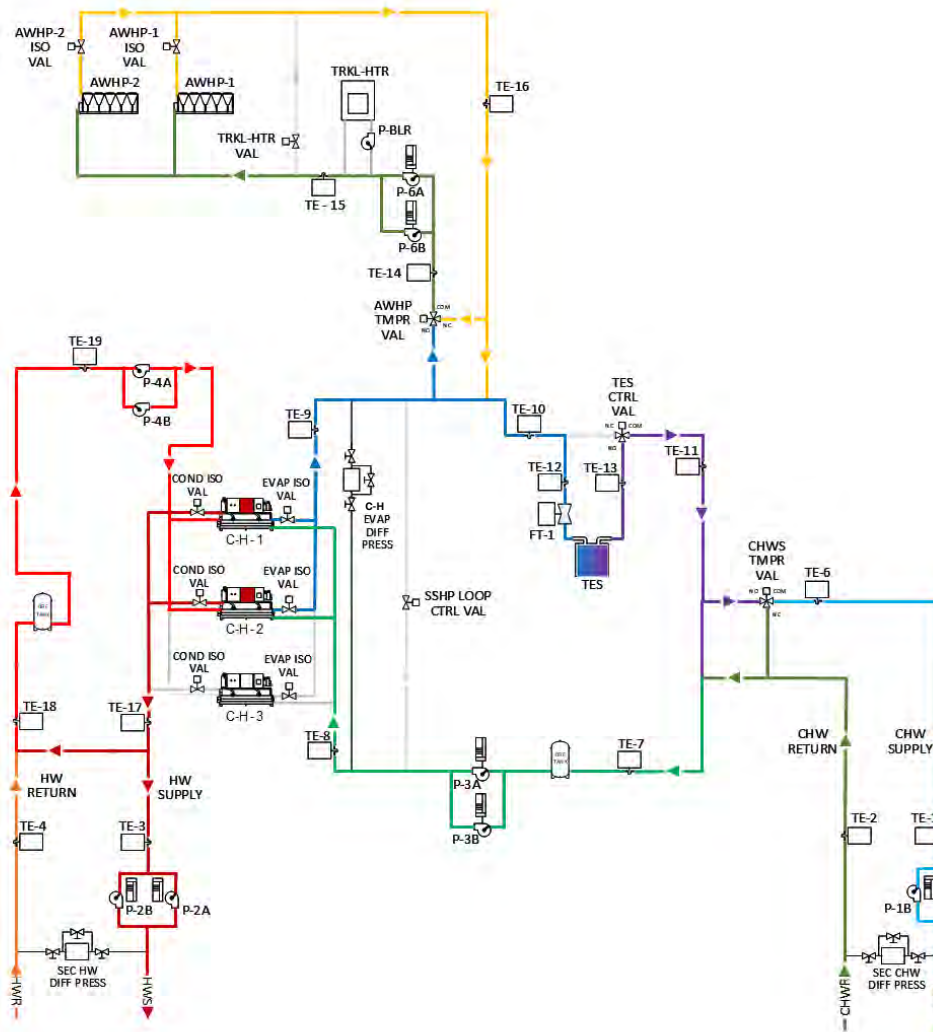




Application Guide

Thermal Battery™ Storage Source Heat Pump Systems Part of the Comprehensive Chiller-Heater Systems Series



SAFETY WARNING

Only qualified personnel should install and service the equipment. The installation, starting up, and servicing of heating, ventilating, and air-conditioning equipment can be hazardous and requires specific knowledge and training. Improperly installed, adjusted or altered equipment by an unqualified person could result in death or serious injury. When working on the equipment, observe all precautions in the literature and on the tags, stickers, and labels that are attached to the equipment.

Preface

As a leading HVAC manufacturer, we deem it our responsibility to serve the building industry by regularly disseminating information that promotes the effective application of building comfort systems. For that reason, we regularly publish educational materials, such as this one, to share information gathered from laboratory research, testing programs, and practical experience.

This publication focuses on air-to-water heat pump hydronic systems for cooling and heating. This manual discusses system design considerations and options, piping, airside considerations, and system operation and control.

We encourage engineering professionals who design building comfort systems to become familiar with the contents of this guide and to use it as a reference. Architects, building owners, equipment operators, and technicians may also find this publication of interest because it addresses system layout and control.

Trane® has a policy of continuous product and product data improvements and reserves the right to change design and specifications without notice. As such all data in this application guide should be considered for reference only, please consult with a Trane® sales associate for current equipment operating range and performance.

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Definitions

The following definitions apply for terms as used in storage source heat pump cooling and heating systems. Please note that these definitions **may or may not** align with their use in other HVAC systems.

Air-to-Water Heat Pump (AWHP). A unit that heats or cools fluid by transferring energy between the fluid and the air via a refrigeration circuit that includes a reversing valve. AWHPs may contain more than one refrigeration circuit and can be configured as a two-pipe or four-pipe unit.

Auxiliary Heat. Heat from an auxiliary source that is independent of the storage source heat pump heating function and can provide heat without chiller-heater or air-to-water heat pump operation. It can provide heating to the building in the event of non-operation of the storage source heat pump system for any reason. It is most typically a hydronic boiler in the heating distribution system but could also be heating in the space. e.g., VAV box electric heaters.

Charge (cooling related). Removing energy from the energy storage tanks, freezing water into ice in the process.

Chiller-Heater (C-H). Refrigerating machines that can be controlled to provide either fluid heating or cooling as a primary function. The function is dependent on what is needed for the application at a particular point in time. When a unit's purpose switches between cooling and heating and it does not have a reversing valve, depending on application, such a unit may be referred to as a chiller-heater. See also **Non-reversible heat pump**

Collect (heating related). Net adding of energy to the thermal energy storage tanks as delivered from the AWHP and/or the cooling load, and/or the trickle-charging boiler; melting ice into water in the process. The chiller-heater may or may not be operating as energy is collected into the TES.

Contingency Heating and Cooling. Critical systems may require additional contingent heating and/or cooling systems in the event of an equipment failure. Piping connections are designed into the system so that rental equipment can be brought in with relatively quick notice when primary equipment requires servicing.

Cooling Dominant. When the system cooling loads plus the heat of compression are greater than the system heating loads. The excess heat may be either rejected or collected (recovered and stored) for future heating use.

Discharge (cooling related). Absorbing energy into the energy storage tanks from the cooling load, melting ice into water in the process.

Dispatch (heating related). Net removal of energy from the energy storage tanks through the water-to-water chiller-heater, typically freezing water into ice during the process. The AWHP and/or trickle-charge boiler and/or cooling heat recovery may or may not be running as energy is removed from the TES.

Energy Exchange. Is a term used to describe the functioning of the thermal energy storage in some system modes. In some of the storage source heat pump system operating modes it is very clear that energy is being sourced from (dispatch or charging) or sinked to (collect or discharge) the TES. But in other modes the energy flow to or from the TES can switch between sourcing and sinking depending on the building heating and cooling loads. The term “TES energy exchange” is used to indicate the TES possible variation in energy flow.

Heating Dominant. When the system heating loads are greater than the system cooling loads plus the heat of compression. The deficit heat may be sourced from supplemental heat and/or dispatched (supplied) from thermal storage.

Non-reversible Heat Pump. A refrigeration unit that includes the capability to pump heat from a lower energy state to a higher energy state and can be controlled to provide either fluid heating or cooling as a primary function but cannot change the roles of the evaporator and condenser. See also **chiller-heater**.

Storage Source Heat Pump (SSHP) System. A heating and cooling system for buildings, combining thermal energy storage with chiller-heaters and other energy collection devices such as heat pumps to enable the collection, use and storage of thermal energy in a grid-interactive way—based on building usage, grid emissions, and customer goals. See “Electrification, Heat Pumps and Thermal Energy Storage” *ASHRAE® Journal*. Vol. 62, No. 7, July 2020, pp. 32-39. McCracken, M.

Trickle Charge Boiler. An auxiliary hydronic heating device (boiler, electric or other) which has the primary purpose of adding heat to the TES when the AWHP cannot run, or make sufficient capacity, because of operating limitations.

Thermal Energy Storage (TES). Technology or systems of accumulating cooling or heating capacity for future use. These systems can be used for balancing energy demand for the building between dominate periods or shift the balance of energy use towards off-peak periods for better renewable energy utilization or reduced utility costs.

Thermal Energy Storage Tank. The container or vessel along with its integral heat exchanger, used for storing thermal energy for future use.



Introduction to Storage Source Heat Pump Heating Systems

Storage Source Heat Pump (SSHP) systems are high efficiency electrified hydronic heating systems that provide the opportunity for exceptional heating decarbonization. SSHP systems help overcome many of the operating limitations of air-source heat pump systems including:

1. Inability to operate in extreme low outdoor air temperatures;
2. Diminishing heating water supply temperature at low ambients;
3. Declining heating capacity at low ambients;
4. Inability to recover heat between non-simultaneous cooling and heating loads.

A SSHP system leverages Thermal Energy Storage (TES) and Chiller-Heaters (C-H) to provide consistent heating system performance at any outdoor temperature. The use of TES as a heat energy source for the chiller-heaters provides several benefits:

1. A consistent temperature energy source for the C-H heating units;
2. Continuous recovery and storage of heat from cooling loads for later heating use;
3. Use of low demand/carbon energy storage to supplement recovered cooling energy when required.

At its core, it is a four-pipe hydronic cooling and heating system that provides conditioned fluid to coils or other loads within a building. It uses conventionally designed variable flow cooling and heating distribution loops. Like any heat pump or chiller-heater based system, it benefits greatly from optimized supply heating water temperature in the range of 95°F to 110°F, although higher supply temperatures are readily achievable.

The basis of the SSHP system is that the chiller-heater can source energy from the storage tanks enabling building heating.

Heat recovery is possible whenever there is a cooling load. Cooling energy can be captured for instantaneous or future use, instead of rejecting the heat outside via airside or waterside economizing. The cooling energy is collected in the TES to provide a source for the later heating operation.

When there isn't sufficient cooling at the moment heating is required (i.e. cooling and heating loads are non-coincident), the thermal energy storage is used to decouple the cooling and heating loads, that is, when loads are not equal and coincident. By doing so, heating is available using energy that was collected into TES tanks, recovered from the building, taken from ambient air using the AWHP, or delivered from a trickle-charge boiler.

WHERE AND WHY USE A STORAGE SOURCE HEAT PUMP SYSTEM?

SSHP systems will most commonly be used to provide electrified heating in climate locations with extreme outdoor air temperatures that drop low enough to make heating with air-to-water heat pumps alone difficult or costly. A SSHP system can effectively and efficiently heat and cool a building without regard to outdoor air temperatures. Alternate methods to accomplish this, such as electric heating or fossil fueled boilers or exotic AWHP designs, are disadvantaged by higher electrical demand, higher utility costs or higher carbon footprint. The electrical energy conversion efficiency of electric resistance-based heat has a COP of one (1) while the SSHP system chiller-heater can have a COP as high as three (3) to four (4), resulting in a much lower electrical demand.

There are other advantages that can make a SSHP the system of choice even when extreme cold outdoor air temperatures would not necessitate it.

- The SSHP system chiller-heaters performance is unaffected by outdoor air conditions. As such it provides practically constant:
 - Heating capacity
 - Leaving heating water temperature
 - Heating efficiency

This reduces the required capacity and or quantity of AWHPs, lessens the outdoor installation area, reduces the peak electrical demand and annual operating cost.

- In general chiller-heaters are available with higher supply heating water temperatures than commonly available AWHP units, opening the door to more electrified heating applications, particularly for existing buildings.
- SSHP maximizes the heat recovery possible from the cooling loads. Since a SSHP system has stored energy for use at any later time, recovery up to the full daily cooling load is enabled, unlike instantaneous heat recovery which is limited to the lesser of the simultaneous cooling and heating loads.
- Thermal Energy Storage (TES) enables demand management in both cooling and heating. TES charging/collecting can be optimized around reduced electrical cost or minimum carbon impact.
- The SSHP TES benefits both the building heating and cooling operation providing demand management and operating savings throughout the year. This double benefit greatly improves the system payback and annual carbon reduction impact.

STORAGE SOURCE HEAT PUMP SYSTEM VARIATIONS

SSHP systems can be designed with a wide range of capabilities and be classified in various ways. For the purposes of this application guide we will simply define “simple” and “complex” building systems. Both have similar benefits. These classifications speak to the complexity of the design, operation, and maintenance.

This application guide discusses the “simple” building system configuration. Simple system characteristics include:

- All air-source/air-cooled products for cooling. No cooling tower in the system.
- Heating only from the chiller-heaters, with the exception of optional dedicated heat recovery units.
- Single temperature cooling distribution.

Complex system characteristics include:

- Air-source heat pumps for energy collection and cooling.
- Connection of chiller-heaters to provide either fluid cooler or cooling tower for cooling and TES charging.
- Water-cooled chillers for primary cooling and TES charging.
- Optional dual temperature cooling distribution.

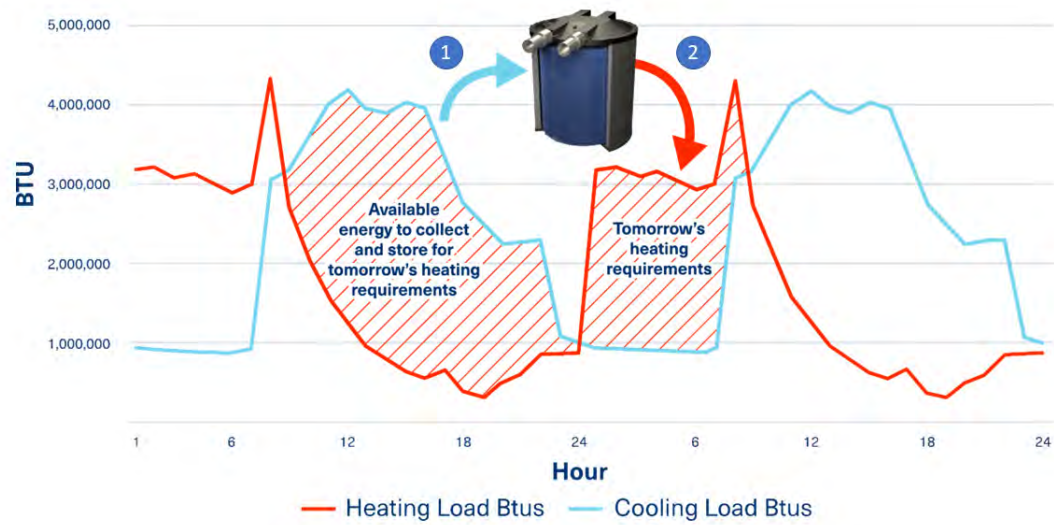
Contact the local Trane® sales office for more information on complex storage source heat pump systems.

ASYNCHRONOUS HEAT RECOVERY

Building and cooling needs fluctuate throughout the day. This allows reclaimed heat to be used from one day to the next.

1. **Heat Storage = Comfort Cooling.** When comfort cooling is required, the building heat is transferred to the ice (in the tanks), the ice melts and changes to water. A tremendous amount of heat is stored in the water for later heating use.
2. **Cooling Storage = Comfort Heating.** When comfort heating is required, the heat is removed from the water (in the tanks) to heat the building. Meanwhile, the water changes back to ice for later cooling use.

Figure 1. Building cooling and heating with ice based thermal energy storage



Storage Source Heat Pump System Configuration

While other system configurations are possible, and will not be unusual, the following configuration provides excellent reliability, flexibility, efficiency, as well as simplicity of design and control.

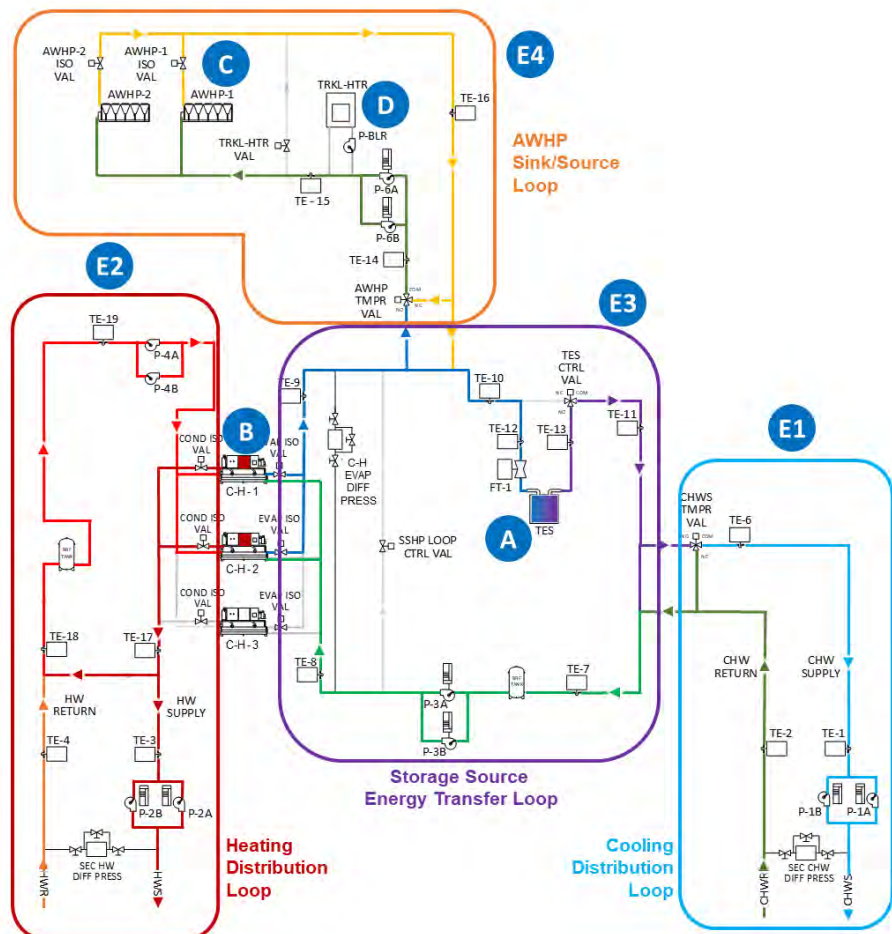
STORAGE SOURCE HEAT PUMP BASE CONFIGURATION OVERVIEW

Figure 2 shows the base SSHP hydronic configuration with loop callouts. Throughout the remainder of this application guide we will refer to this as the “base configuration.”

