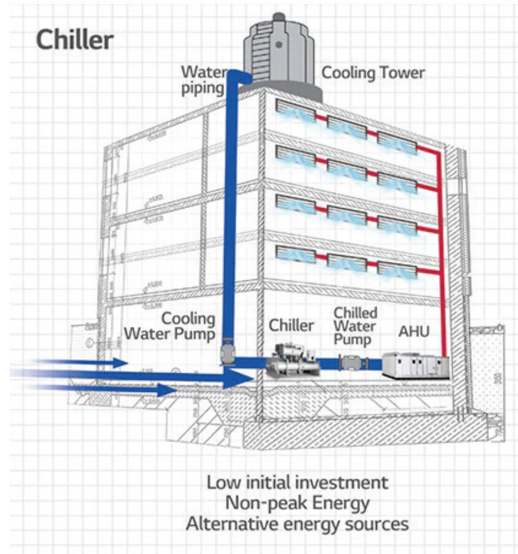


Courtesy of [Carrier]

Chilled Water Systems

Chilled water utilizes a refrigeration machine to chill water down to about 44°F (7°C). The cold water is then pumped through a distribution piping system that is run throughout the building to cooling coils located within central air handling units (AHU). The AHU moves air across the coil, allowing the air temperature to drop as heat is transferred to the colder water in the coil. The cold air is delivered to each zone based on demand, and the chilled water (now about 12-16°F (6.5°C) warmer) is piped back to the chiller where the cycle continues. The system can be enhanced through the use of controls to allow pumps, chillers, and individual AHU fans to step down or up as the demand in the building changes.

Chilled water systems use piping to transport a liquid for heat transfer. One of the biggest differences between chilled water and VRF systems is that water is less efficient for the transport of heat than refrigerant, which means that the required piping is larger in diameter. Larger piping means we lose more floor space to piping risers, and the cost of the piping increases. Chilled water systems also require separate pumping systems that typically require a mechanical room in the building.

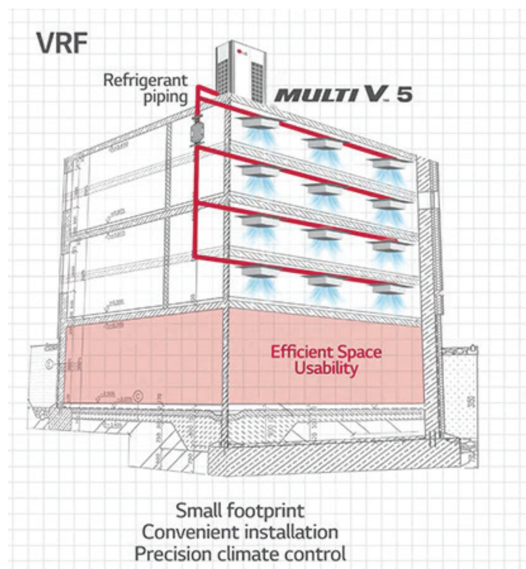


Courtesy of LG Business Solutions

Air-Source VRF Systems

A VRF system has a similar function, but varies the refrigerant flow to different areas of the building based on the specific heating or cooling demand in each area instead of continuously distributing large quantities of refrigerant. This technique creates small zones, giving occupants the ability to adjust the temperature of their space to the preferred comfort level.

Though a VRF system provides benefits for a wide range of facility types, there are some limitations with refrigerant pipe length and mechanical room space in high-rise applications. Since the heat pumps need to discharge heat outside, the systems must have components that are located on the roof or ground level. This equipment limitation further impacts the refrigerant or water piping length needed throughout a multi-level building. To combat this issue, some buildings place heat pumps on a separate mechanical floor, often paying the price of using valuable floor space.



Courtesy of LG Business Solutions

Summary

If we take the structure of a water source heat pump and combine it with the flexibility and efficiencies of a VRF system and the central heat rejection of a chilled water system, we have the makings of a Water-Cooled VRF. This method combines the key benefits of each system to save energy cost and increase usable building square footage.

This white paper will break down the components of a Water-Cooled VRF system and address the advantages and disadvantages of using this system in high-rise building applications.

Water-Cooled VRF

Overview

In 2008, a 42-story office building in Indonesia lacked the floor space to install air cooled condensers. As a solution, Daikin Manufacturing installed outdoor water source heat pumps for every floor in the rear of the main elevator shafts. This method created the ability to control HVAC equipment for every floor with the flexibility to position outdoor units on each floor[1]. As this method is beginning to gain traction in the United States, this white paper provides the specific components necessary for using the system we refer to as a Water-Cooled VRF.

This hybrid system removes the need for multiple outdoor air-source heat pumps in numerous locations and replaces it with a single cooling tower. Instead of each individual system rejecting heat from the building to the outside, they will all reject heat into a condenser water loop. Heat would then either be rejected outside via the cooling tower, or can be transported through the condenser water loop to other parts of the building that may require heating.

