The Future of Heating Equipment is Electric

Heat Pump Technology Deep Dive

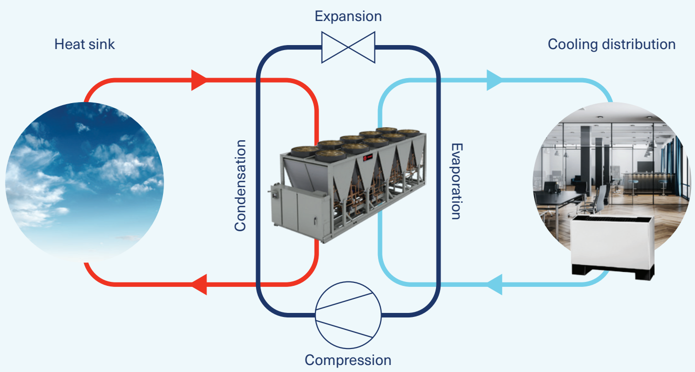
White Paper

Introduction

Reducing or eliminating carbon emissions is a key goal for modern buildings. To achieve this, many building owners are increasingly opting for electrified HVAC equipment, such as heat pumps, instead of using traditional fossil fuel-based systems like gas-fired burners to heat their buildings. While electrification alone won't eliminate environmental emissions, the vision is for renewable energy to power the majority of the electric grid in the future.

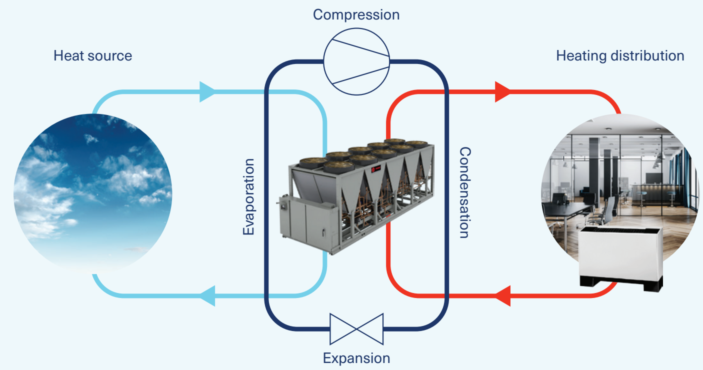
Working Principle – In Summer

During warmer days, heat pumps extract heat from the building and releases it to the atmosphere, similar to an air-cooled chiller.



Working Principle – In Winter

On colder days, thermal energy contained in outdoor air will be used to heat your building. The heat pump fully utilizes a renewable energy source.



Heat Pump Technology Overview

Heat pumps were first introduced in the 1950s, but are now emerging as a key enabler for electrification of heat and have the potential to transform the industry. Heat pump solutions do not generate heat. Rather, they transfer heat from one place to another. Due to the laws of thermodynamics, it takes less energy to transfer heat than to generate it, which results in significant energy and cost savings. Heat pumps are a practical, efficient solution for electrification of heat and will play an important role now and in the future.

Technically, a heat pump is a mechanical-compression cycle refrigeration system that can either be controlled to heat or cool a space. In a building application, a refrigeration unit—such as an air-to-water heat pump—raises heat from a lower energy state to a higher energy state by moving heat from outside to inside the building. Water-cooled chillers, also known as **water-to-water heat pumps,** source heat from a chilled water loop or ground and can provide heat recovery or heater capabilities.

A **reversible heat pump** changes the roles of the evaporator and condenser through the use of a reversing valve inside the unit. Either cooling or heating may be the primary duty depending on the operating mode and application.

Heat pumps offer several significant benefits, particularly in terms of their ability to provide both heating and cooling from a single piece of equipment and their capability for simultaneous heating and cooling within a building.

Types of Commercial Heat Pumps

Traditionally, heat pumps were seen as a residential heating and cooling solution and rarely scaled to the sizes needed for larger buildings. Their use was limited to climates with outdoor temperatures greater than 20°F (-7°C). Below that temperature, second stage heat from either fossil fuel or electric resistance is activated. Additionally, when outdoor air temperature drop to 40°F (4.4°C) and below, air source heat pumps lose some heating capacity due to the need to defrost the outdoor coil. The same constraints that limit heat pumps in residential use in colder climates must also be considered for commercial buildings, but on a much larger scale.