Note: The piping diagrams in this application guide do not include all required hydronic system requirements and these must be defined and designed into the system by the job design/consulting engineer of record. Examples of possible additional components include expansion tanks, glycol make-up, air separators, strainers, vibration isolators, VFDs, etc.

Piping coloring and temperatures shown are for illustration only and do not necessarily represent actual operating conditions.

Figure 2. Storage source heat pump with four-pipe cooling/heating distribution



MAIN SYSTEM COMPONENT OVERVIEW

A. Thermal Energy Storage (TES)

The TES is both a heat energy source for heating and a cool energy source for cooling the building. They use the latent heat of water's change of state to store energy effectively and efficiently in a compact package. They enable:

- Heating at any OAT condition;
- Complete building heat recovery;
- Electrical demand management;
- Mitigation of the impact of AWHP defrost cycles.

B. Water-to-Water Chiller-Heaters (C-H)

C-H's take energy recovered from the building cooling, AWHP unit(s) and/or the TES and provide elevated temperature heating supply water to meet the building heating loads. They enable:

- Heating in any OAT condition with energy from the TES.
- Heating water supply temperature higher than available from AWHP units if required.
- Uninterrupted heating during AWHP defrost cycles.
- Increased heating COP compared to AWHPs operating at cold ambient temperatures.

C. Air-to-Water Heat Pumps

AWHPs provide heating and cooling energy. They provide:

- Building cooling.
- Low heating temperature energy source cascading to chiller-heater heating.
- Charging energy (freezing) of TES for later cooling and demand avoidance.
- Collecting energy (melting) of TES for later heating.

D. TES Trickle Charging Unit

Trickle charging units are primarily electric boilers but any heating unit that can operate at extreme low OATs can be applied, such as low temp AWHP, geothermal heat pumps or fossil fueled boilers.

The trickle charging units provide three key functions:

- Low demand electrical sourced heating energy collection (melting) in TES during extreme cold OAT conditions.
- Mitigation of cold water temperature entering AWHP during defrost cycles.
- Low cost redundancy for AWHP heat generation.

E. Four Key Hydronic Loops

The four hydronic loops are to meet the diverse flow requirements of the various system components and enable efficient and simple system pumping energy optimization.

1. Chilled water variable flow distribution
This is a classic variable flow chilled water distribution system.
2. Heating water variable flow distribution
This is a classic variable flow heating water distribution system.

3. Storage source energy transfer loop
This loop provides flow control for the C-H units as well as the TES. It facilitates heating and cooling energy flow between the various system components. It also helps mitigate the impact of AWHP defrost cycles.
4. Air-to-water heat pump sink/source loop
This loop manages the flow and temperature to the AWHPs as well as trickle-heater boilers. It also is the external source and sink for charging and collecting energy for the TES system.

Base Configuration General Characteristics

- Decoupling of each loop for independently optimized flow control.
- Tempering/mixing valves to maintain suitable operating conditions for all components.
- Separation of fluids in the heating distribution loop from the cooling, SSHP and AWHP loops, which may allow for some loops to use water instead of antifreeze (e.g., heating distribution loop).
- Multiple cooling and heating modes depending on the building operating requirements.
- Ability to install the Thermal Energy Storage (TES) tanks indoors or outdoors depending on job requirements.
- Optional features (see options section)
 - Backup heating boilers
 - Dedicated heat recovery unit
 - Air-cooled chillers

SYSTEM COMPONENT EXPANDED DESCRIPTION

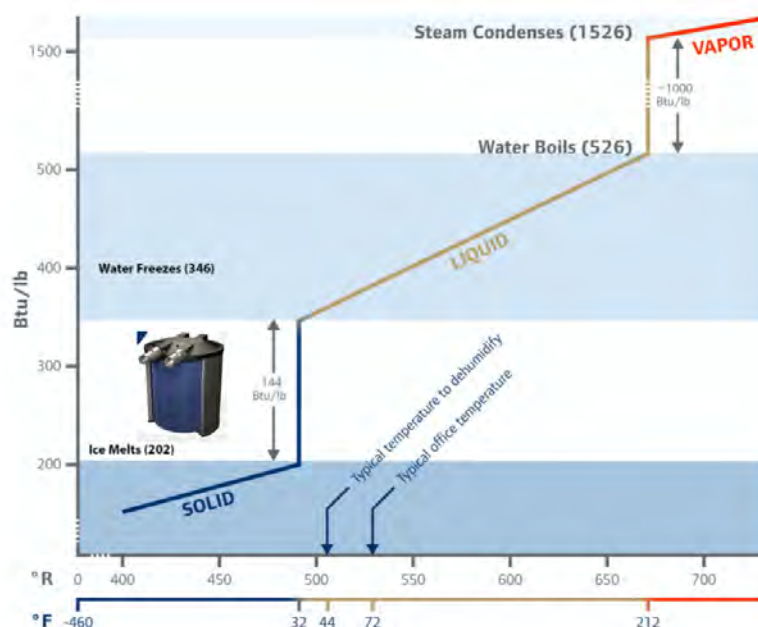
Thermal Energy Storage Tanks (TES)

In a SSHP system, the TES tanks enable asynchronous energy transfer and recovery, without typical AWHP constraints. The TES tanks serve as an energy sink for building cooling by melting ice during peak energy cost periods, also enabling downsizing of the chillers. The building waste energy is stored in the tanks in the form of liquid water that is used as an energy source for the chiller-heater to provide heated fluid to the system later. During heating, the energy in the tanks is efficiently 'lifted' from a relatively low temperature (near 32°F) by a Chiller-Heater (C-H) to the temperature appropriate for heating coils, freezing the TES tanks in the process. This energy transfer loop enables the use of today's waste energy for tomorrow's heating.

TES tanks used in the SSHP system are decades proven Calmac Ice Bank™ Energy Storage tanks used widely in cooling only systems. They leverage the latent energy absorbed or released with water's change-of-phase from solid to liquid or liquid to solid, making them well suited components in cooling and heating applications, respectively. This provides proven, reliable, sustainable, and economical energy storage.

Water releases 1 Btu (1055 J) of energy when the temperature of one pound of water is reduced 1°F (0.6 C). That same pound of water releases 144 Btus (152 kJ) when it changes from its liquid phase (water) to its solid phase (ice). This phase change is also known as the latent heat of fusion. Applying this principle in the SSHP system's energy transfer loop provides for a high-density potential energy source and sink. Figure 3 shows the heat of fusion and vaporization for water as it transitions from solid (ice) to liquid to vapor.

Figure 3. Heat of fusion and vaporization of water



The SSHP thermal energy storage is used to enhance both the cooling and heating operation of the HVAC system. Because the TES will now be used for cooling and heating, new terminology is needed to distinguish between these two functions.

For cooling, when ice is being made in preparation for building cooling, heat is being sourced from the TES and this is called charging. When ice is being melted during cooling, heat is sinking into the TES and this is called discharging. These terms have been in place for quite some time.

In heating, when ice is melted in preparation for building heating, heat is sinking into the TES, this is termed collecting. When ice is being made during heating, heat is being sourced from the TES and this is termed dispatching.

Figure 4 demonstrates the TES states and the related SSHP components for both cooling and heating.

Figure 4. Thermal energy storage tank operation



Chiller-Heater (C-H)

The chiller-heater provides the heating water in the SSHP system. It sources energy from the SSHP loop and uses that energy to provide heating to the heat distribution loop. The source(s) of energy that is extracted from the SSHP loop may be any combination of; the chilled water loop load (direct heat recovery), the TES, and/or the AWHP units.

Since the chiller-heater unit's heating operation does not depend on direct sourcing of energy from the outdoor air, they can provide heating in any ambient condition. This is one of the key benefits and reasons to apply the SSHP system.

As applied in the SSHP system outlined in this manual, the C-H primarily provides for heating. In other configurations it may also provide cooling. Contact the local Trane® office for more information on that option.

Chiller-Heater Selection and Sizing. In the base configuration the chiller-heater is typically sized to meet the full design heating load. Sizing should also take the following into consideration; low load operation which may occur during shoulder season or summer operation and heating redundancy requirements. An additional unit may be required to provide N+1 redundancy if no other form of heating backup is designed into the system.

The *as applied* operating capabilities of the selected chiller-heater units must be carefully considered in the initial phases of the system design process. Units are typically "rated" to provide a certain full load leaving condenser heating water temperature, e.g., 140°F (60°C) assuming a typical leaving evaporator chilled water temperature of 40°F to 45°F (4.4°C to 7.2°C). In the SSHP system the evaporator design leaving fluid temperature will be 23°F to 26°F (-5°C to -3.3°C). Glycol will be in the evaporator loop and may also be in the condenser loop. This may constrain the unit's actual leaving heating fluid temperature to less than the "rated" value. The heating system must be designed for the *as applied* capabilities of the C-H units.

Chiller-Heater Operating Limitations. Consult with the manufacturer for specific model C-H operating limits. Items of particular interest include:

- Flow limits, particularly minimum operating flow. Depending on the type and model of chiller-heater, the heating and or cooling distribution loop flows may be near or below the minimum allowed operating flow of the unit. The unit will have to be selected and applied with this in mind. Because of this, the base configuration used in this manual includes decoupled pumping.
- Temperature limits including:
 - Maximum condenser leaving heating water temperature at the design leaving evaporator temperature.
 - Minimum required unit refrigerant differential temperature (or pressures) to determine if head pressure control is required.
 - Maximum operating entering evaporator temperature to determine if evaporator temperature control is required.
 - Maximum allowed unit water temperature when the unit is off to prevent refrigerant release.
- Glycol requirement for intended operating temperatures.

Air-to-Water Heat Pump (AWHP)

The SSHP system uses a two-pipe air-to-water heat pump that can operate in a heating mode or cooling mode using a reversing refrigeration system. At any time, it can provide heating **or** cooling, but not both simultaneously. It uses outdoor air as a heat sink in the cooling mode and as a heat source in the heating mode.

The purpose of this unit is to provide cooling or heating to the SSHP loop. The AWHP units and SSHP loop work together to overcome the short coming of an AWHP unit alone which is loss of capacity or the complete inability to heat in extremely cold outdoor air temperatures. The AWHP provides several different functions in the SSHP system, depending upon the system mode of operation, including:

- Full cooling to the cooling distribution loop;
- Partial cooling to the cooling distribution loop augmented with cooling from the TES;
- Charging (freezing) of the TES in preparation for cooling;
- Full dispatching (sourcing) of low temperature heat to the chiller-heaters;
- Partial sourcing of low temperature heat to the chiller-heaters augmented with heat from the TES;
- Collecting energy (melting) to the TES in preparation for heating.

AWHP Selection and Sizing: The total AWHP capacity required depends heavily on the cooling and heating load profiles of the building along with the design intent and options in the system and the expected outdoor operating conditions. Both the required cooling capacity and heating capacity requirements must be considered to determine the appropriate sizing.

While the AWHPs provide for the building cooling load, they do not necessarily need to be sized for the building peak cooling load. The TES can be leveraged to downsize the AWHP cooling capacity and reduce first cost. In addition, if high cooling loads drive significant upsizing of the AWHPs, cooling only air-cooled chillers can be added to the system to carry the excess cooling load and the AWHPs can be sized only to meet the heat requirement. Air-cooled chillers have the added advantage of higher cooling efficiencies than AWHPs.

Since the chiller-heaters actually meet the building peak heating loads (BTUH) the AWHPs total capacity (BTUH) does NOT need to be sized to meet the peak heating load *rate* (BTUH). Instead, the heating capacity of the AWHPs is dictated by the summation of the total heat *energy* (BTU) required by the chiller-heaters to meet the building heating load throughout the heating design day. In sizing the AWHP the design day heat energy requirement, design day outdoor air temperature as well as the AWHP defrost derate must be considered. For buildings in extreme cold, climates that prevent or severely limit the design day operation of the AWHP, a “trickle-heater” is applied for heat collection. In that case the AWHPs need only be sized based on the heat energy required on a day when the AWHPs are expected to run based on the system design and the AWHP manufacturer’s operating limits. This is discussed in more detail in the “Storage Source Heat Pump System Design Process,” p. 26.

AWHP Operating Limitations: The refrigeration systems in air-to-water heat pumps are called upon to run in extremely diverse operating conditions that push the limits of their refrigeration components. It is important to understand the operating limitations of the specific units being applied, then design and control the system correspondingly.

Consult with the manufacturer for specific model AWHP operating limits. Items of particular interest include:

- Flow limits, particularly minimum operating flow. Depending on the type and model of AWHP the SSHP loop flows may be near or below the minimum allowed operating flow of the unit. The unit will have to be selected and applied with this in mind. That is why the manual’s base configuration includes decoupled pumping.
- Temperature limits including:
 - Minimum operating ambient temperature. The AWHP unit will not be able to run in heating mode below this temperature.

Note: When evaluating the minimum outdoor air temperature, that the building and AWHP may be subject to, the designer should look at the location 20- or 50-year extreme temperature history.

- Minimum allowed leaving cooling temperature. The TES requires 23°F to 26°F (-5°C to -3.3°C) fluid to complete a charge mode. The AWHP must support this operation.
 - Minimum allowed entering heating water temperature. When collecting energy (heating mode) to send to the TES the return water temperature from the TES will be 32°F to 35°F (0°C to 1.7°). The AWHP piping includes a mixing loop to allow control of the return water at a higher temperature.
 - Minimum allowed entering defrost-cycle water temperature. The trickle-heater is installed to moderate the return temperature to the AWHP during a defrost cycle, if required.
- Glycol requirement for intended operating temperatures.

See the specific model AWHP manufacturer's catalog and application or installation manuals for other unit application requirements.

Trickle-Heater

Heat energy beyond that which the AWHPs can provide will be required in many installations. The two main reasons for this are: extended periods of extreme cold outdoor temperature that limit or prohibit AWHP daily operation and/or the need to moderate the return water temperature to the AWHP during defrost cycles. A trickle-heater provides the heating to overcome these issues.

A trickle-heater is a hydronic boiler of some type. It may be an electric boiler, condensing gas boiler or even a non-condensing gas boiler. The trickle-heater provides an alternative source of heat "collection" (melting) of the TES so that TES maintains enough stored energy to support the heating needs of the building.

What is important to understand is that, like the AWHPs, the trickle-heater does NOT have to meet the building peak heating demand (BTUH). It is much smaller, and must only meet the greater of:

- The sum of the design day heating energy (BTU) divided by 24. (Twenty-four comes from the assumption that the trickle-charge can operate 24 hours a day if required.)
- The heating rate required to moderate the AWHP entering water temperature during a defrost cycle.

Also, the actual annual operating hours of the trickle-heater are very low. For this reason, its impacts on the building utility cost and carbon footprint are minimal, even if it is a fossil fueled boiler.

See the "Boiler Types and Storage Source Heat Pump Application Considerations," p. 80 in the system options section for a more detailed discussion of boiler types.

SYSTEM FLUIDS

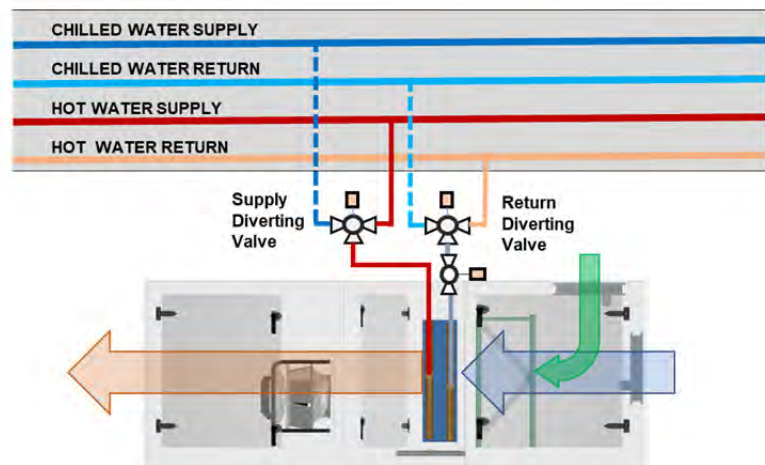
From the plant point of view, in the base configuration the heating distribution fluid and the cooling distribution fluid are isolated from each other.