There are three major components to a Water-Cooled VRF System:

1

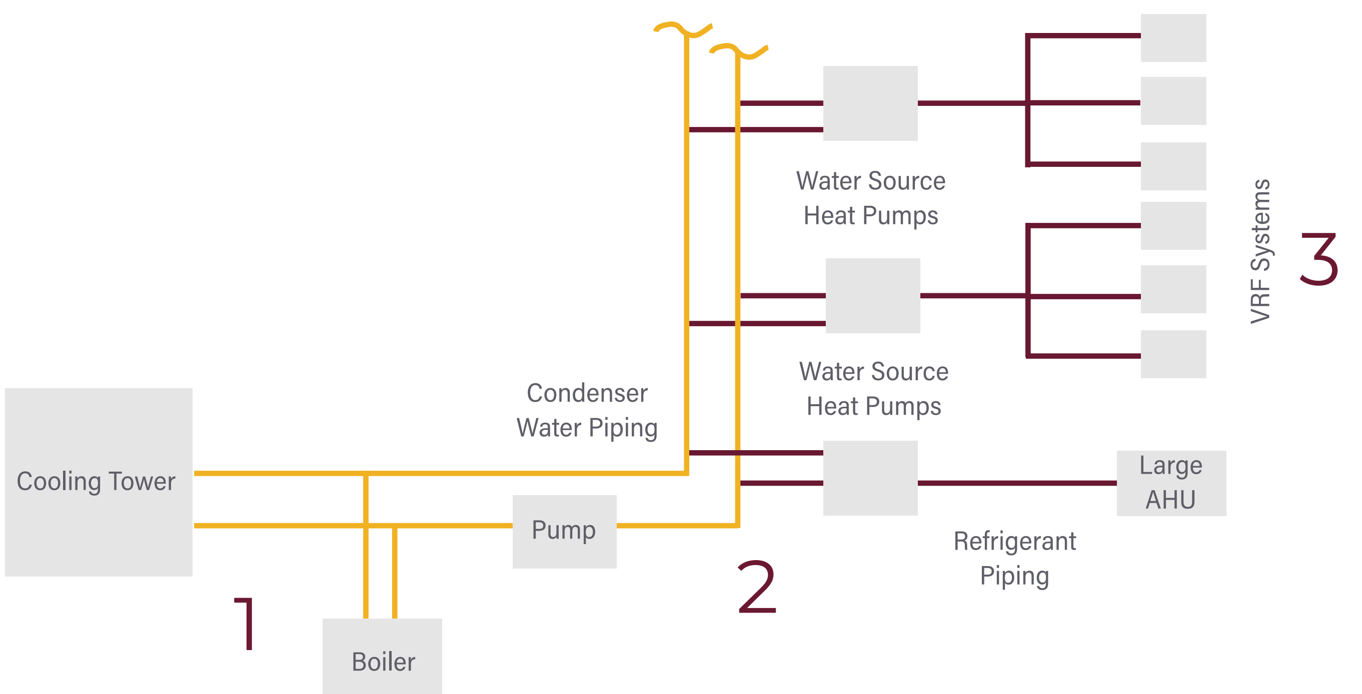
Condenser water piping is routed from the cooling tower (typically on the roof or at grade) to a mechanical room that contains the condenser water pumps and heating water boilers.

2

The condenser water piping is then extended up or down the building through as many floors as needed. The condenser water riser and water source heat pumps can be located in mechanical closets on each floor.

3

Refrigerant piping would then extend from the water source heat pump to individual indoor units, similar to a traditional VRF system.



1 *Challenging Energy Savings in High-Rise Buildings with Limited Space. Daikin Global. https://www.daikin.com/products/ac/case_study/city_center/index.html*

Advantages & Design Considerations

Advantages

Efficiency

Energy will not be wasted on continuously moving large quantities of refrigerant at all times, nor will new energy be used to constantly reject heat outside. The hybrid system moves energy within the building instead of rejecting it to the atmosphere.

The use of a cooling tower in this application also takes advantage of our ability to evaporate water into the atmosphere. The latent heat of vaporization provides much more heat rejection per unit of water flow, compared to using the typical liquid-to-air heat exchanger (like the typical condensing unit) that moves atmospheric air across a hot refrigerant coil. Air-side heat rejection would require the pressure of the refrigerant to be raised so it is far enough above ambient temperature for the air to heat and cool the refrigerant.

Flexibility

There is flexibility to add, remove, or relocate indoor units as needed to fit a different floor layout or adapt to a new owner's needs. If required, additional tonnage can be added to a floor by adding a water source heat pump and connecting it into the condenser water loop.