Recent and ongoing innovations have enabled heat pumps to overcome their limitations, making them suitable for a wider range of commercial applications, from large to small, and even in colder climates. Different all-electric equipment types like variable refrigerant flow (VRF) systems, packaged units, split systems and chillers may be considered heat pumps. **Because they do not generate heat and simply move heat, they can be up to three times more efficient than traditional electric resistance heating.**

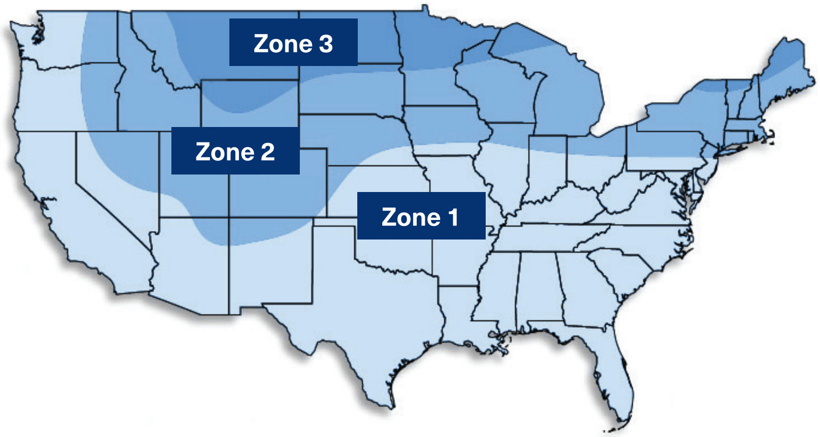
HOW A BAS CONTRIBUTES TO DECARBONIZATION

According to research conducted by the scientific teams of Project Drawdown, building automation systems (BAS) can boost heating and cooling efficiency by more than 20% and reduce energy use for lighting, appliances, etc., by 8%. Globally, BAS adoption ranges from 0% to 75% in high income countries. Substantially expanding adoption—at a net first cost of US $287.70-393.35 billion—could save building owners $2.27-3.42 trillion (US) in operating costs. It could also avoid 9.55-14.01 gigatons of CO_2 emissions by 2050.[1]

1. Project Drawdown, Building Automation Systems. Web.

Heat Pump Considerations

There are many factors to consider when selecting the best electrified heating system for an application. A location's climate zone is a good starting point, as air-source heat pump performance is highly dependent on ambient conditions. As ambient temperature drops, the efficiency of air-source heat pumps decreases. Ambient temperature and humidity also affect the need for defrost. The defrost cycle reverses the refrigeration cycle, applying heat to the outdoor coil to melt frost when condensate freezing is detected. For single circuit heat pumps, defrost mode consumes all the unit's heat, leavin none for space heating and resulting in cold air being sent into the occupied space. Utilizing a modular heat pump design with multiple circuits or redundant modules can mitigate the impact of defrost cycles, providing more consistent heating an minimizing disruption to the occupied space. Dual fuel (natura gas) and auxiliary (electric resistance) backup can be used in heat pump systems to compensate for this limitation. Systems may employ advancements in thermal energy storage systems, chiller heat recovery, and cascade systems to fit the needs of the heating application.



Zone 1: Traditional heat pump zone
Zone 2: Advanced heat pump technology
Zone 3: Advanced heat pump technology + supplemental heating

Packaged Units and Split Systems

For small to mid-size applications, there are several types of heat pumps designed specifically for ease of retrofit, including packaged terminal heat pumps, split system heat pumps, rooftop unit (RTU) heat pumps and water-source heat pumps. All these products share a similar footprint and accessibility to their respective gas heat counterparts, allowing for an in-kind replacement. However, they are limited on cold climate capability to varying extents and may require dual fuel or auxiliary backup for some applications.

Combining fan, coil and compressor in a single package/platform, **packaged units** are the most common type of heat pump used in commercial buildings. For heating, a packaged system pumps outside heat into the building using a compressor and vapor compression cycle. Conversely, it cools a building by pumping heat out of it through a reversible refrigeration cycle.

A **split system** affords similar design flexibility for buildings of any size when rooftop access is not ideal. Simple and inexpensive, split systems may be used in residential houses or small office buildings. They have limitations in extremely cold climates, however, as it's more difficult to extract heat from air at frigid temperatures. For heating in cold climates, these heat pumps are typically paired with a gas-burning furnace.

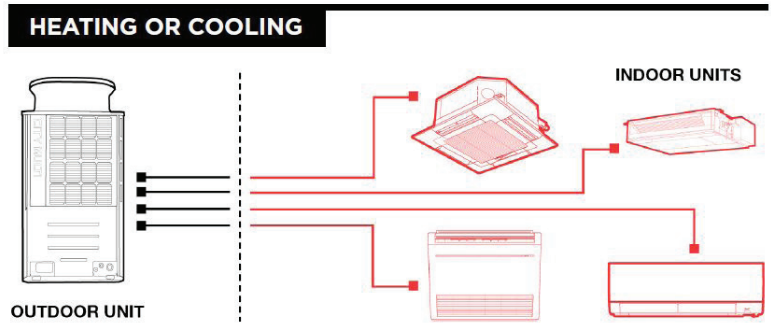
A **commercial split DX system** consists of a condensing unit and an air-handling unit (AHU). The condensing unit houses one or more compressors and an air-cooled condenser with propeller-type fans. The AHU contains the evaporator coil, expansion devices, along with a fan, filter, heating coil or gas-fired burner, and in some cases, an air-to-air heat exchanger. The condensing unit is typically installed on the roof or on the ground next to the building, while the AHU can be installed indoors or outdoors. The two components are connected by field-installed refrigerant piping to complete the refrigeration circuit. A packaged unit typically offers less flexibility in selection and fewer options, whereas a split DX system provides greater flexibility. The AHU in a split DX system generally offers more options for fans, air cleaning devices, air-to-air energy recovery devices, and sound attenuation.