The same fluid is used throughout the cooling distribution loop, the SSHP energy transfer loop and the AWHP loop. This would be a freeze inhibited glycol solution.

The heating loop is separate and may use a different fluid.

However, if the distribution systems intermix at the air-handling units, as when there are change-over coils piped and valved for use in both heating and cooling, then the same fluid should be used in both the heating- and cooling loop.

Figure 5. System fluid in heating and cooling loops



Fluid isolation heat exchanger(s) could be properly applied between the SSHP loop and cooling distribution loop(s) if the designer calls for differing fluids in the two loops. If a fluid isolation heat exchanger is applied, the designer must take into consideration that fluid below freezing temperature may enter the heat exchanger from the SSHP loop during system changeover or a defrost cycle, and take the appropriate design precautions.

FOUR-PIPE DISTRIBUTION

As the name implies the system has four-pipe distribution employing separate heating and cooling distribution loops. These are standard distribution loops and may be optimized for the supply temperatures, flows, and temperature changes as required by the airside design. The airside coil capacity will typically be controlled with two-way valves causing widely variable distribution flow for both the chilled water and heating water distribution. This provides for significant operational flexibility and opportunities for pumping energy savings.

At the heart of the system are the decoupler lines. These lines provide the hydronic isolation that allows for optimization of flows and temperatures in both the distribution and production loops.

DECOUPLING – HYDRONIC ISOLATION

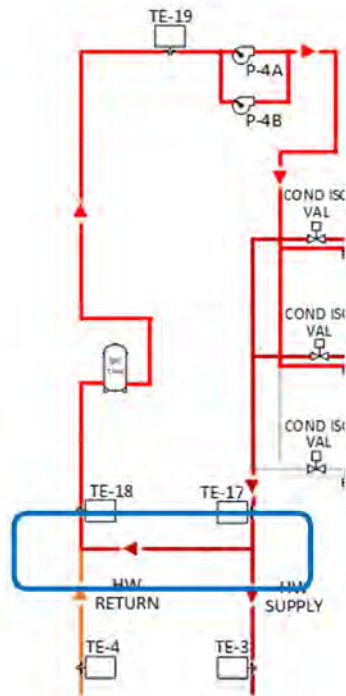
Decoupling greatly simplifies system design and allows flexibility of production unit sizes and types that can be applied to best match system requirements. The principal requirement for the heat pump selection is that it can produce the supply water **temperature** required for cooling or heating. Unit flow and pressure drop requirements are of much less concern since the decouplers provide hydraulic separation of systems' flows and operating pressures.

There are two forms of decoupling used in this system, classic primary/secondary and side-stream

Classic Primary/Secondary Decoupling

This uses a dedicated decoupling pipe as highlighted by the blue rectangle in [Figure 6](#). This provides hydraulic separation of the distribution (secondary) system pumping from the production (primary) system pumping.

Figure 6. Distribution loops classic decoupling lines



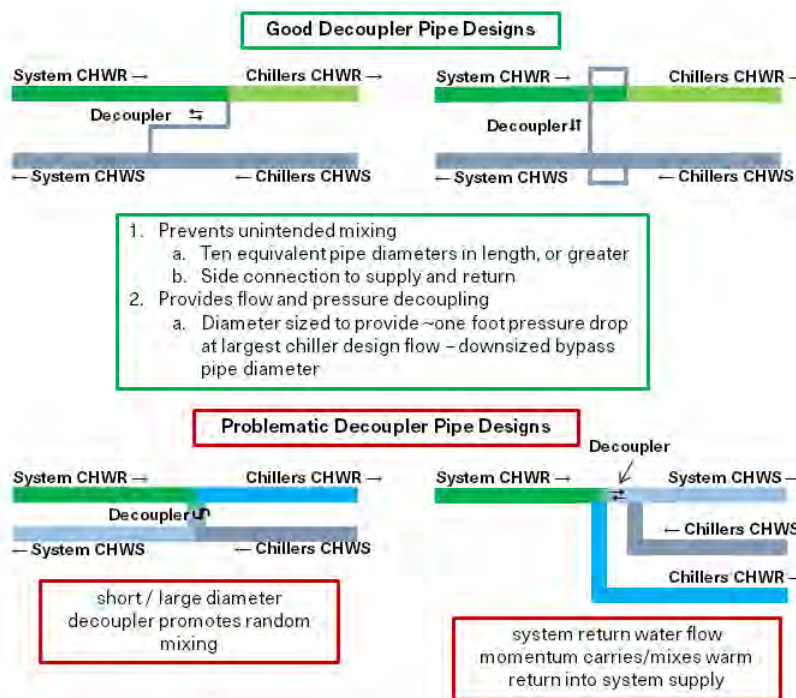
The classic decoupler pipes must be configured and sized to meet two primary requirements:

1. Prevent unintended mixing of the return and supply water streams.
2. Provide *adequate* flow and pressure decoupling between the hydronic production and distribution loops.

Achieving these requirements typically means observing several principles.

Classic Decoupler Pipe Connection Tees. The decoupler pipe should be configured so that it enters and exits in and out the side of the return and supply system piping with tee type connections. See [Figure 7](#). This is to prevent water velocity momentum in the supply or return pipe from inducing flow and/or mixing in the decoupler pipe.

Figure 7. Classic decoupler pipe connections examples



Classic Decoupler Pipe Diameter. The decoupler pipe diameter sizing differs depending on the plant operating intent.

- For systems with constant unit flow it should be sized based on the higher of the largest design flow of any single unit in the plant. This typically means no larger—often a size smaller—than the diameter of pipe connecting to the largest unit.

In multiple unit systems it should NOT be sized for **system** design flow, such as equal to the distribution piping diameter. It is sized based on one unit's design flow.

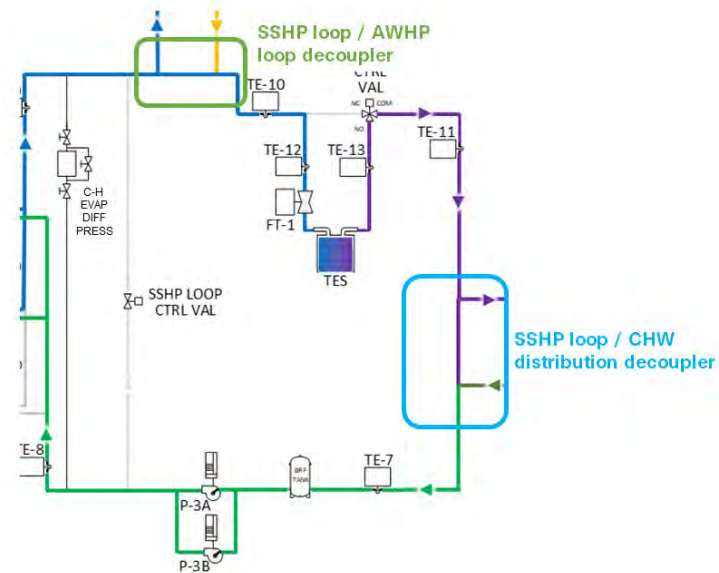
- For Variable Primary/Variable Secondary systems, with varying flow through the operating heat pumps, the decoupler is sized for the largest **minimum** flow of any unit in the plant. This is typically one or more pipe sizes smaller than the diameter of piping connecting to the largest unit. Although if the heat pump's selected design flows are close to the minimum allowed heat exchanger flow the decoupler may be the same size as the unit piping connection. Larger is not better, and it increases the likelihood of undesired flow mixing and installation cost.

Classic Decoupler Pipe Length. The decoupler pipe length should be approximately ten (10) equivalent pipe diameters long or greater (elbows are counted appropriately). Another rule of thumb is for the pipe to have about one (1) foot of pressure drop at the decoupler design flow. In large chilled- or hot-water systems a somewhat higher pressure drop generally does not cause operational problems.

Side-Stream Decoupling

The second form of decoupling is used for side-stream loop connections. [Figure 8](#) shows an example of decoupling as used in an AWHP system with a chilled water loop connected to the SSHP energy transfer loop. It is also applied to the side-stream boiler and optional dedicated heat recovery unit connections.

Figure 8. Side-stream decoupling lines



In side-stream decoupling the “decoupler pipe” is actually the SSHP energy transfer loop return pipe so the sizing and length rules for classic decoupler pipes do not apply. The most important design characteristic of side-stream decoupling is the design of the outlet and inlet tees. Note that there can still be forward or reverse flow in the “decoupler” but it’s typically at a much lower velocity than a classic decoupler.

The requirements for proper side-stream connections include:

- The outlet and inlet tees are located in a straight section of pipe at least five pipe diameters downstream and upstream from other pipe fittings or devices that create extreme turbulent flow in the main pipe. Including, but not limited to, other tees, elbows and valves.
- The side-stream connections tee out and in at right angles to the main loop. This helps prevent “ghost flow” in the side-stream loop.
- The outlet and inlet tees should be separated by minimum of two and maximum of ten pipe diameters of the main pipe. This prevents unintended reverse flow mixing while maintaining the pressure drop between the tees at an acceptable level.

If the side-stream loop operation includes maintaining a specific temperature in the main loop, the control temperature sensor must be installed far enough downstream of the inlet pipe to ensure complete mixing of the flows, preferably downstream of one elbow—or even better two.

System Fluid Volume

Adequate system fluid volume in the cooling and heating loops is critical to system reliability and comfort.

HEATING AND COOLING VOLUME

For the heating and cooling distribution loops of the system a minimum fluid volume providing for a two-minute circulation time is recommended. That translates to a volume of water in the heating loop equal to or exceeding two times the design heating flow rate. It also translates to a volume of water in the cooling loop equal to or exceeding two times the design chilled water flow rate.

For chilled water or heating water loops that do not meet the recommended fluid volume in the piping alone a volume buffer tank should be installed in the SSHP loop and/or the distribution lines.

Note: The heating loop volume requirement for an SSHP system is less than an all AWHP system because the unit's defrost cycles do not directly impact the heating system.

For systems with a rapidly changing load profile or requirement for highly accurate supply temperature the amount of volume should be increased.



Storage Source Heat Pump System Design Process

Today, traditional HVAC Design and Analysis tools do not support the automated design, sizing or financial analysis of storage source heat pump systems. Trane® is actively developing software tools for design and sizing; as well as economic and environmental impact analysis of SSHP, and other electrified heating systems. System designers are encouraged to periodically check with local Trane representatives for support and availability of these tools.

STORAGE SOURCE HEAT PUMP DESIGN PHILOSOPHY

This equipment sizing process focuses on the base configuration. Other configurations may require other sizing considerations. The design assumptions for the following process include:

Important: Storage Source Heat Pump (SSHP) systems differ from standard heating systems in several ways. One key is that the SSHP system equipment is not only sized for the peak heating and cooling loads, it must also be sized for the heating design day 24-hour cumulative heating and cooling load energy consumption. The thermal energy storage and any charging devices are sized based on peak heating demand and daily consumption. Additionally, there are several important design considerations in applying vapor-compression systems for heating systems that are different from non-storage cooling and/or heating systems. Storage source systems use these units differently so there are special considerations related to that usage. This includes the application of the air-to-water heat pumps and chiller-heaters. These differences must be noted and addressed in the design process. More specifically some of these considerations include:

1. To properly size the AWHP, C-H and TES; 24-hour cooling and heating design day load profiles are required, including weather conditions.
 - Building hourly load information is an important start to the SSHP design process. Undersizing the heating system is obviously unacceptable but excessive oversizing is problematic as well. Electrified heating systems have a higher first cost than conventional systems and oversizing exacerbates that cost. Oversizing also penalizes operating cost and can result in excessive compressor cycling, shortening system life.
 - 20- and 50-year extreme cold weather events must be considered as they may result in the inability of AWHP units to operate for some periods of time.
These temperatures are available from ASHRAE® Standard 169 "Climatic Data for Building Design Standards." Data for 9237 specific locations can be accessed from the on-line ASHRAE® Fundamentals Handbook via the link on the Chapter 14 opening page.
 - Nighttime (unoccupied) cooling and heating loads must be evaluated because they can degrade the ability to store adequate energy for the following day's use. If nighttime loads exceed approximately 10 percent of the design TES cooling or heating charging rates the AWHP or trickle-heaters may have to be upsized, or dedicated cooling or heating units applied to support those continuous night loads.

2. The vapor-compression units are applied at operating temperatures which can significantly decrease their capacity and/or attainable leaving water temperature, compared to typical rating point operating conditions. The SSHP loop, airside, and waterside, must be designed in compliance with the equipment at AS APPLIED operating capabilities. For example:
 - An AWHP unit rated to produce 140°F leaving heating fluid at 47°F OAT may be limited to producing 90°F leaving heating fluid temperature at 0°F.
 - A C-H unit rated to produce 140°F leaving heating fluid at 42°F leaving evaporator water may be limited to producing 120°F heating fluid temperature at the leaving evaporator temperature when sourcing energy from the thermal energy storage tanks, e.g., 23°F leaving evaporator temperature.
3. Because of heat exchanger flow requirements the heating distribution system's design flow rates may be close to, or below, the heating units' minimum allowed flow limit. (i.e., gpm/ton or gpm/MBh). Since it is quite likely, the system should be designed with flow decoupled pumping, to reliably and simply meet the varying requirements of the distribution system as well as the cooling and heating units.
4. Vapor-compression units' minimum and maximum allowed water temperatures in each mode of operation need to be evaluated and designed for. This may drive the need for tempering circuits to moderate entering water temperatures to the units, or extend transition times between modes to ensure the unit operating limits are not violated.

Details on these subjects are called out in the unit selection and specification tables in the discussion below.

Enhanced AWHP and C-H capabilities are in development. Consult with the local Trane® representative for up-to-date information on the operating capabilities of equipment being considered for the specific job.

REDUNDANCY

The sizing process outlined below does not include redundant capacity. Consider redundancy only after capacity required to satisfy building loads been established.

There are various approaches to cooling and heating redundancy depending on the specific building circumstances.

Heating Redundancy. This may be the most important consideration. There are multiple ways to provide heating redundancy depending on the base system features.

- Optional auxiliary heat may inherently provide heating redundancy in all situations. Auxiliary choices include boilers in the heating distribution loop or in-space electric heat.
 - For auxiliary boiler systems, N+1 boilers are the most logical redundancy solution.

- If the auxiliary heat is electric resistance based, then building backup generators must be sized for the boiler electrical draw which can require upsizing of the generators. If a generator engine cooling heat recovery option is available, it can be used to supplement the building hydronic heating.
- If the auxiliary heat is fossil fuel based, backup generators may be smaller as they will only need to support pump, AHU, and control operation to sustain building operation.
- For systems without auxiliary boilers then N+1 chiller-heater units are required to support heating redundancy.
 - Since the chiller-heaters depend on TES supplied energy to heat the building, AWHP and/or trickle-heater sizing must ensure sufficient daily capacity is available for collection into the TES. So, N+1 AWHP or trickle-heater capacity may be required to ensure sufficient energy can be stored in the event of a failure of one of those units.
 - If N+1 redundancy is required, the base quantity of C-H units may be selected to minimize installed cost.

For example: If the base system is designed with one C-H unit, the redundant unit and its supporting infrastructure will double the base installation size and first cost.

If instead the base design has two, 50 percent capacity units. The redundant unit will only be 50 percent of the base resulting in less total installed C-H capacity, which may reduce first cost. This provides the added benefit of deeper unloading and better efficiency at low heating loads.
 - Backup generators need to be sized to support C-H operation and possibly trickle-charge boiler operation, in the event of an electrical power failure. Because of the chiller-heater's COP advantage and trickle-heater's smaller size relative to electric resistance auxiliary heating, the backup generator(s) capacity may be less when N+1 chiller-heater redundancy is chosen. Trickle-charge electric boilers will typically require significantly less capacity than full auxiliary electric boilers.

Cooling Redundancy. Many buildings do not require cooling redundancy; they can ride through a partial or full loss of cooling until repairs or contingency (rental) cooling solutions are available. The TES inherently provides some level of redundancy, particularly if the base system has multiple refrigeration units. If one unit fails the other units can be run extra hours to charge the TES and meet the cooling load.

- That said, N+1 cooling units and/or pumps may be installed for full redundancy.
 - If N+1 redundancy is required, the base number of AWHPs may be modified to reduce installed cost.

For example: If the base system is designed with one unit, the redundant unit and its supporting infrastructure will double the base installation first cost.

If instead the base design has two 50 percent capacity units, a redundant unit will only be 50 percent of the base resulting in less total installed capacity, which may reduce first cost.

TES Redundancy. The TES tanks are likely the most reliable component in the system. They have proven to be extremely trouble free. There are a few design precautions that can be taken to minimize the impact of a rare problem.

- Control device failure is the most likely cause of TES malfunction. High quality sensors along with annual control calibration and testing are the best insurance against control issues.
- The tanks can be piped and isolated with manual valves in groups of 1/3 or 1/4 of the total capacity, so that a subset of tanks can be isolated for repairs, leaving sufficient capacity available to support cooling or heating.
- Incremental tank capacity can be installed. The only downside to additional TES capacity is the incremental first cost and space requirements.
- Beyond the redundancy provided, additional TES capacity improves system performance and efficiency. This additional capacity also supports future changes in building usage that may benefit from the additional TES capacity.