Low Operating/Maintenance Cost

Based on calculations using computerized building simulations, the Water-Cooled VRF system will have a lower maintenance and operating cost versus a 4-pipe chilled/heating water system. Also, the equipment is less complex to service compared to central chillers, and the smaller variable speed compressors that share heat around the system reduce operation cost.

Space Conscious Design

You will no longer need large mechanical rooms for air handling units. Instead, they will be located in smaller mechanical closets, above the ceiling, or below the floor, depending on what works best in the building.

Design Consideration

Refrigerant Risk

The main challenge for a Water-Cooled VRF system, just like traditional VRF systems, is ensuring the system is designed properly in case of a refrigerant leak. If the total volume of the zone/space is too small, an accidental release of refrigerant into the space could cause air concentrations that are harmful to building occupants.

Summary

A Water-Cooled VRF system approach allows the owner and design team the flexibility to use indoor units provided by VRF manufacturers, simpler equipment to reduce installation cost, combined efficiency of VRF and cooling towers to lower the building's energy footprint, and a compact design to save usable space.

Test Model for Water-Cooled VRF Usage

To test the Water-Cooled VRF system, a 23-story high-rise residence was modeled, matching a project that had recently been constructed. The intent was to test the feasibility of this system for high-rise buildings and evaluate the operating benefits.

The test building is a 373,000 SF dual-use apartment residency and hotel. The building includes 150 apartment suites and 167 hotel guest rooms. The base building design uses a water-source heat pump system that includes a cooling tower, indoor water source heat pump air handling units, a boiler, condenser water pumps, and dedicated outside air units (DOAS) for ventilation.

The base building was designed to utilize a common cooling tower and condenser water loop with two sets of pumps serving each half of the building. There are three common boilers that heat the condenser water loop during colder weather months and approximately 367 water source heat pumps located throughout the building. The condenser water loop is then routed to each indoor unit.

In our analysis, we modeled the building using three different types of HVAC systems: water-source heat pumps, water-source chillers and boilers (4-pipe), and a hybrid Water-Cooled VRF design. In each iteration, the building design and operation was the same. For our example, we considered the test building to be located in Dallas, Texas.

Proposed Water-Cooled VRF Design

VRF systems are known for their energy efficiency and compact size compared to other system types. The advantages of a chilled water system come from its ability to have long runs of water piping with a central location for heat rejection. Combining these key elements creates the framework for a Water-Cooled VRF system.

A central cooling tower is sized and located on the roof or at ground level. We used a roof-mounted tower for this design due to limited site area. Condenser water piping is designed and piped from the cooling tower, down through the building, routed through a mechanical room where condenser water pumps and heating water boilers are located to keep the water flowing through the system at the right temperature. Risers are routed down through the building, where they can be tapped at each floor in a mechanical closet to be routed to water source heat pumps for that floor. VRF heat recovery systems can also be located on floors in this location where that type of system makes sense, to supplement or provide the primary domestic hot water for the building.

Refrigerant piping would then extend from the water source heat pump(s) at each floor and be routed to individual zone HVAC units. The downstream design would mimic a traditional VRF indoor design, utilizing zoned indoor units to cool and heat spaces, selector boxes if needed to transfer heat from zone to zone on the floor (if needed), and associated refrigerant piping and valves.


Cooling Towers

Results

Mechanical Cost

In addition to the technical process, cost measures play a crucial role in a project's development. The test project's cost breakdown was: (approximate)

- Baseline mechanical cost for the test project: $6,500,000
- Cost of four-pipe chilled and heating water system: $6,700,000
- Cost for Water-Cooled VRF system: $4,900,000


Water Source Heat Pumps

Courtesy of BH Synergy

Anticipated Energy Cost

The final step includes comparing anticipated energy consumption (based on actual usage by the building owner and occupants) between the three different systems. We calculated this through the use of Carrier's Hourly Analysis Program (HAP) software that models the building and hourly weather conditions for a typical year. By inputting local utility cost (natural gas and electricity) and anticipated operating schedules, the computer model is able to calculate hourly system performance and energy usage throughout the year. The totals are then converted to the energy cost to operate each modeled system type. The results were:

- Baseline annual mechanical operating cost: $446,000 ($1.12 per SF/yr)
- Four-pipe chilled / heating water system: $407,000 ($1.02 per SF/yr)
- Water-Cooled VRF system: $401,000 ($1.01 per SF/yr)

The computerized building simulation results show that a Water-Cooled VRF system can be more energy efficient, space conscious, and offer upfront cost savings over traditional HVAC systems for a high-rise multi-use project.

BHB strives to create environmentally conscious solutions to meet each client's needs. As the demand for efficient climate control systems increases, our engineers and designers look forward to incorporating Water-Cooled VRF designs into future projects.


VRF Indoor Unit

Interested in discussing Water-Cooled VRF design ideas for your project? Send us an email at mail@bhbinc.com.