TRANE SOLUTION

Trane's packaged units and split systems portfolio includes a full line of air conditioners and heat pumps for small commercial applications. Matching air handlers are available with single- or variable-speed motors for year-round, energy efficient comfort.

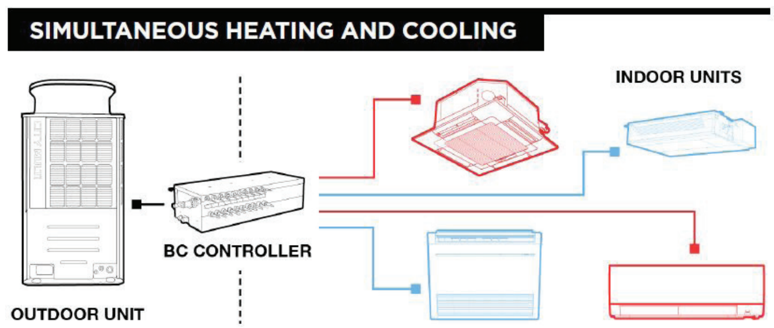
Variable Refrigerant Flow (VRF) Systems

VRF systems are a popular choice for a variety of buildings due to their high energy efficiency, smaller footprints, and system flexibility. These systems help building owners meet sustainability goals while lowering utility costs. Designed for extended life cycles, VRF systems provide sustainable performance well into the future. They are suitable for most commercial applications, such as offices, hotels, schools, multifamily buildings, and indoor agriculture facilities.



Traditional VRF Systems

VRF technology consolidates heating and cooling into an electrified, multizone system. Each zone can be conditioned by its own indoor unit(s) and can have its own set point. Instead of burning fossil fuels, VRF heat pumps and heat recovery systems consist of an outdoor unit and up to 50 indoor units connected via refrigerant lines and a controls network. The system provides heating to different zones via the refrigerant circuit and vapor-compression cycle, which the outdoor unit extracts from the air or a nearby water source. During cooling, VRF heat pumps reverse this process as indoor units transfer heat from zones to the outdoor unit which then rejects the heat. Indoor units are available in ductless and ducted styles.



Heat Recovery VRF systems have the same capabilities as VRF heat pumps, but they also use a branch circuit (BC) controller to leverage load diversity and provide simultaneous heating and cooling. They can move heat *from* zones that require cooling to zones that require heating. By repurposing thermal energy that would have been rejected by the outdoor unit, heat recovery systems increase the total applied capacity and energy efficiency.

VRF systems typically include a system to distribute outdoor air to the building occupants for ventilation. One of the most common types of **dedicated outdoor air (OA) equipment is a standalone, air-cooled, direct-expansion (DX) unit.** This might be a packaged unit DOAS or a split system DOAS (comprised of two separate sections connected by refrigerant piping). A packaged DOAS DX unit is typically installed on the roof of the building and contains a fan, filter, an auxiliary heat, or heating coil and all the components of a DX refrigeration system—an evaporator (cooling) coil, one or more compressors, an air-cooled condenser and an outdoor condenser section. In addition, it may contain an air-to-air heat exchanger for exhaust-air energy recovery.