Contingency Connections: Including equipment piping stubs and electrical connections in the heating and cooling systems to enable the quick connection of a rental unit costs very little - making it a wise investment. Some equipment rental agencies will pre-survey buildings to determine and record all the components required to connect a temporary unit. This helps speed the delivery of equipment if required.

DESIGN STEPS OVERVIEW

Consult with a Trane® representative for assistance and to validate initial SSHP sizing criteria.

1. Establish building design criteria including building cooling and heating loads.
 - Design days peak and 24-hour load profiles
2. Chiller-heater and TES sizing for heating,
 - Peak Load
 - 24-Hour Load – cumulative heating energy
3. Air-to-water heat pump and TES sizing for cooling.
4. Evaluate AWHP capacity for heat collection.
5. Trickle-charging boiler sizing.
6. Obtain manufacturer rated selections for all equipment to validate design intent. C-H and AWHP units that contain freeze protection fluids are rated in accordance with AHRI® 550/590 because freeze protection fluids are outside the scope of the certification program.

BUILDING DESIGN CRITERIA

Determine the system design data listed in the following tables. This is the basic building information required to begin the SSHP design process.

Job information is used to identify the specifics of the building. Building type and the location data for appropriate weather data can be used along with generic ASHRAE® 90.1/Pacific Northwest National Laboratory load curves to help generate an initial generic building load profile. This can be especially useful in early economic analysis.

Table 1. System design data

Job Information		
	Data values (example data shown)	Notes
Project name	SSHP application guide example	
Building type	Office	Office, school, high rise apartment, hotel
Country	USA	
State/Province	Wisconsin	
City	La Crosse	

Building load design parameters and design day 24-hour loads are required to properly size the system components including, chiller-heaters, air-to-water heat pumps, thermal energy storage, trickle-heaters; as well as optional auxiliary boilers, dedicated heat recovery units and/or air-cooled chillers. For proper sizing and evaluation of equipment such as a dedicated heat recovery unit an 8,760-hour data is recommended.

Table 2. Building load design parameters

	Data Values (Example Building Data Shown)	Notes	
Cooling Design Day OAT DB – (2%, 1% or 0.4%) (°F)	88.6	³Ambient design and extreme temperature data is required to evaluate the need for trickle-charging boilers and/or backup heating equipment. Ensure selected condition meets the requirements of the owner and jurisdiction.	
Heating Design Day OAT DB – 99.6% (°F)	-9.2		
Annual OAT DB Extreme Low Temp (°F)	-16.3		
20 Year OAT DB Extreme Low Temp (°F)	-30.6		
50 Year OAT DB Extreme Low Temp (°F)	-36.2		
CD¹ Peak Cooling Load (tons)	960	For sizing cooling equipment	
CD Peak Heating Load (MBh)	0	For sizing equipment for summer space heating requirements. Potential low load operation.	
CD Peak Night Cooling Loads (tons) (e.g., data closets)	0	For sizing ice making equipment and/or dedicate night cooling units	
CD 24-Hour Plant Cooling Loads (tons)	24-hour table	For sizing TES for cooling	
8760-Hour Plant Cooling Loads (tons)		Required for proper sizing of optional dedicated heat recovery and evaluation of low load operation.	
8760-Hour Plant Heating Load (MBh)			
HD² Peak Heating Load (MBh)	6,150	For sizing heating equipment	
HD Peak Cooling Load (tons)	160		for TES & AWHP sizing
HD 24-Hour Plant Heating Loads (MBh)	24-hour table		
HD Cumulative Heating Energy (MBTU)	57,530	Summation of 24-hr Heating loads	
HD 24-Hour Plant Cooling Loads (tons)	24-hour table		
HD Cumulative Cooling Energy (ton-hr)	706	Summation of 24-hr Cooling loads	for AWHP & Trickle-Heater sizing
HD Cumulative Cooling Energy (MBTU)	8,472	Conversion of ton-hr	
HD Recoverable Cooling Energy Ratio	0.85	0.0 - 1.0 – The amount of daily Clg energy that can be recovered into storage or directly for Heating.	
HD Net 24-Hour Supplemental Heating Energy (MBTU)	49,058	= HD Cum Heating Energy - (HD Rec Clg Ratio * HD Cum Clg Energy)	
1 – CD – Cooling Design 2 – HD – Heating Design 3 – Available from ANSI/ASHRAE Standard 169-2020 Climate Data for Building Design Standards via ASHRAE® Fundamentals Handbook on-line – chapter 14.			

The 24-hour load data for the cooling and heating design days are required similar to that shown in the following table. The net loads are the sum of the cooling and heating loads for the given design day. The values at the bottom of the table are the totals of column data.

Table 3. Design day 24-hour loads and daily cumulative energy cooling/heating

Design Day Hour	Cooling Design Day				Heating Design Day			
	CD Cooling Load	CD Heating Load		CD Net Cooling Load	HD Heating Load	HD Cooling Load		HD Net Heating Load
	tons	MBh	tons	tons	MBh	tons	MBh	MBh
1					-628			-628
2					-1,035			-1,035
3					-1,020			-1,020
4					-1,116			-1,116
5					-1,175			-1,175
6					-1,213			-1,213
7	401			401	-1,190			-1,190
8	466			466	-6,150			-6,150
9	632			632	-5,548			-5,548
10	740			740	-4,052			-4,052
11	787			787	-2,489			-2,489
12	847			847	-1,770	85	1,020	-750
13	849			849	-1,593	160	1,920	327
14	931			931	-1,701	155	1,860	159
15	952			952	-1,261	148	1,776	515
16	960			960	-1,044	114	1,368	324
17	952			952	-1,159	44	528	-631
18	858			858	-1,721			-1,721
19	803			803	-2,521			-2,521
20					-3,788			-3,788
21					-4,354			-4,354
22					-5,268			-5,268
23					-5,401			-5,401
24					-333			-333
	Cooling Design Day Cumulative Energy				Heating Design Day Cumulative Energy			
	CD 24-hr Cooling	CD 24-hr Heating		CD 24-hr Net Cooling	HD 24-hr Heating	HD 24-hr Cooling		HD 24-hr Net Heating
	ton-hr	ton-hr		ton-hr	MBTU	MBTU		MBTU
	10,178	0		10,178	-57,530	8,472		-49,058

Hydronic system design parameters are required for unit selection and performance evaluation. Electrified systems using compressor-based heating units benefit from low heating supply water temperatures. Lower temperatures have at least three benefits:

- Higher heating efficiency
- Ability to meet setpoint at lower outdoor temperature for air-source units.
- Somewhat higher heating capacity

For considerations related to various HVAC unit heating temperatures see the August 2022 *Engineers Newsletter* “Heating with Lower-Temperature Hot Water” (ADM-APN084-EN) or contact a Trane® representative.

Table 4. Hydronic system design parameters

	Data Values (Example Data Shown)	Notes
SSHP energy transfer loop fluid type	25% Ethylene Glycol	The chilled fluid to the TES, C-H, & AWHF requires anti-freeze solution. For the base configuration, the SSHP Loop and Chilled Water intermix and so will have the same fluid type.
Chilled water (CHW) supply temperature	42°F	42°F to 44°F is recommended. If the glycol solution is distributed to the AHU and fan coils it may be beneficial to design with as low as 38°F CHW temp.
Chilled water Delta T	15°F	15°F or greater Delta T is recommended, Per ASHRAE Standard 90.1-2019 requirements.
Heating water fluid type	Pure water	For the base configuration, the heating water and SSHP water are isolated and so may be different fluid types. If the design is modified such that the fluids intermix the fluid types will be the same.
Heating water supply temperature	105°F	100°F to 120°F is recommended. Higher supply temperature may not be supported by available Chiller-Heater and/or heat pump equipment. Confirm performance with Trane.
Heating water Delta T	15°F	15°F or greater Delta T is recommended. This balances heating equipment and pump energy use in the system, at the typical supply water temperatures.

THERMAL ENERGY STORAGE PERFORMANCE

Note that Ice Bank® Energy Storage tank performance varies depending upon the fluid temperatures and flows provided to the tanks in each operating mode. To simplify the design process example, typical performance is assumed. That performance is listed in [Table 5](#). Contact a local Trane® representative for help in evaluating the impact of other system operating conditions on TES performance.

Table 5. Thermal energy storage design parameters for Calmac® Ice Bank Energy Storage

	Data values
Calmac TES tank model	*1190C
Per tank cooling discharge capacity (tons)	20
Fluid type	ethylene glycol - 25%
Cooling mode design flow (gpm)	73
Cooling mode design pressure drop (ft)	30
Cooling charging period (hr.)	10
Per tank cooling energy storage (ton-hr)	†150
TES charging / dispatching (freezing) Delta T (°F)	6.5
TES charging supply termination temp (°F)	24
Per tank heating dispatch capacity (tons)	20
Per tank heat energy storage (MBTU)	†2,100
Dispatch mode design flow (gpm)	73
Dispatch mode design pressure drop (ft)	30
<p>* For alternate tank performance, contact a local Trane® representative. † The available TES cooling and heating energy storage may be different as a result of differing rates of energy demand from the tanks when discharging for cooling and dispatching for heating.</p>	

Example Equipment Selection Process

CHILLER-HEATER SELECTION

The C-H unit size and quantity are selected based on the peak heating load.

1. Determine the initial number and nominal size of the C-H units.

- A. Divide the "heating design day load (MBh)" by the desired number of C-H units to get the per unit "peak heating output (condenser)". Work with a local Trane® representative for available unit capacities and performance.

- At least two units are recommended to meet peak heating load to provide for low load capacity turndown. This does not include redundant unit(s).

For the building example with 6,150 MBh peak heating load; Four (4) model RTWD 180 chiller-heater units per Table 6 would meet the load, providing 1,586 MBh of heating capacity each for a total of 6,344 MBh.

Four units would provide good heating capacity turndown, as well as potentially acceptable redundancy, providing 75 percent of the peak heating load with one unit out-of-service.

- B. Record the unit sizing and performance in chiller-heater schedule.

Table 6. Chiller-heater (C-H) performance, *RTWD 180

105°F supply heating temperature at 24°F LCHW	
HD cond peak heating output, MBh	1,586
HD evap input at peak heating output (evap), tons	97
Power draw, kW	123.2
Efficiency, COP	3.77
Condenser	
Cond leaving temp, °F	105
Cond entering temp, °F	90
Design flow, gpm	213
PD at design flow, ft of H ₂ O	4.2
Min flow, gpm	190
PD at min flow, ft of H ₂ O	3.4
Evaporator	
Cond leaving temp, °F	24
Cond entering temp, °F	30
Design flow, gpm	407
PD at design flow, ft of H ₂ O	17.9
Min flow, gpm	348
PD at min flow, ft of H ₂ O	12.8
* Application guide example values Important: All Heating Capacity data is for the Application Guide example only. Validate all performance with manufacturer's rated unit submittal data.	
Note: Design Best Practice is to design with unit flows <i>at least</i> 10% above and below the minimum and maximum listed flows respectively, to allow for variations during normal operation. Product application, options and continuous product improvement impacts the <i>as applied</i> unit flow range. Flow range must be verified with rated product selection submittals.	

2. TES tanks sizing.

The SSHP TES is determined based on the greatest capacity required to meet each of the:

- Heating peak load
- Heating design day 24-hr cumulative energy
- Cooling peak load

- A. The design process evaluates the number of TES tanks required to meet each load category based on the related components involved in meeting the loads. Enter the minimum number of tanks required to meet each load into [Table 10](#) shown in the tank evaluation section on [p. 42](#). The greatest number of tanks from any of the calculations will be the number required for the job.

3. Heating peak load.

TES capacity. The heating peak load-based TES tank size and minimum heating quantity are selected based on the chiller-heater total evaporator energy draw (cooling input in tons) at the selected unit peak heating load.

- A. Multiply the per chiller-heater cooling input at peak heating by the quantity of chiller-heaters required to meet the peak heating load.
- B. Divide the required cooling capacity by the TES per tank dispatch capacity and round up to the next whole number of tanks.

$$\text{TES Tank Qty} = \text{Chiller-Heater Qty} \times \frac{\text{HD Evap Input (tons)}}{\text{TES Tank Dispatch Rate (tons)}}$$

Note: This example uses the full heating capacity of the selected C-H to determine the HD Evap Input. This provides ~15 percent heating capacity margin in the TES. Using the HD Evap Input based on the peak heating load would reduce TES cost.

- C. For the application guide example with the four (4) chiller-heaters with a cooling capacity of 97 tons the required TES dispatch capacity is 388 tons. Dividing by the typical tank capacity of 20 tons, the required number of tanks to meet the peak heating load is 20 tanks.

$$\text{TES Tank Qty} = 4 \text{ Chiller-Heaters} \times \frac{97 \text{ tons}}{20 \text{ tons}} = 19.4 \text{ tanks} = 20 \text{ tanks}$$

- D. Record the minimum number of tanks for the heating peak load into [Table 10](#).

Note: Per tank dispatch capacity varies based on the tank flow and temperature conditions. The local Trane® representative can provide TES performance and alternative conditions.

4. Heating design day 24 hr. cumulative energy TES capacity.

The TES tank size and minimum quantity are selected based on either the full or net heating design 24-hour cumulative energy requirement (MBTU) and the corresponding chiller-heater cumulative evaporator cooling input (ton-hr.).

Note: If there is a possibility that the cooling load does not occur or is not recovered for any reason and the TES is sized based on the NET value. The TES may run out of energy to dispatch resulting in a lack of heating. The designer must consider this possibility when selecting the TES capacity required to meet the heating design day cumulative energy requirement.

5. To determine the required TES tank cumulative energy for dispatch.

- A. From the design day data determine the building HD 24-hr heating cumulative energy and select either the FULL or NET energy. See [Table](#) for 24-hour loads.
- B. Multiply the 24-hr cumulative energy by the ratio of the chiller-heater's design heating cooling input and the heating output.

$$\text{HD C-H Cumulative Clg Input Energy (MBTU)} = \text{HD C-H Cumulative Htg Energy (MBTU)} \times \frac{\text{C-H Clg Input (tons)} \times 12 \text{ (MBh/ton)}}{\text{C-H Peak Htg Output (MBh)}}$$

6. To determine the required number of TES tanks to support the cumulative energy requirement.

- A. Divide the HD cumulative cooling input by the TES per tank heating dispatch energy capacity and round up to the next whole number of tanks.

$$\text{TES Tank Qty} = \frac{\text{HD C-H Cumulative Clg Input Energy (MBTU)}}{\text{TES per Tank Dispatch Energy (MBTU)}}$$

- B. Record the minimum number of tanks for the cumulative heating energy in [Table 10](#).

For the building example the conservative approach is taken and the TES tank quantity to meet the heating cumulative energy requirement will be based on the FULL HD 24-hr heating energy, not decreased by the potential recovered heat from the cooling load.

7. Determining the HD C-H cumulative clg input energy.

- A. From [Table](#), the full HD 24-hr heating cumulative energy is 57,530 MBTU. From [Table 6](#), chiller-heater performance for the design heating output of 1,586 MBh the evaporator requires a cooling input of 97 tons.

$$\text{HD C-H Cumulative Clg Input Energy (MBTU)} = 57,530 \text{ MBTU} \times \frac{97 \text{ tons} \times 12 \text{ MBh/ton}}{1,586 \text{ MBh}} = 42,222 \text{ MBTU}$$

8. Determining the HDC tank quantity.

- A. Divide the HD cumulative clg input energy by TES per tank heat energy storage.

$$\text{TES Tank Qty} = \frac{42,222 \text{ MBTU}}{2,100 \text{ MBTU/Tank}} = 20.1 \text{ Tanks} = 21 \text{ Tanks}$$

- B. Record the minimum number of tanks for the cumulative heating energy in [Table 10](#).

Note: Per tank storage capacity varies based on the tank flow and temperature conditions. The Trane® representative can provide TES performance and alternative conditions.

AIR-TO-WATER HEAT PUMP SIZING

For the base configuration, the AWHP units are sized to meet the most demanding of the cooling and heat collecting modes.

In a partial storage cooling system, the chiller is typically sized to carry 50 percent to 70 percent of the peak cooling load with the TES providing the remaining capacity. For the application guide example, the chiller will be selected to provide 60 percent of the peak cooling capacity and the ice to provide 40 percent of the peak cooling capacity.

Note: The local Trane® representative has software tools they can use to assist with the sizing of the AWHP and TES based on the specific building load curves.

Cooling Sizing

1. AWHP units size and number to serve the cooling loads.

- A. Multiply the peak cooling load by 0.60 to calculate the AWHP total cooling capacity.
- B. Divide the AWHP total cooling capacity by the desired number of AWHP units to get the per unit cooling capacity.
 - A key component of determining the number of units is the available capacity range of the equipment. The Trane® model ACX unit is available in nominal cooling capacities ranging from 140 to 230 tons.
 - At least two units are recommended to meet peak cooling load to provide for low load capacity turndown. This does not include redundant unit(s).

$$\frac{\text{AWHP Unit Cooling Mode Capacity}}{\text{Mode Capacity}} = \frac{\text{CD Peak Cooling Load (tons)} \times 0.60}{\text{Quantity of AWHP Units Desired}}$$

2. TES Tank quantity to serve the peak cooling load.

- A. Multiply the peak cooling load by 0.40 to calculate the TES total cooling capacity.
- B. Divide the TES total cooling capacity by per tank cooling discharge capacity from [Table 7](#) and round up to the next whole number to determine the quantity of tanks needed.

$$\frac{\text{TES Tank Cooling Mode Quantity}}{\text{Mode Quantity}} = \frac{\text{CD Peak Cooling Load (tons)} \times 0.40}{20 \text{ tons/tank}}$$

- C. Record the peak cooling load number of tanks and cooling performance in [Table 10](#).
- D. Request a manufacturer's rated selection for the selected units.

Note: In addition to the previously stated TES performance design assumptions these selections assume the night cooling load is less than 10 percent of the selected chillers' ice making capacity and an available charge time of ten (10) hours or greater. If there is a higher night load or shorter available charge time consult with the Trane® representative for appropriate alternative sizing strategies.

For this example: The design cooling minimum AWHP and TES sizing with a 960-ton cooling load would be:

1. Determine the AWHP per unit cooling capacity.

- A. Based on selections with a 47°F CHW leaving temperature, its decided that four (4) ACX 160 units will be applied as they have a capacity of 140.5 tons which is very close to the estimated building load requirement of 144 tons. See [Table 7](#) and [Table 8](#).

$$\frac{\text{AWHP Unit Cooling Mode Capacity}}{960 \text{ tons} \times 0.60} = \frac{144 \text{ tons}}{4} = 144 \text{ tons}$$

- B. This sizing is approximate and does not take into account needs such as redundancy, safety factors, night loads or alternate unit operating modes such as “quiet operation”.

2. Determine the TES cooling capacity and tank quantity.

- A. Based on the total cooling capacity with a blended 42°F CHW supply temperature to the system and a per tank cooling discharge capacity of 20 tons / tank, this would require the TES to provide 384 tons using twenty (20) tanks.

$$\frac{\text{TES Tank Cooling Mode Quantity}}{960 \text{ tons} \times 0.40} = \frac{19.2 \text{ tanks}}{20 \text{ tons/tank}} = 19.2 \text{ tanks} = 20 \text{ tanks}$$

- B. Record the minimum number of tanks for the cooling performance in [Table 10](#).
- C. Request a manufacturer's rated selection to verify it meets the required performance.

Table 7. Air-to-water heat pump cooling mode and thermal energy storage tank capacities selection request

System load	
Peak cooling load	960 tons
Return/supply CHWT	57°F to 42°F
AWHP capacity	
Total cooling capacity	576 tons
Design day OAT	95°F
Ent/Lvg CHWT	57°F to 47°F
Proposed number of units	4
Cooling capacity	144 tons
TES tank capacity	
TES cooling capacity	384 tons
Proposed number of tanks	20
Ent/Lvg blended CHWT	47°F to 42°F

Table 8. Air-to-water heat pump performance, ACX 160

95° OAT DB	
Cooling capacity	140.5 tons
Efficiency	10.3 EER
Fluid flow	390 gpm
PD at flow	24.0 ft of H ₂ O
5°F OAT DB	
Heat collection capacity	876 MBh
Efficiency	2.56 COP
Lvg fluid temp	80°F
Fluid flow	261 gpm
PD at flow	8.8 ft of H ₂ O

This sizing is approximate and does not consider needs such as redundancy, safety factors, night loads or alternate unit operating modes such as “quiet operation.”

Air-to-Water Heat Pump Heating Capacity Verification for Thermal Energy Storage Energy Collecting Mode

- Determine if the AWHP units selected to meet the cooling load provides sufficient heating capacity in the operating time allowed to collect enough heat energy to meet the heating energy storage requirement. This confirmation must consider the:

- Size and quantity of AWHP units
- Heating design day OAT
- Hours per day available to run
- Heating mode defrost derate

- Divide the HD cumulative heating energy (MBTU) by the number of hours the AWHP is expected to run on a heating design day, or the coldest day the AWHP can run, to get the HD hourly energy collection requirement.

The maximum possible time per day is 24 hours, however a lower number may be specified to account for electrical demand management or other operating time limits.

$$\text{HD Hourly Energy Collection (MBh)} = \frac{\text{HD Cumulative Heating Energy (MBTU)}}{\text{HD AWHP Operating Hours}}$$

- Divide the hourly energy collection by the quantity of AWHP selected based on the cooling load; and then multiply by the AWHP unit energy collection by the defrost capacity factor for the design day OAT in [Table 9](#), to get the AWHP unit heating capacity requirement.

$$\text{HD AWHP Minimum Required Heating Capacity (MBh)} = \frac{\text{HD Hourly Energy Collection (MBh)}}{\text{Quantity of AWHP units}} \times \text{AWHP Defrost Capacity Factor}$$

Table 9. Air-to-water heat pump heating defrost capacity factor

Design Day OAT (°F)	AWHP Defrost Capacity Factor
>47	1 (no derate)
35-47	1.05-1.01
20-34	1.11~1.05
5-20	1.18~1.11
0-5	1.25~1.18

- C. If the selected AWHP energy collection capacity does not meet the system requirement, consider upsizing the AWHP units or increasing the number of units.
- Record the unit sizing and performance in the AWHP heating mode (energy collection) schedule.
 - Request a manufacturers rated selection for the selected unit from the manufacturer to verify it meets the required performance.

For the application guide example: The AWHP heating capacity to meet the 42,222 MBTU Heating design C-H cumulative clg input energy (MBTU) requirement is:

1. The HD hourly energy collection (MBh) capacity is 2,880 MBh.

- A. A heating operating time of 20 hours is used to allow for time during the day when the AWHP may not be heating because of potential control or operating limitations.

$$\text{HD Hourly Energy Collection (MBh)} = \frac{42,222 \text{ MBTU}}{20 \text{ Hours}} = 2,111 \text{ MBh}$$

- B. This sizing is approximate and does not take into account needs such as redundancy, safety factors, night loads or alternate unit operating modes such as “quiet operation”.

2. The AWHP heating capacity (MBh) required is 850 MBh.

- A. Four units are specified.
- B. A defrost derate of 1.18 is applied assuming the ACX will operate down at an OAT of 5°F.

$$\text{HD AWHP Minimum Required Heating Capacity (MBh)} = \frac{2,111 \text{ MBh}}{4} \times 1.18 = 623 \text{ MBh}$$

From the selection data in [Table 8](#), each ACX 160 can produce 876 MBh of heat at 5°F OAT and leaving heating temp of 80°F. This confirms that the ACX 160 units will meet the required heating capacity to collect enough energy into the TES on a heating design day.

Note: One practical design principle applied to the example sizing. The AWHP can operate down to an outdoor air temperature of 0°F, however since this installation has multiple units there is the possibility of a “micro-climate” around the units because of outdoor coil air recirculation. Therefore, for the purpose of the example the AWHPs will be sized around a 5°F localized OAT.

Evaluate the Required Thermal Energy Storage Tank Quantity

The TES Capacity is sized to meet the most demanding of the cooling and heat loads, both peak and daily cumulative.

1. From previous design calculations enter results from the prior TES tank quantity calculations into [Table 10](#), select the largest number of tanks required and calculate the TES peak load and energy storage capacity.

Table 10. Thermal energy storage tank quantity evaluation

Load Category	Building design peak load, & 24-hr cumulative load	Selected minimum number of tanks	Peak load supported by total tank quantity	Energy storage supported by total tank quantity
Heating design day – heating peak load (MBh)	6,150*	20*		
Heating design day – 24-Hr TES heating energy (MBTU)	42,222	21		
Cooling design day – cooling peak load (tons)	960	20		
Job number of tanks[†]		21		
* - Application guide example values † - Select the highest number of tanks for each load				

- A. Request a manufacturer's rated selection for the selected tanks to verify they meet the required performance per [Table 11](#). AHRI Guideline T provides additional information when specifying thermal storage equipment.

Note: The only downside to installing more than the minimum number of tanks for any operating mode is the incremental first cost. More tanks provide several benefits including:

- Heating and cooling demand safety factor when the building operating schedule is unsure or may change in the future.
- The ability to ride through longer periods of extreme cold that limit AHP units' operation without operating higher carbon backup heaters or trickle-heater boilers. Some owners may choose to install two or three days of heat storage capacity for this reason.
- Greater electrical demand avoidance/management opportunities particularly during the cooling season and to leverage real-time electric rates.
- More efficient cooling and heating. A greater number of tanks results in more moderate system operating temperatures and therefore higher C-H and AHP efficiency.

Table 11. Thermal energy storage tank performance

TES selection input	
Note: TES must meet or exceed all capacity requirements	
Unit	TES-1
Manufacturer	Trane
Model	1190C
Quantity	21
Fluid type	
System schematic	
24-hour design day heating and cooling load profiles	
Maximum allowable pressure drop - ft H ₂ O	
Cooling - discharge	
TES cooling discharge rate - tons	
TES entering fluid temperature - °F	57
TES cooling discharge flow - gpm	
TES cooling minimum energy storage - ton-hr	
Cooling - charge	
TES cooling charge rate - tons	
TES entering fluid temperature - °F	25
TES cooling charge flow - gpm	
Heating - dispatch	
TES heating minimum required dispatch rate - MBTU/hr	
TES entering fluid temperature - °F	24
TES heating dispatch flow - gpm	
TES heating minimum energy storage - MBTU	
Heating - collection	
TES heating collection rate - tons	
TES entering fluid temperature - °F	39
TES heating collection flow - gpm	

TRICKLE-HEATER SELECTION

In the base configuration the trickle-heater is sized to support the larger of two heating loads; the design day energy collection load, or the ACX defrost load compensation.

1. Design day energy collection load.

- A. Divide the HD C-H cumulative clg input energy (MBTU) by the number of hours the trickle-heater is expected to run on the design day.
 - The maximum possible time per day is 24 hours, however a lower number may be specified to account for electrical demand management or other operating limits. Using a lesser time builds a safety factor into the trickle charging operation.

$$\text{Trickle-Heater Design Energy Collection Capacity (MBh)} = \frac{\text{HD C-H Cumulative Clg Energy (MBTU)}}{\text{HD Trickle-Heater Operating Hours}}$$

2. Defrost compensation heating.

The SSHP can use the trickle-heater to compensate for the cooling effect of the defrost cycle and maintain the operation of the AWHP water temperatures in an acceptable range during a defrost cycle. In this case the trickle-heater must be sized to offset the defrost cycle cooling effect of one circuit for the largest AWHP unit in the system.

- A. The design intent is to keep the ACX entering water temperature 10°F higher than the minimum defrost cycle entering temperature for the AWHP units. (Default 60°F, assuming the minimum entering temp to the AWHP in defrost is 50°F).

This is required since the other circuit or other units may be operating in the heating mode and their heating mode minimum entering water temperature must be maintained.

- B. The ACX defrost cooling effect, at the worst case condition of 0°F OAT is approximately equal to the nominal cooling capacity of the ACX unit at 42°F leaving water temperature and 95°F OAT.

This is because, for the ACX unit, one circuit operating in defrost at 0°F OAT can produce approximately the same cooling capacity as the unit's nominal cooling capacity.

$$\text{Trickle-Heater Defrost Compensation Capacity (MBh)} = \text{AWHP Unit Nom Clg Cap (tons)} \times 12 \text{ (MBh/ton)}$$

- C. The following data is used in the trickle-heater schedule.
The total heating capacity as the higher of the two values above.
- D. Request a manufacturers rated selection for the selected unit from the manufacturer to verify it meets the required performance.

Table 12. Trickle-heater performance

Trickle-Heater Selection Input										
Input								Output		
Unit	Manuf.	Model	Energy source	Qty	Total heating capacity Mbh	Leaving fluid temp °f	Entering fluid temp °f	Power input Kw	Design fluid flow Gpm	PD at design flow Ft H ₂ O
TKLC-1			Electric			60	50			

For the application guide example:

1. From previous calculations the HD C-H Cumulative Clg Input Energy is 42,222 MBTU.

- A. As with the ACX heating capacity for TES energy collection this example will assume a maximum of 20 hours of operation to allow for operation and control delays or limitations.

$$\text{Trickle-Heater Design Energy Collection Capacity (MBh)} = \frac{42,222 \text{ MBTU}}{20 \text{ hours}} = 2,111 \text{ MBh}$$

- B. Since the nominal cooling capacity of an ACX 160 units is 147 tons

$$\text{Trickle-Heater Defrost Compensation Capacity (MBh)} = 147 \text{ tons} \times 12 \text{ MBh} = 1,764 \text{ MBh}$$

- C. The greater of the two values is 2,111 MBh so that will be the specified capacity of the trickle-charge boilers.

Supporting Tools

Trane® account managers have the software tools available to them to assist in the design of SSHP systems. As a part of its analysis, it sizes the chiller-heaters, air-to-water heat pumps, and thermal energy storage in the SSHP system using a load profile scaled from ASHRAE® 90.1 building models or accepting custom load profile.

Modes of System Operation

The purpose of this section is to help the designer better understand the operation of the SSHP system. This section provides figures and descriptions of some of the modes possible with the base configuration. Other modes are possible and maybe implemented depending on the building requirements.

Note that, when operating, the chilled and hot water loops operate the same regardless of the rest of the plant operation.

Example SSHP Plant Modes

1. Cooling only (chilled water distribution loop operation)

- A. AWHP cooling
- B. TES cooling (discharge)
- C. AWHP + TES (discharge)
- D. AWHP ice making + TES charging (night cooling)
- E. TES cooling + AWHP heating for collection

2. Heating only (heating water distribution loop operation)

- A. C-H heating with TES energy dispatch (freezing)
- B. C-H heating with AWHP heating + TES energy exchange
- C. C-H heating with trickle-heater + TES energy exchange

3. Cooling and heating (chilled and heating water distribution loops operation)

- A. C-H heating with TES energy exchange
- B. C-H heating with AWHP cooling
- C. C-H heating with trickle-heater + TES energy exchange

4. TES charging – ice making

- A. TES charging (freezing) with AWHP in ice making

5. TES heat collection – ice melting

- A. TES collection (melting) with AWHP heating
- B. AWHP defrost
- C. TES collection (melting) with trickle-heater boiler

Figure 9. Chilled and hot water distribution loops

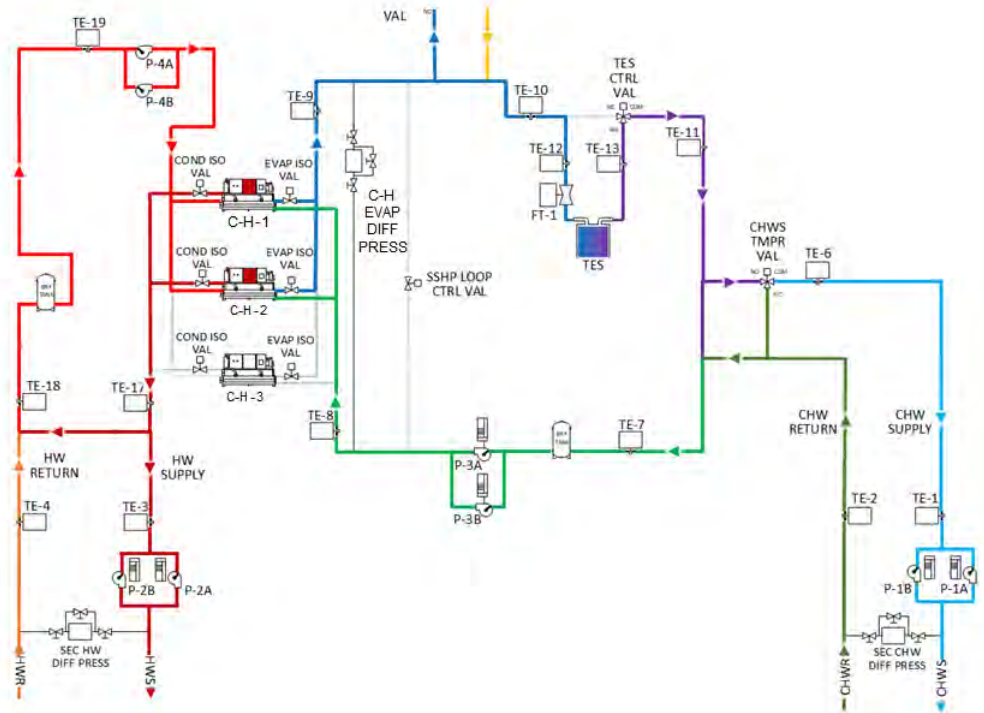


Figure 9 shows the chilled and hot water distribution loops which, when enabled, operate similarly in the various SSHP plant modes. They are designed and operated based on standard engineering practices. These would include:

- Design and operation in compliance with ASHRAE® 90.1 section 6.5 requirements. Including but not limited to:
 - 6.5.4.2 – Variable flow with flow or minimum differential pressure control
 - 6.5.4.3 – Simultaneous heating and cooling limits
 - 6.5.4.4 – Chilled and hot water reset
 - 6.5.4.7 - Chilled water coil selection, 15°F delta T
 - Energy optimization strategies such as critical valve pump pressure reset could be applied and maybe required by codes.
- Although the distribution loops could be designed for constant flow (three-way control valves on AHUs coils) it will be more common for the chilled and hot water distribution loops to be variable flow (two-way control valves on AHU coils).
- Chilled water distribution loop pumps speed and staging controlled to a differential pressure setpoint.
 - Optimization strategies such as critical-valve pump pressure optimization and/or chilled/hot water temperature reset can be applied as appropriate for the chilled or hot water distribution and air-side system design.
- The chilled water control valve in the chilled water distribution system modulates to maintain a minimum distribution water temperature in various SSHP plant operating modes.