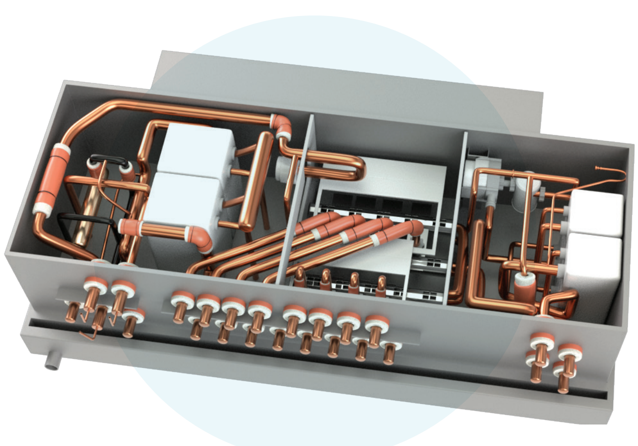
TRANE SOLUTION

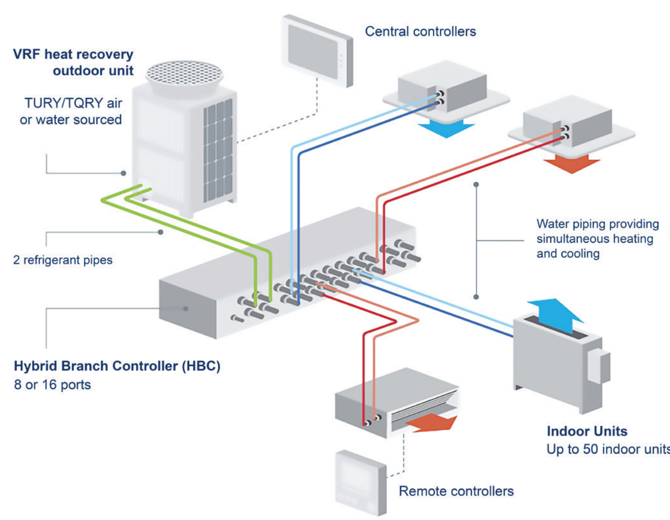
Trane® / Mitsubishi Electric VRF Systems consolidate heating, cooling, ventilation, and controls into an electrified, multi-zone system. These systems include outdoor units, terminal units, and ventilation solutions like the Trane Horizon® packaged DX dedicated outdoor air system (DOAS). System controls using Tracer® SC+ are essential for operating VRF and ventilation systems, ensuring seamless integration and optimization.

With options for outdoor units, branch controllers, and indoor units—including the hybrid Trane® / Mitsubishi Electric HVRF that uses water and refrigerant—the VRF portfolio suits various buildings, from new constructions to retrofits, including offices, hotels, schools, multi-family, and mixed-use spaces.

Hybrid VRF

As part of the drive to decarbonize HVAC systems, hybrid VRF systems are a popular strategic electrification solution. "Hybrid" refers to a VRF system that uses both water and refrigerant to provide heating and cooling for a building.Refrigerant runs from the outdoor unit to a hybrid branch controller, similar to traditional VRF. The hybrid branch controller (HBC) acts as a heat exchanger between refrigerant and water. Water is piped to indoor units that provide heating or cooling, depending on what the space is calling for.





Water-Source Heat Pumps (WSHPs)

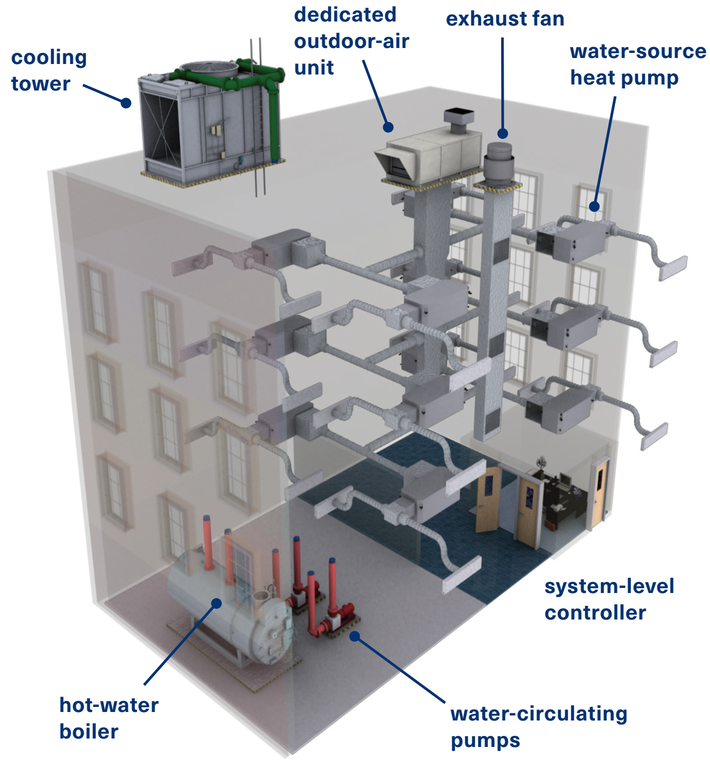
A water-source heat pump (WSHP) transfers the heat via heat exchanger into a source-sink loop that carries water through the building. Typically, the loop temperature is maintained within limits to enable efficient heating and cooling with a central cooling tower and boiler or by utilizing a geothermal loop system to source and sink heat to the ground. By connecting all units to this common loop, heat recovery between spaces is enabled. With multiple configurations and the ability to place WSHP units in dropped ceilings or hidden in mechanical rooms they offer design flexibility for buildings with a lot of occupied spaces such as multi-family housing.