Figure 10. Cooling only: air-to-water heat pump cooling (mode 1A)

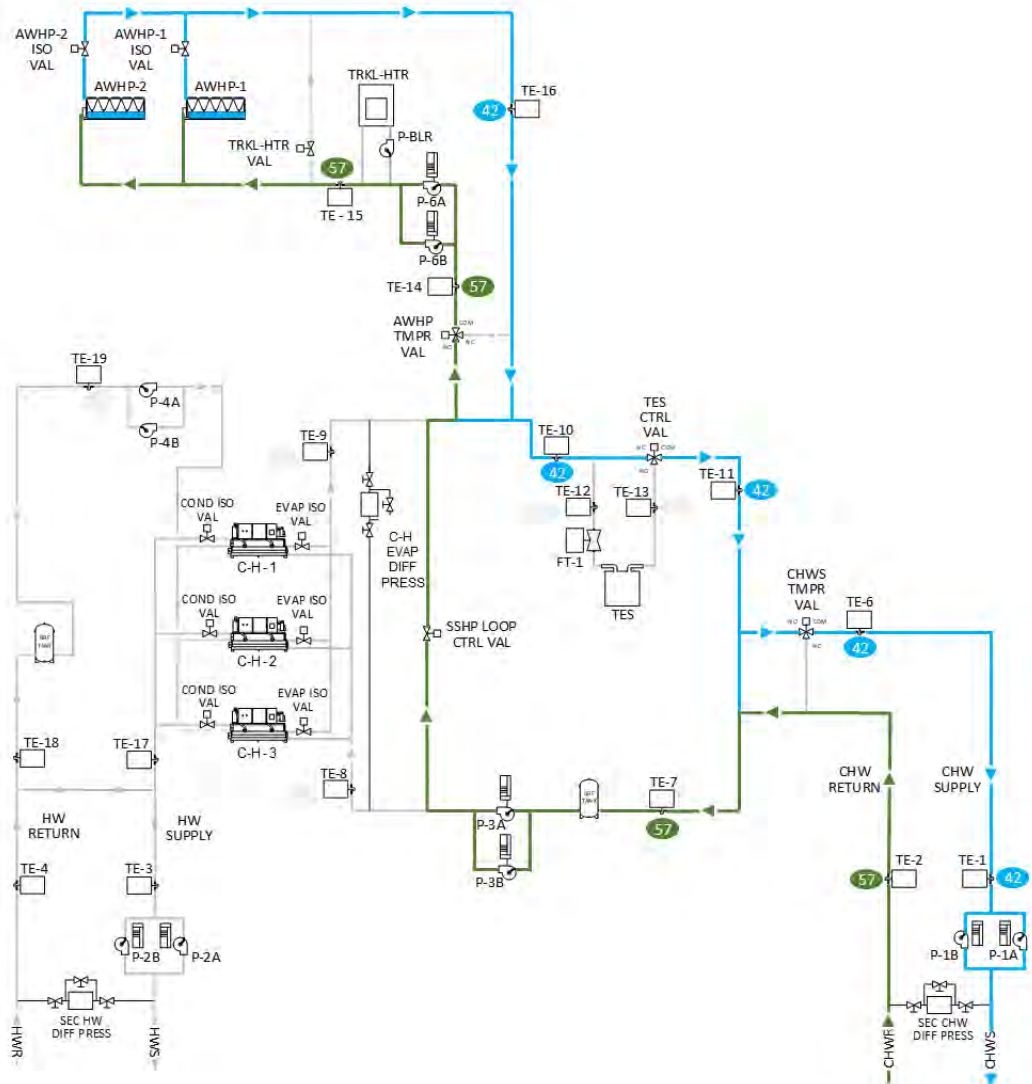


Figure 10 shows the system operating in a cooling only mode with cooling supplied by the AWHP units. Units may be sequenced on and off to meet the cooling load.

Component control includes:

- Chilled water distribution loop pumps speed and staging controlled to a differential pressure setpoint.
 - Energy optimization strategies such as critical valve pump pressure reset could be applied and maybe required by codes.
- SSHP loop pumps speed and staging controlled to provide slightly greater flow than required by the chilled water distribution loop to keep slight positive flow through the decoupler.
- AWHPs operated in the cooling mode with chilled water setpoint at the required system chilled water temperature.
- AWHP units are staged to provide the desired chilled water system supply temperature.
- AWHP loop/unit pumps are controlled to constant flow of the heat pump cooling design flow rate. This is because the variable distribution design flow rate will typically be close to or less than the chillers' minimum allowed flow precluding further reduction in unit flow.
Optionally, if the chillers' minimum allowed flow is less than 60 percent of design cooling flow, implementation of variable primary/variable secondary flow control logic could be considered.

Figure 11. Cooling only: thermal energy storage cooling/discharge (mode 1B)

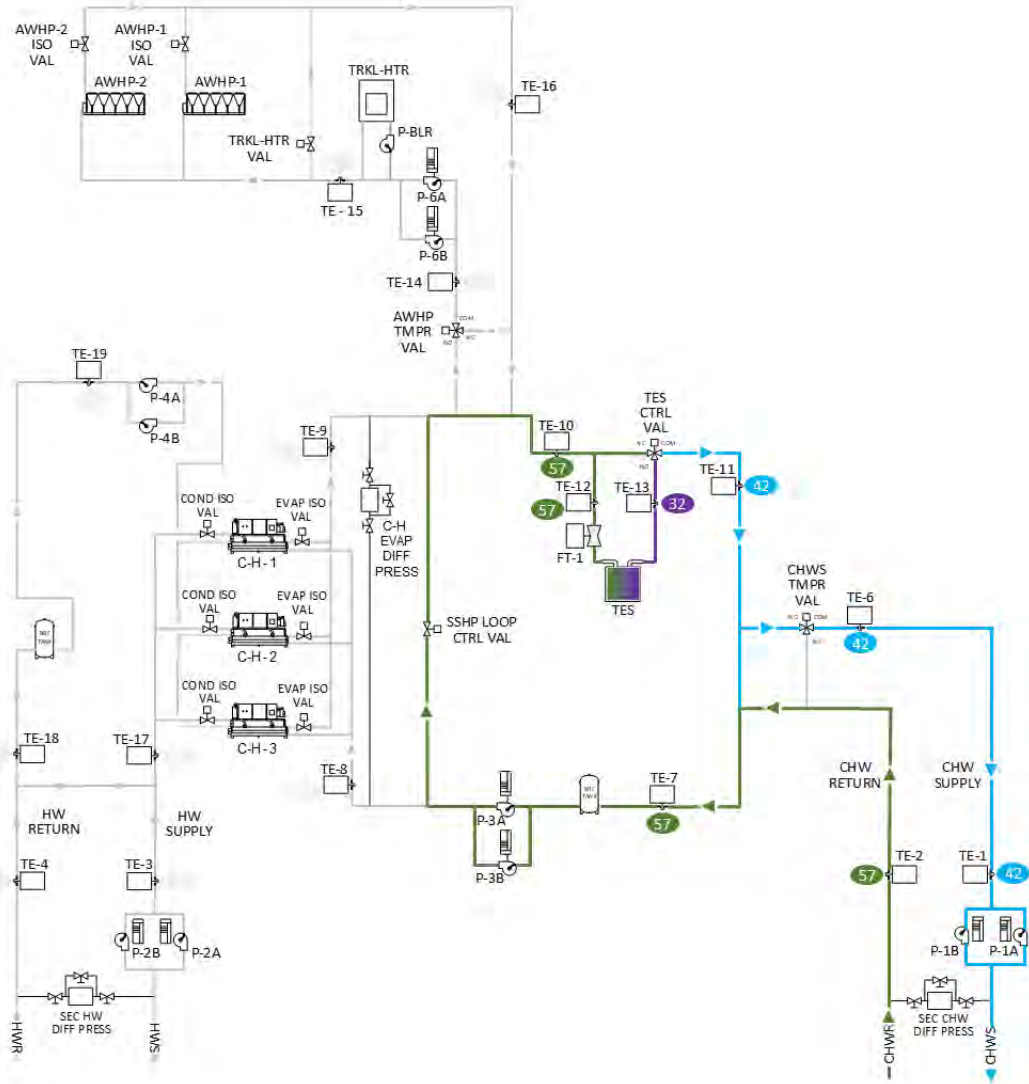


Figure 11 shows the system operating in a cooling only mode with cooling supplied by the TES thermal batteries. In the summer, this mode could be used for electrical demand management or to meet very low cooling loads to eliminate chiller low load cycling. In the heating season, it is an energy recovery mode with energy collected from the cooling load for later heating use.

Depending on the amount of stored energy required for heating, the air-handler's economizer cooling function must be modulated or disabled to increase the energy collection.

Component control includes:

- Chilled water distribution loop pumps speed and staging controlled to a differential pressure setpoint.
- Energy optimization strategies such as critical valve pump pressure reset could be applied and may be required by codes.
- SSHP loop pump(s) speed and staging are controlled to provide slightly greater than the required cooling distribution flow.
- The TES control valve modulates to provide the chilled water supply water temperature.

Figure 12. Cooling only: air-to-water heat pump + thermal energy storage discharge (mode 1C)

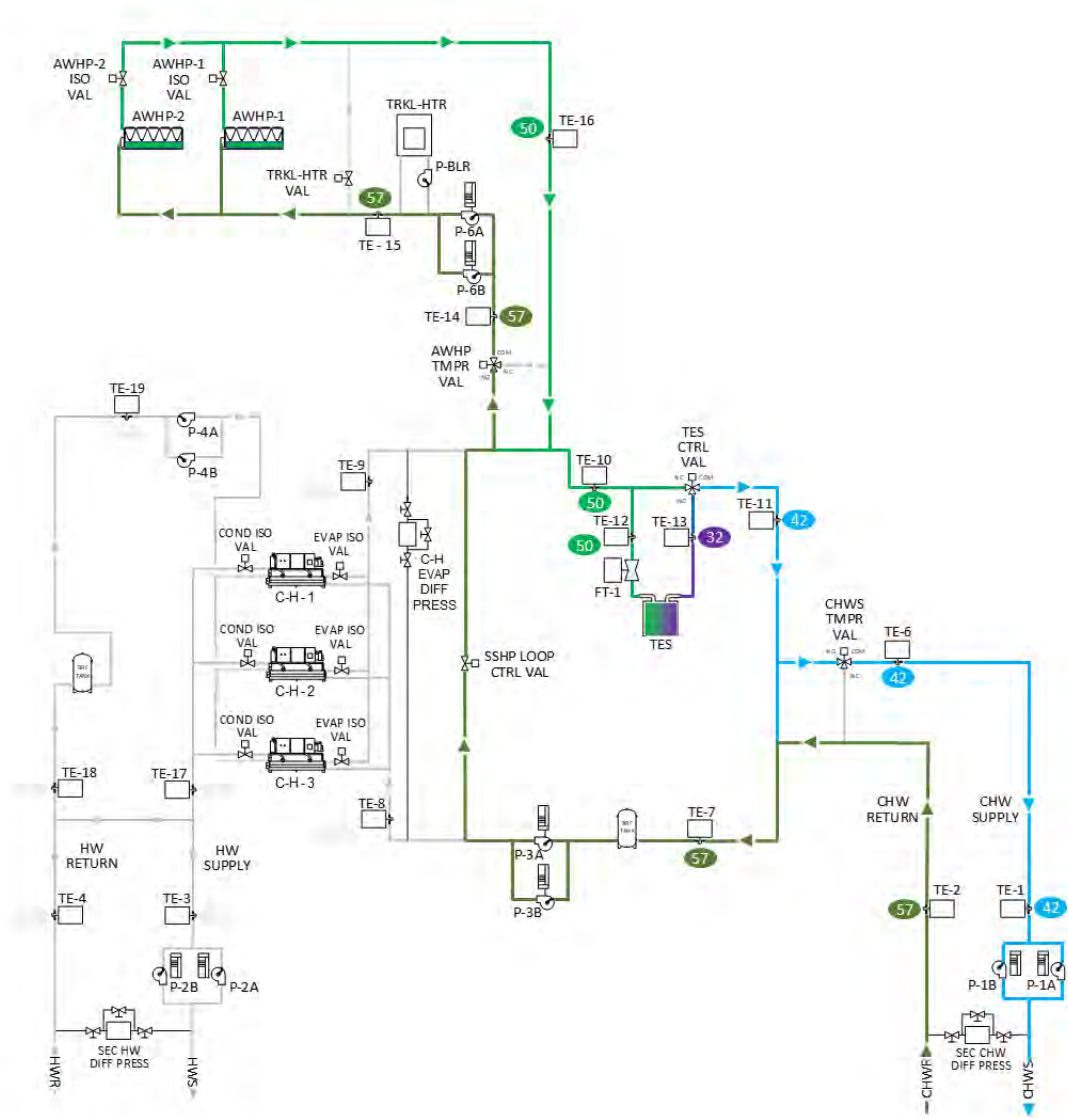


Figure 12 shows the system operating in a cooling only mode with cooling supplied by the AWHPs and TES. In the summer, this mode would be used to meet loads greater than either the AWHP or TES could meet alone. It would also be used for electrical demand management. AWHP setpoint control would use classic thermal storage control and optimization logic, depending on the system requirements.

Component control includes:

- Chilled water distribution loop pumps speed and staging controlled to a differential pressure setpoint.
 - Energy optimization strategies such as critical valve pump pressure reset could be applied and may be required by codes.
- SSHP loop pumps speed and staging controlled to provide slightly greater flow than required by the chilled water distribution loop to keep slight positive flow through the decoupler.
- AWHP loop/unit pumps are controlled to constant heat pump units cooling design flow rate.
- AWHPs operated in the cooling mode:
 - The units chilled water setpoint and/or demand limit setpoint are dynamically reset by the BAS to control the loading of the AWHP units to meet desired building demand and/or TES discharge rate.
 - AWHP units are staged to provide the desired AWHP loop chilled water supply temperature.
- The TES control valve modulates to provide the system chilled water supply water temperature.

Figure 13. Cooling only: air-to-water heat pump + thermal energy storage charge - night cooling (mode 1D)

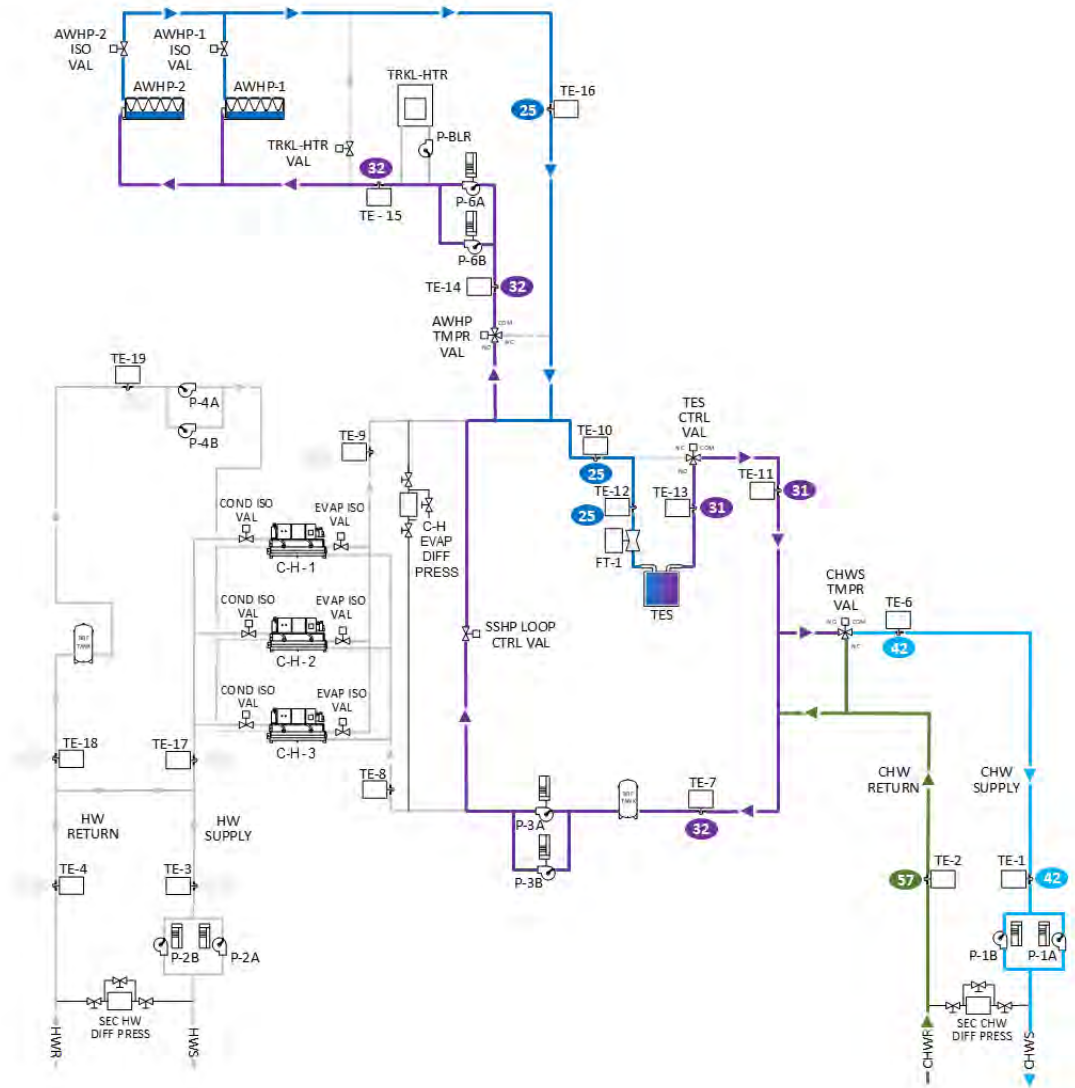


Figure 13 shows the system operating in a cooling only mode with cooling supplied by the AWHPs and TES. This mode is very similar to the cooling only – AWHP + TES cooling mode. The main difference is that the AWHP units are operating in their ice making mode.

This mode is used to charge the TES for cooling when there is a building cooling load to meet, often a “night cooling load.”

Note: If the cooling load exceeds 10 percent of the ice making capacity an alternate form of cooling to meet that load should be considered. High night cooling loads can cause operating problems. Consult with a local Trane® account manager for recommendations on handling high night cooling loads.

Component control includes:

- Chilled water distribution loop pumps speed and staging controlled to a differential pressure setpoint.
 - Energy optimization strategies such as critical valve pump pressure reset could be applied and maybe required by codes.
 - The chilled water control valve in the chilled water distribution system modulates to maintain a minimum distribution water temperature in various operating modes.
- SSHP loop pumps speed and staging controlled to provide slightly greater flow than required by the chilled water distribution loop to keep slight positive flow through the decoupler.
- AWHP loop/unit pumps are controlled to constant heat pump unit cooling mode design flow rate.
- AWHPs operated in the ice making mode.
 - AWHP units are staged on per the system design intent.

Figure 14. Cooling only: thermal energy storage cooling + air-to-water heat pump heating collection (mode 1E)

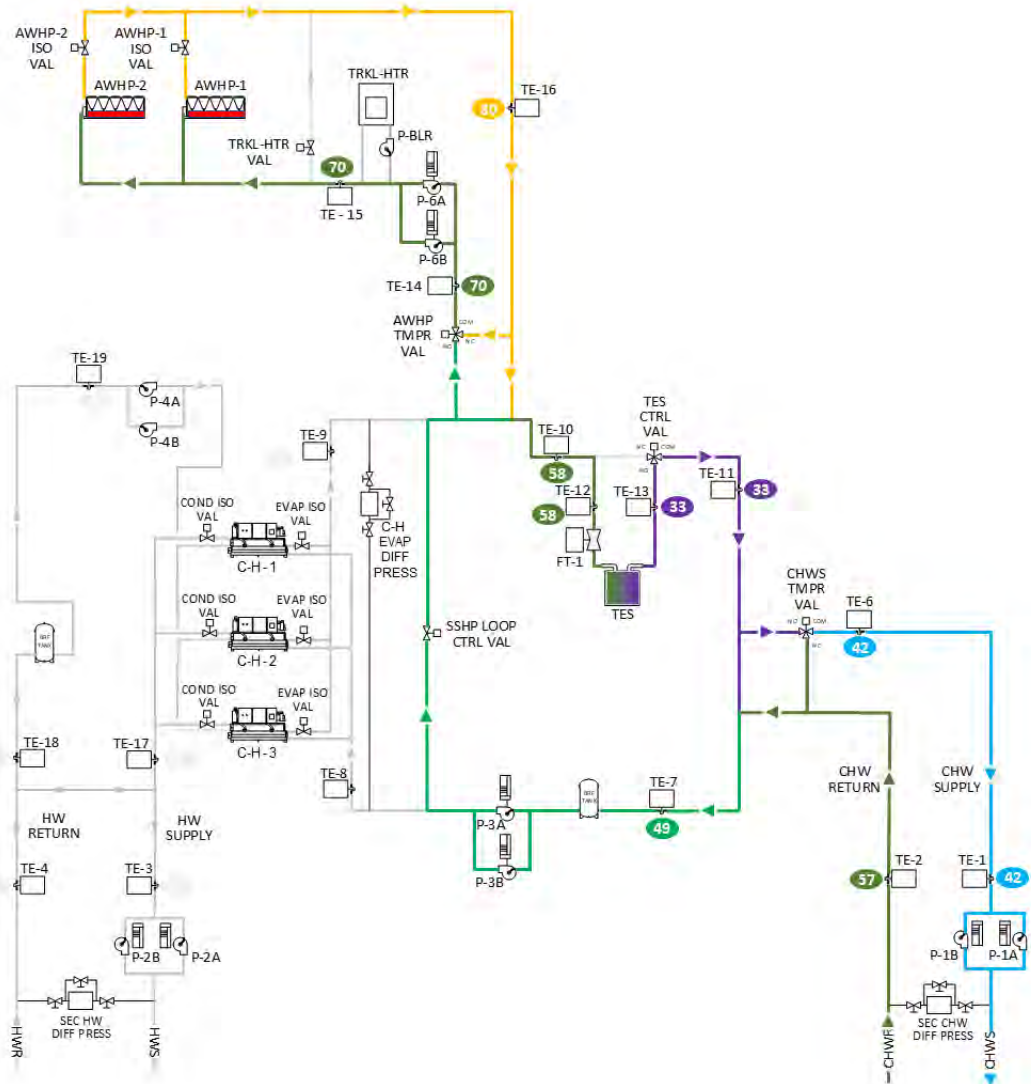


Figure 14 shows the system operating in a cooling only mode with cooling supplied by the TES thermal batteries and the AWHP in its heating mode. The purpose of this mode is to cool the building and collect energy into the TES for later use in building heating. Energy is collected from recovered cooling energy as well as the AWHP(s).

The operation of the AWHP units is controlled by the BAS to the rate and amount of energy collection that will be required to meet the coming day's heating load.

Component control includes:

- Chilled water distribution loop pumps speed and staging controlled to a differential pressure setpoint.
 - Energy optimization strategies such as critical valve pump pressure reset could be applied and may be required by codes.
 - The chilled water control valve in the chilled water distribution system modulates to maintain a minimum distribution water temperature in various operating modes.
- SSHP loop pumps speed and staging controlled to provide the greater of:
 - The chilled water distribution loop flow, to keep slight positive flow through the decoupler.
 - The TES design collecting mode flow.
- AWHP loop/unit pumps are controlled to the constant heat pump unit heating mode design flow rate, depending on the number of units operating.
- AWHPs operated in the heating mode.
 - AWHP units are staged on per the system design intent and the required energy collection rate determined by the BAS.
- The AWHP tempering valve is controlled to maintain the AWHP return heating water temperature as required by the AWHP heating mode. Consult with the manufacturer for unit operating requirements.

Figure 15. Heating only: chiller-heater heating with thermal energy storage dispatching (mode 2A)

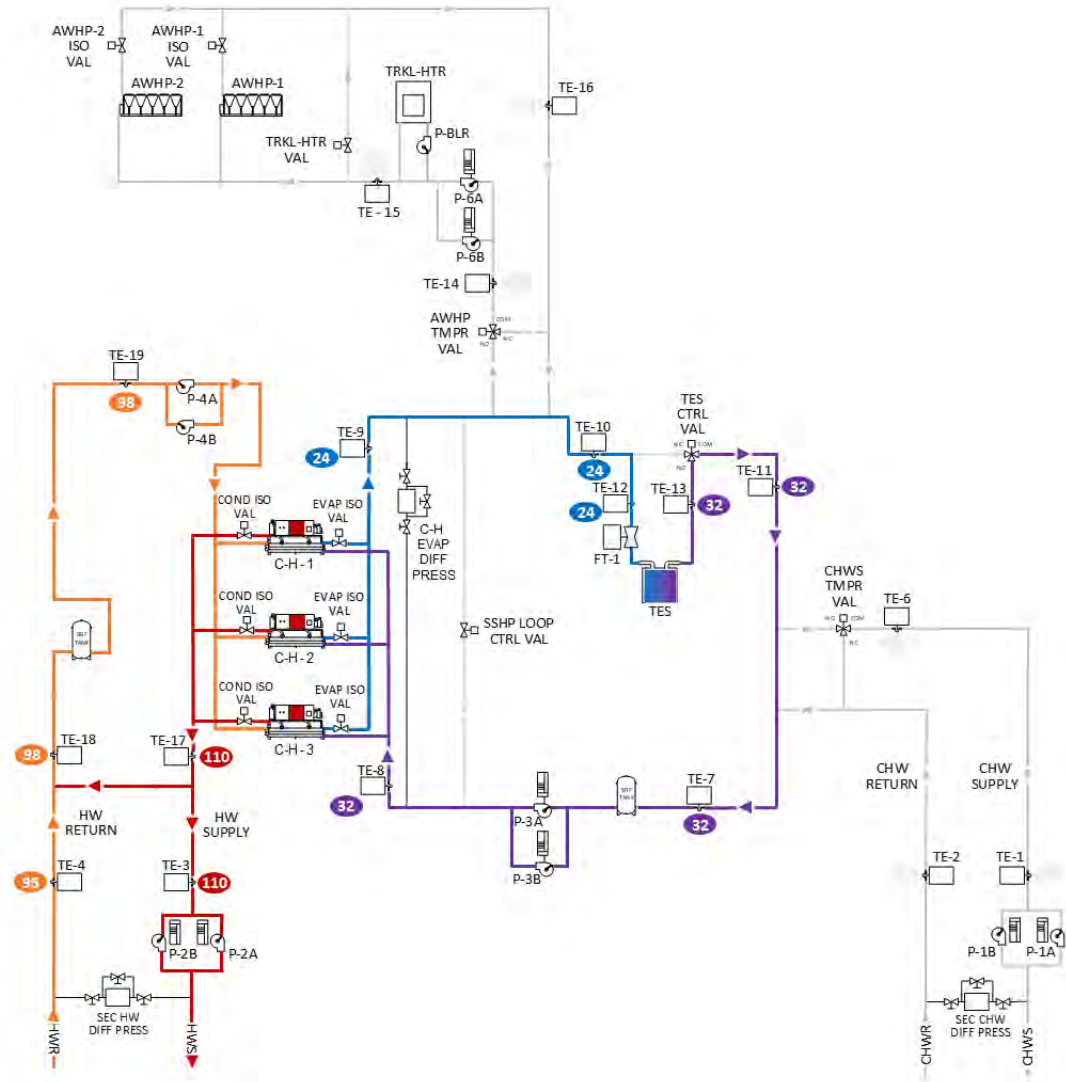


Figure 15 shows the system operating in the heating only mode with the chiller-heater(s) sourcing energy from the TES thermal batteries. This image shows all three units operating in heating, but any number of units can be staged on to meet the building heating load.

Component control includes:

- Heating water distribution loop pumps speed and staging controlled to the loop differential pressure setpoint.
- C-H unit(s) operate in a heating mode controlling their capacity to the required system supply hot water setpoint.
 - Units are staged to meet the building heating load.
- The C-H condenser pumps are controlled to a constant flow at the unit heating mode design condenser flow rate.
- SSHP loop pump(s) speed and staging are controlled to provide the C-H units heating design evaporator flow rate.
- SSHP flow is directed through the TES, where it is warmed and dispatched to the C-H units.

Figure 16. Heating only: water-to-water heat pump + air-to-water heat pump heating and thermal energy storage energy exchange (mode 2B)

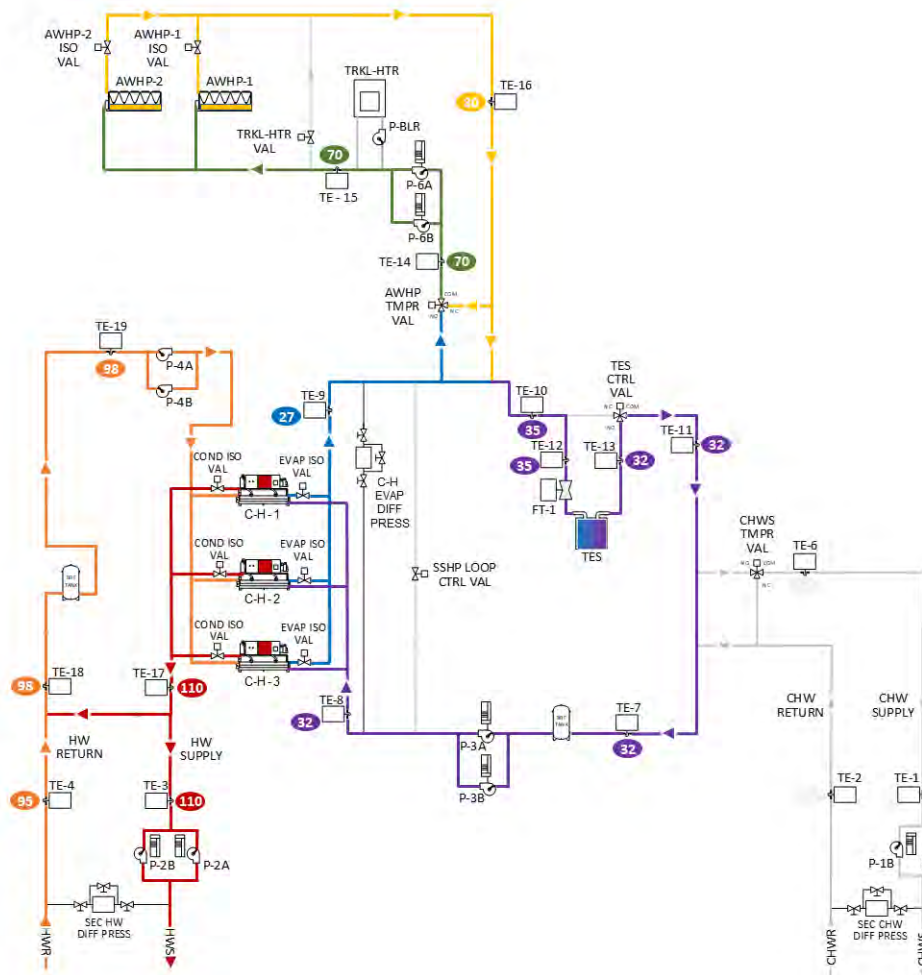


Figure 16 shows the system operating in the heating only mode. The goal (i.e., daily) of this mode is to collect energy into TES thermal batteries to meet the building 24-hour cumulative heating energy requirement.

However, at any given moment in time energy may be collected or dispatched by the TES, depending on the current heating load, the AWHP capacity and the system control. Hence the term “TES energy exchange” since the TES energy flow may shift between collecting and dispatching energy throughout the day.

The C-H and AWHP units are operating in heating. The TES sinks or sources (exchanges) energy as required to balance the SSHP loop energy extracted by the chiller-heaters versus the energy added by the AWHP.

Component control includes:

- Heating water distribution loop pumps speed and staging controlled to the loop differential pressure setpoint.
- C-H unit(s) operate in the heating mode, controlling their capacity to the leaving hot water setpoint.
 - Units are staged to meet the building heating load.
- SSHP loop pumps speed and staging controlled to provide the greater of:
 - The C-H heating design evaporator flow depending on the number of units operating.
 - The TES design collecting mode flow.
- The SSHP loop control valve modulates based on the WWCH evaporator differential pressure (flow) to limit the C-H maximum evaporator flow.
- AWHP loop pumps are controlled to the constant heat pump unit heating mode design flow rate, depending on the number of units operating.
- AWHPs operated in the heating mode.
 - AWHP units are staged on per the system design intent and the required energy collection rate determined by the BAS.
- The AWHP tempering valve is controlled to maintain the AWHP return heating water temperature as required by the AWHP heating mode. Consult with the manufacturer for unit operating requirements.