A water-source heat pump typically heats or cools a particular zone in a building. A WSHP contains all the components of a refrigeration circuit, including one or more compressors, a refrigerant-to-air heat exchanger, a refrigerant-to-water heat exchanger and an expansion device. In addition, a reversing valve allows the WSHP to reverse the direction of refrigerant flow and change the operation of the refrigeration circuit to provide either cooling or heating.

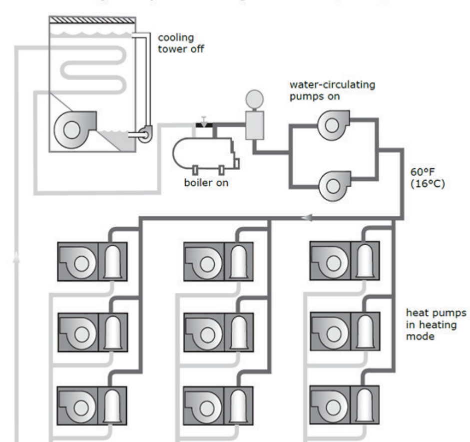
During mild weather, such as spring or fall, the heat pumps serving the sunny perimeter and interior of the building may operate in cooling mode and reject heat to the water loop. At the same time, the heat pumps serving the shady perimeter of the building may operate in heating mode and extract heat from the water loop. Heat rejected by units operating in cooling mode raises the loop temperature while heat extracted by units operating in heating mode lowers the loop temperature. If the water temperature stays between about 60°F (16°C) and 90°F (32°C), for example, neither the boiler nor the cooling tower needs to operate. In this manner, a WSHP system provides a form of heat recovery.

During cold weather, when most (or all) of the heat pumps are operating in heating mode, heat is extracted from the water loop and transferred to the air. This causes the temperature of the water in the loop to decrease, making it necessary to add heat to the water. A "heat adder" (such as a hot-water boiler or geothermal loop) is used to add heat to the loop, maintaining a leaving water temperature of approximately 60°F (16°C).

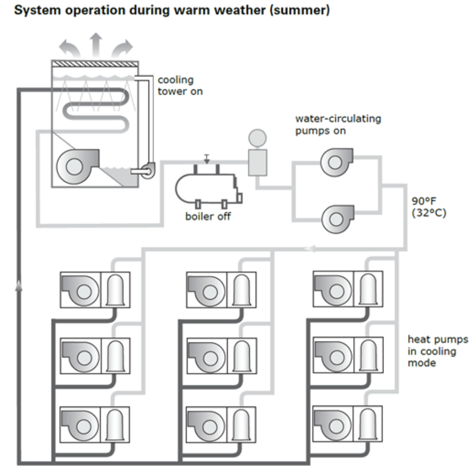
Additionally, the packaged RTU units can be operated (to control indoor humidity after hours, for example) without requiring the pumps, and possibly the boiler or cooling tower. The drawbacks of this approach include limited flexibility (especially when a packaged unit is used), lower efficiency and installation of some or all of the equipment outside.



System operation during cold weather (winter)



System operation during warm weather (summer)



Heat Pump Chillers

Chillers today can do more than cool spaces. Many models can be configured with heat recovery option or selected as a heat pump.

The full Trane heat pump chiller portfolio integrates with Tracer® SC+ building automation controls and its embedded suite of pre-engineered applications to complete the system and help the equipment work more efficiently.

Chillers Configured with Heat Recovery and as Heaters

Adding heat recovery to a chiller is a common first step toward electrification of heat. **Heat recovery chillers** use existing heat that would otherwise be rejected in the cooling process. To be beneficial, they require a simultaneous demand for cooling and heating or the ability to store the thermal energy (heat) for later use, but they are one of the most efficient forms of heating available.

Heat recovery units are set to the cool water set point. So, as long as there is a demand for cooling, the unit can also provide heat.

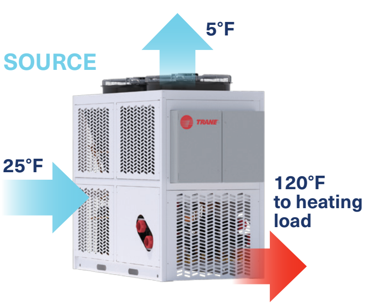
When a building is heating-dominant, water-cooled chillers may be controlled to the hot water set point to operate primarily as heaters instead. These systems are extremely energy efficient and flexible for integrating into hydronic systems. (Note that water-cooled chillers may also be referred to as heat pumps since they can move energy to heat the spaces within the building.)

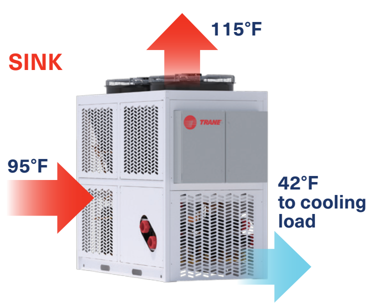
Reversible Hydronic Heat Pumps and Multi-pipe Units

A key enabler for decarbonization, a heat pump configured with a reversing valve can move energy in two directions to provide electrified heating or cooling. Electrifying your building and heating with either an air-source or water-source heat pump not only helps meet your decarbonization goals but can also be far more efficient than using a natural gas boiler.

Hydronic Heat Pump

- A heat pump with a reversing valve is a unit that allows the evaporator and condenser to switch roles by reversing the flow of refrigerant within the circuit in order to cool or heat the building's hydronic system..
- Hydronic heat pumps can come in a wide range of sizes and are available in water-source and air-source versions





Multi-pipe Units are capable of providing simultaneous cooling and heating by being controlled to maintain both the heating and cooling set points for fluid temperature regulation. More energy-efficient than other forms of electric heating, they're also the most flexible, because one unit can provide heating, cooling or both, regardless of the dominant load.

TRANE SOLUTION

Trane air-to-water heat pumps provides heating or cooling from one all-electric source to support compliance with policies and incentives to decarbonize buildings. The air-to-water heat pumps are available in either modular or packaged units.

Trane's packaged unit, the **Ascend® Air-to-Water Heat Pump model ACX** capacity range is from 80 to 230 tons of nominal cooling with 1000 to 2500 MBH heating capacity and low ambient heating capability down to -15°F (-26°C). It provides an energy-code-compliant electrification solution (complies with ANSI/ASHRAE®/IES 90.1-2022) that can serve the needs of a broad spectrum of commercial buildings, including government facilities, commercial real estate, K-12 schools, hospitality and retail.

TRANE SOLUTION

Water-Cooled Portfolio
Our water-cooled portfolio includes chillers with heat recovery capabilities, effectively making them heat pump chillers. Heat recovery is an efficient method for heating while cooling, as the chiller heat pump recycles waste heat generated during the cooling process.

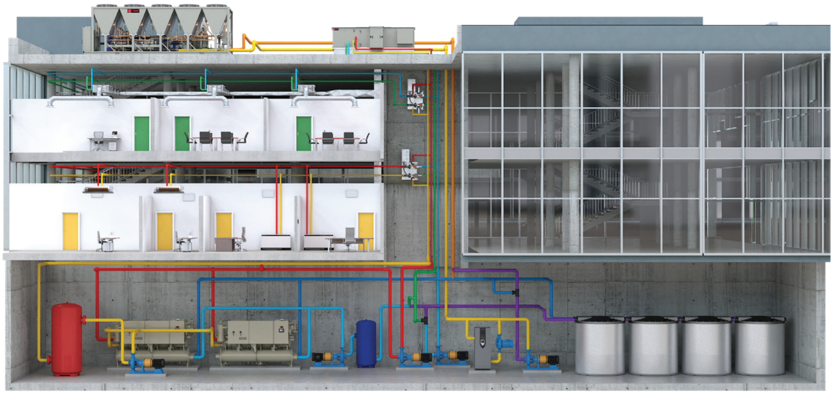
Agility® Portfolio
Available options for integrated heat recovery up to 130°F (54°C).

CenTraVac® Portfolio
Available options for integrated partial or full heat recovery up to 140°F (60°C).

Series R™ Portfolio
Available options for integrated heat recovery up to 165°F (74°C).

TRANE SOLUTION

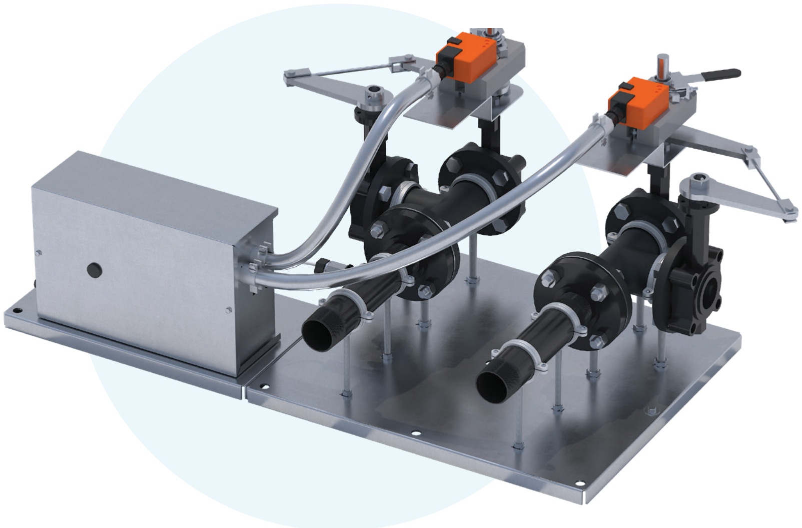
Trane's modular unit, the **Theramfit™ Air-to-Water Heat Pump model AXM** is easy to install (and expand) especially in dense urban environments and retrofits. AXM modular heat pumps move through freight elevators and lift onto rooftops. Each modules nominal capacity is 30 tons of cooling and 390 MBH in heating. Connect up to 12 heat pumps for a nominal 360-ton bank. AXM uses vapor injection compressors to extend the effective operating range of the scroll compressor which provides reliable comfort in colder climates. This feature allows for higher leaving hot water temperatures down to -18°F (-28°C) outdoor ambient temperature.



Storage-Source Heat Pump Systems

Thermal energy storage has been and will continue to be a key tool to decarbonize. Because thermal energy storage can capture and store thermal energy for heating and cooling, thermal energy storage provides ultimate flexibility to reduce summer and winter peak electricity demand, help reduce carbon emissions and lower operating cost.

A storage-source heat pump (SSHP) system combines the functionality of a heat pump with thermal energy storage, typically ice tanks. This system is suitable for cold climates where air source heat pumps lose capacity and where the system requires a more stable heat source temperature. Excess heat recovered from the building or sourced from the outdoors is stored in the tanks. A water-to-water heat pump moves the heat from the tanks into the building to heat it in the winter. Unlike an air source heat pump, the source energy in a SSHP is never below 32°F (0°C) which results in much higher efficiencies.



Hydronic Branch Conductor

When integrated with hydronic heat pumps or heat pump chiller systems, the Hydronic Branch Conductor enables existing buildings with 140°F (60°C) to 180°F (82°C) hot water to convert to more energy-efficient 105°F (40°C) hot water supply—without replacing branch piping. This approach provides a simple, flexible, and efficient pathway to introducing sustainable heat pump technology in both new and existing buildings, supporting decarbonization goals and operational reliability.

TRANE SOLUTION

Trane offers a portfolio of complete **Thermal Battery Systems** for cooling and heating built on Trane's expertise in chillers, thermal energy storage tanks, controls, and service. Liken thermal energy storage to a battery for your HVAC system. It gives you the ability to store and dispatch thermal energy, based on operational needs, utility rates/programs, and availability of renewable resources.

TRANE SOLUTION

Available as an option for Trane's existing Air-to-Water Heat Pump System, the **Air-to-Water Cascade Heat Pump System** is a fully packaged high-temperature hydronic heating solution. It uses multiple heat pump chillers in a cascade arrangement to achieve hot water supply temperatures up to 165°F (74°C) even at -15°F (-26°C) ambient temperature. With a wide turndown range, a minimum of 20% heating unloading capabilities, and a heating efficiency is up to 3 times more efficient than traditional boilers. This system enables a cost-effective retrofit solution of traditional boiler systems, while maintaining the existing building distribution and infrastructure.

TRANE SOLUTION

A comprehensive heat pump chiller solution from Trane provides guidance on how to apply a mix of chillers and heat pumps for reliable, cost-effective, energy-efficient options to cool and heat facilities while reducing carbon emissions. It also supports indoor air quality (IAQ) objectives because it can be applied to fit with many central air-handling and dedicated outdoor air systems, as well as zone terminal products such as fan coils, unit ventilators, sensible cooling units and VAV terminals.

Trane Comprehensive **Heat Pump Chiller Systems** deliver what building owners need:

Flexibility—to satisfy diverse heating and cooling loads and comply with electrification regulations and sustainability objectives.

High performance—by exploiting significant improvements in heat pump heating to enable buildings to function better and reduce carbon emissions.

Reliability—by managing equipment capabilities to reduce the impact of defrost on system performance and enabling cold climate operation.

Lower cost of ownership—by reducing equipment and energy costs while increasing efficiency and reliability for building owners.

Commercial Hot Water Heaters

Domestic hot water (DHW) accounts for roughly 25% of energy usage in multifamily and residential buildings.[2,3,4]

DHW heat pump water heaters can source heat from the outdoor air, cooling loads, or geothermal loops to efficiently heat potable water. Optimal performance and cost benefits for all-electric heat pumps require proper design, installation, and commissioning. This starts with cooperation and information exchange among project team members, including the developer or building owner who will decide whether the facility will participate in utility demand-response programs. Designers must understand the building's domestic hot water usage demand profiles, including the gallons per hour, duration and timing associated with peak loads and off-peak loads. The system's storage capacity is based on how often the system will run. Additionally, designers account for climate and may make provisions for snow, rain, wind, and marine salt.

2. U.S. Energy Informational Administration
3. Passive House Institute US
4. Bonneville Power Administration

TRANE SOLUTION

Trane's Domestic Hot Water Heat Pumps capture and repurpose excess heat to produce hot water, reducing energy waste and lowering operating costs. These water-source heat pumps can efficiently heat water up to 175°F (79°C), minimizing the need for gas boilers. With COPs exceeding 4.0, they ensure industry-leading performance. Unlike conventional water heaters and boilers that generate heat, Trane DHWHPs transfer existing heat from a water source to the water in their tank, using far less energy. They can operate as standalone systems or supplement hot water production from gas boilers or electric water heaters.

Trane® / Mitsubishi Electric HEAT2O™ is an all-electric CO2 refrigerant heat pump water heater designed to enhance sustainability and reduce energy consumption in multifamily buildings and large-scale commercial facilities. Unlike traditional systems that heat air, HEAT2O heats potable water by transferring ambient thermal energy from outdoor air using a CO2 refrigerant. This natural refrigerant allows HEAT2O to supply hot water up to 176°F (80°C) even in low ambient conditions (to -13°F). The system features highly efficient heat exchange through three refrigerant lines wrapped around a twisted water pipe, increasing the heat conductive area and enhancing turbulence for better performance. An inverter-driven scroll compressor further boosts energy efficiency by modulating refrigerant flow and heating capacity. With a coefficient of performance (COP) of up to 4.52, HEAT2O can deliver energy savings of up to 60% to 70% compared to electric-resistance water heaters, benefiting both building owners and tenants.

Availability of Trane® / Mitsubishi Electric HEAT2O may vary by region.

Achieving Electrified Heating Solutions

Today's heat pump technologies provide a variety of ways to help building owners comply with regulations around decarbonization and meet their ESG goals. While some building operations may allow for total electrification of heat in a single upgrade or new construction, others may require a phased or hybrid approach.

The flexibility of heat pump systems enables building owners to craft a solution based on their budget, needs and goals. Each building that achieves electrification of heat helps society as a whole take positive steps to address climate change challenges.

Solutions Available

Packaged Units and Split Systems	
Rooftop Units	Precedent® Heat Pumps | Models WSK and WHK Precedent® Hybrid Dual Fuel Heat Pumps | Models DSK and DHK
Split Systems	Odyssey™ Heat Pump | Model TWA
Water-Source	Axiom™ High-Efficiency Console | Model GEC Axiom™ Horizontal & Vertical Heat Pump | Models GEHV, EXHV, DXHV and VSHV Axiom™ Rooftop Heat Pump | Model GSK Axiom™ Vertical Stack Heat Pump | Model GET Axiom™ Water-to-Water Heat Pump | Model EXW
VRF Systems	
Air-Source VRF Condensing Unit	R2-Series Heat Recovery | CITY MULTI® and HVRF Y-Series Heat Pump
Water-Source VRF Condensing Unit	WR2-Series Heat Recovery WY-Series Heat Pump
Indoor Units	Ceiling-Concealed | CITY MULTI® and HVRF Ceiling-Recessed | CITY MULTI® and HVRF Ceiling-Suspended | CITY MULTI® Floor-Mounted | CITY MULTI® One-Way Ceiling-Recessed | CITY MULTI® and HVRF Wall-Mounted | CITY MULTI® and HVRF
Branch Controller	Trane® / Mitsubishi Electric CITY MULTI®
Optional Hydronic Branch Conductor	Trane® / Mitsubishi Electric HVRF
Chiller Heat Pumps	
Air-Source	Air-Cooled Scroll Chiller with Partial Heat Recovery | Model CGAM Ascend™ Air-Cooled Chiller with Partial Heat Recovery | Model ACS Ascend™ Air-to-Water Heat Pump | Model ACX Thermafit™ Air-Source Modular Multi-Pipe Chiller| Model MAS Thermafit™ Air-to-Water Modular Heat Pump | Model AXM
Water-Source	Agility® water-cooled magnetic bearing centrifugal chiller | Model HDWA CenTraVac® water-cooled centrifugal chiller | Models CVHE, CVHF, CVHH and CDHH Series R™ water-cooled helical rotary screw chiller | Models RTHD and RTWD Thermafit™ Water-Cooled Chiller Model MWC Thermafit™ Water-to-Water Modular Heat Pump Model WXM Thermafit™ Water-Source Multi-Pipe Model MWS
Comprehensive Heat Pump Chiller Systems	Air-to-Water Heat Pump System Air-to-Water Cascade Heat Pump System Thermal Battery™ Storage-Source Heat Pump System Hydronic Branch Conductor
Commercial Hot Water Heaters	
Air-Source	Trane® / Mitsubishi Electric HEAT2O™
Water-Source	Trane® Domestic Hot Water Heat Pumps (DHWHPs)

Trane – by Trane Technologies (NYSE: TT), a global climate innovator – creates comfortable, energy efficient indoor environments through a broad portfolio of heating, ventilating and air conditioning systems and controls, services, parts and supply. For more information, please visit *trane.com or tranetechnologies.com.*

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