Figure 17. Heating only: chiller-heater heating with trickle-heater and thermal energy storage energy exchange (mode 2C)

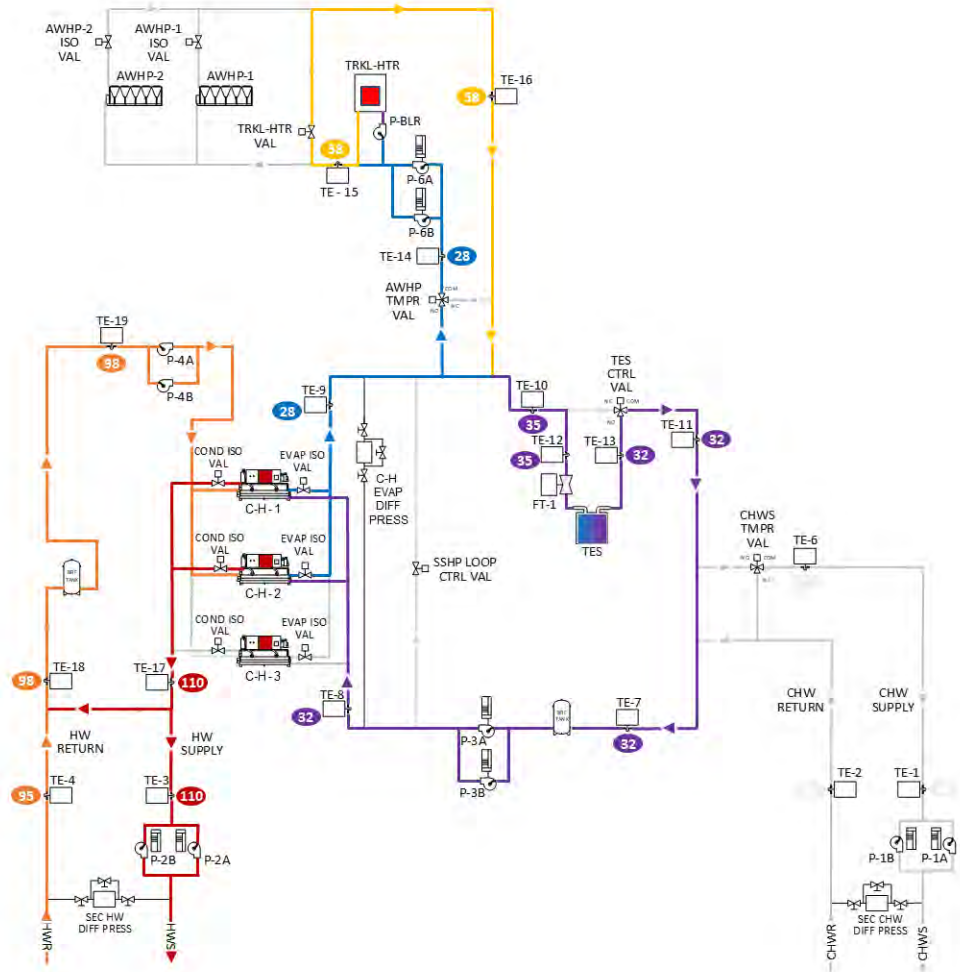


Figure 17 shows the system operating in the heating only mode. The goal (i.e., daily) of this mode is to collect energy into TES thermal batteries to meet the building 24-hour cumulative heating energy requirement. This mode is most typically used when the AWHP units are not available to provide heat energy to the system. An example of this is when the outdoor air temperature is too low for AWHP unit operation.

The trickle-heater(s) capacity is normally less than the building peak heating requirement. As a result, at any time, energy may be collected or dispatched by the TES, depending on the current heating load, the trickle-heater capacity, and the system control. Hence the term “TES energy exchange” since the TES energy flow may shift between collecting and dispatching energy throughout the day.

The C-H and trickle-heater units are operating in heating. The TES sinks or sources the energy required to balance the SSHP loop energy extracted by the chiller-heaters versus the energy added by the trickle-heater.

Component control includes:

- Heating water distribution loop pumps speed and staging controlled to the loop differential pressure setpoint.
- C-H unit(s) operate in the heating mode, controlling their capacity to the leaving hot water setpoint.
 - Units are staged to meet the building heating load.
- SSHP loop pumps speed and staging controlled to provide the greater of:
 - The C-H heating design evaporator flow depending on the number of units operating.
 - The TES design collecting mode flow.
- The SSHP loop control valve modulates based on the WWCH evaporator differential pressure (flow) to limit the C-H maximum evaporator flow.
- AWHP loop pumps are controlled to the constant trickle-heater heating design flow rate.
- Trickle-heater(s) add heat to the SSHP loop.
 - Units are staged on per the system design intent and the required energy collection rate determined by the BAS.
 - Trickle-heater operation is terminated by the BAS when it determines the tanks have sufficiently energy collected to meet the next day's cooling and heating loads.

Figure 18. Heating and cooling: chiller-heater heating with thermal energy storage energy exchange (mode 3A)

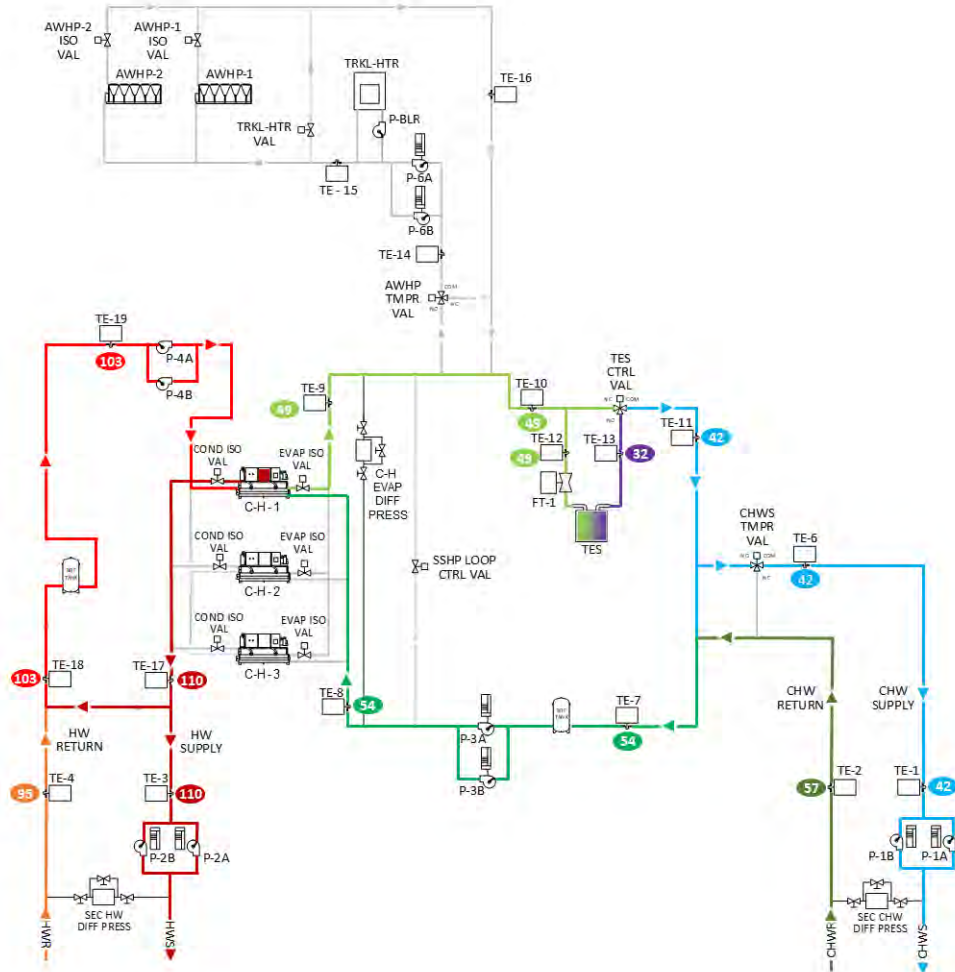


Figure 18 shows the SSHP system operating in a cooling dominant, cooling and heating mode. The chiller-heater(s) source energy from the building cooling load and TES supplements (discharges) the cooling effect of the C-H units to meet the cooling load. This image shows one unit operating in heating, but any number of units can be staged to meet the heating load.

If the plant load changes to be heating dominant, the C-H energy use will exceed the recovered cooling distribution energy and the deficit in energy will be sourced from the TES. Depending on the building loads the TES may be source or sink energy. The term “TES energy exchange” is used to indicate this possible variation in TES energy flow.

Component control includes:

- Chilled water distribution loop pumps speed and staging controlled to the loop differential pressure setpoint.
- The CHWS mixing valve controls the chilled water distribution supply water temperature.
- Heating water distribution loop pump speed and staging controlled to that loop's differential pressure setpoint.
- C-H unit(s) operate in a heating mode, controlling their capacity to the leaving hot water setpoint.
- Units are staged to meet the building heating load.
- SSHP loop pumps speed and staging controlled to provide the greater of:
 - The C-H heating design evaporator flow depending on the number of units operating.
 - The chilled water distribution loop flow, to keep slight positive flow through the decoupler.
- The SSHP loop control valve modulates based on the WWCH evap differential pressure (flow) to limit the C-H maximum evaporator flow.
- The TES control valve modulates to:
 - Direct the SSHP loop flow through the TES when the system is operating in cooling dominant conditions.
 - Control the supply chilled water temperature to the system supply setpoint when the system is operating in heating dominant conditions.

Figure 19. Heating and cooling: chiller-heater heating with air-to-water heat pump cooling (cooling dominant, mode 3B)

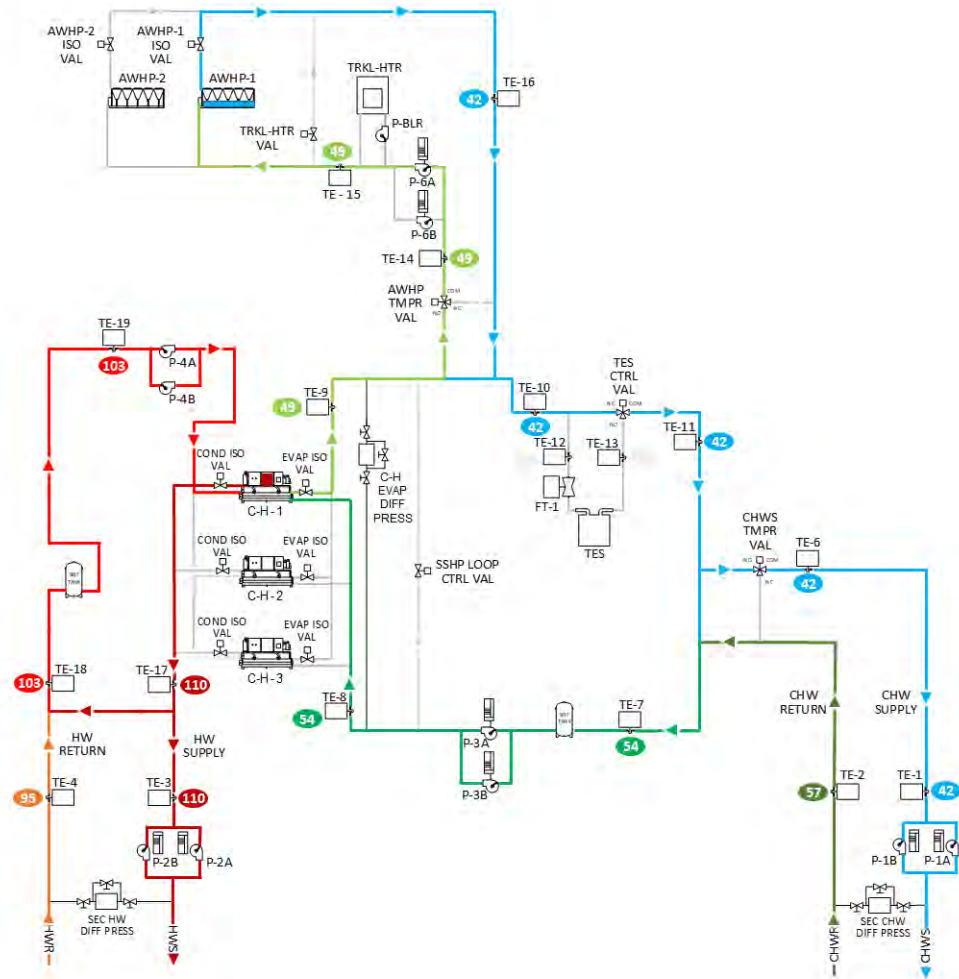


Figure 19 shows the SSHP system operating in a cooling dominant, cooling and heating mode. The chiller-heater(s) source energy from the building cooling load and AWHPs augments the cooling effect of the C-H units to meet the building cooling load. This image shows one C-H unit operating in heating, and one AWHP in cooling—but any number of units can be staged to meet the heating and cooling loads.

If the plant loads change to heating dominant, the AWHP unit operating mode would change to heating. This would be considered a change of system operating mode.

Component control includes:

- Chilled water distribution loop pumps speed and staging controlled to the loop differential pressure setpoint.
- Heating water distribution loop pump speed and staging controlled to that loop's differential pressure setpoint.
- C-H unit(s) operate in a heating mode, controlling their capacity to the leaving hot water setpoint.
 - Units are staged to meet the building heating load.
- SSHP loop pumps speed and staging controlled to provide the greater of:
 - The C-H heating design evaporator flow depending on the number of units operating.
 - The chilled water distribution loop flow, to keep slight positive flow through the decoupler.
- The SSHP loop control valve modulates based on the WWCH evaporator differential pressure (flow) to limit the C-H maximum evaporator flow.
- The TES control valve bypass the SSHP loop flow around the TES:
- AWHP loop/unit pumps are controlled to constant heat pump unit cooling mode design flow rate, depending on the number of units operating.
- AWHPs operated in the cooling mode with a chilled water setpoint controlled to provide the chilled water distribution loop with the required chilled water system supply water temperature.
 - AWHP units are staged on per the required cooling capacity.

Figure 20. Heating and cooling: chiller-heater heating with trickle-heater + thermal energy storage energy exchange (mode 3C)

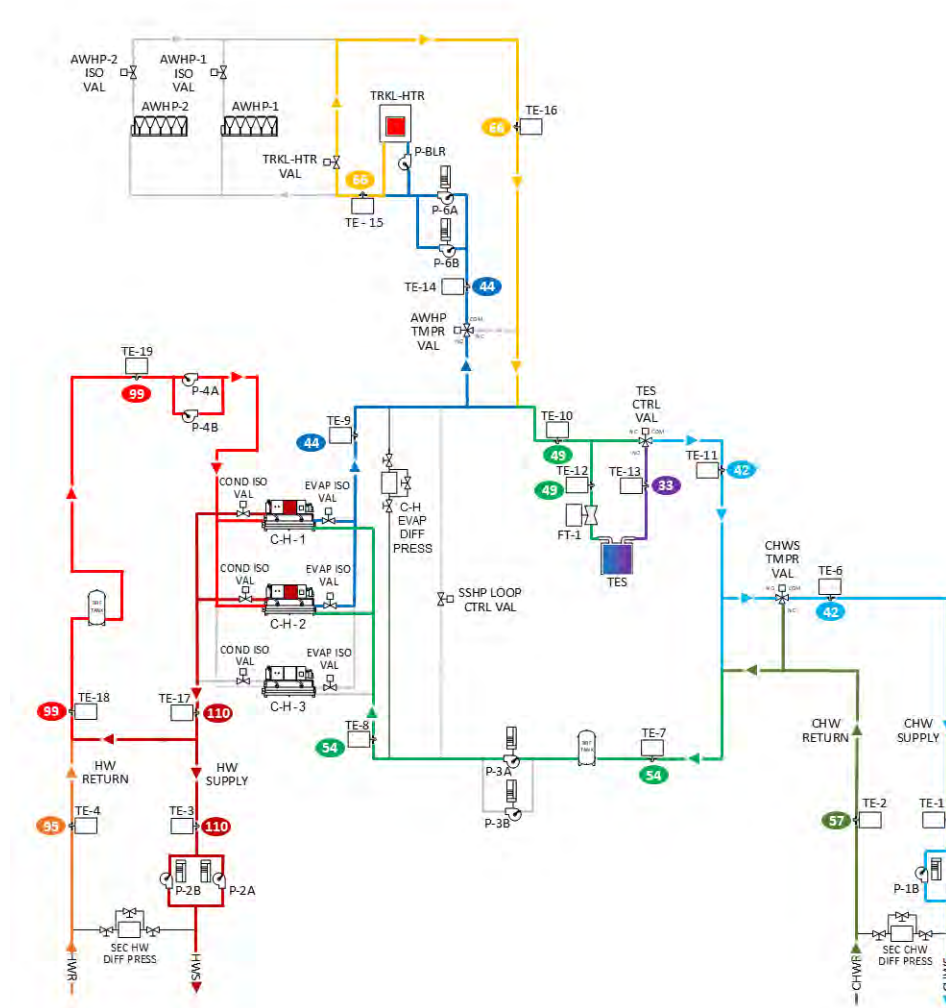


Figure 20 shows the SSHP system operating in a cooling dominant, cooling and heating mode. The goals of this mode are:

- Meet the cooling load
- Meet the heating load
- TES to collect enough heat throughout the day to meet the next day's cumulative heating loads.

The chiller-heater(s) meets the heating load with energy sourced from the building cooling load. The trickle-heater provides additional heat to the SSHP loop. The TES collects heat energy and provides cooling to meet the building cooling load.

If the plant load changes to be heating dominant, the C-H energy use will exceed the recovered cooling and trickle-heater energy and the deficit in energy will be sourced from the TES. Depending on the building loads the TES may be source or sink energy. The term "TES energy exchange" is used to indicate this possible variation in TES energy flow.

Component control includes:

- Chilled water distribution loop pumps speed and staging controlled to the loop differential pressure setpoint.
- Heating water distribution loop pump speed and staging controlled to that loop's differential pressure setpoint.
- C-H unit(s) operate in a heating mode, controlling their capacity to the leaving hot water setpoint.
- Units are staged to meet the building heating load.
- SSHP loop pumps speed and staging controlled to provide the greater of:
 - The C-H heating design evaporator flow depending on the number of units operating.
 - The chilled water distribution loop flow, to keep slight positive flow through the decoupler.
- The SSHP loop control valve modulates based on the WWCH evaporator differential pressure (flow) to limit the C-H maximum evaporator flow.
- The TES control valve modulates to provide the system chilled water supply water temperature.
- Trickle-heater(s) add heat to the SSHP loop.
 - Units are staged on per the system design intent and the required energy collection rate determined by the BAS.

Figure 21. Thermal energy storage charging only: air-to-water heat pump ice making (mode 4A)

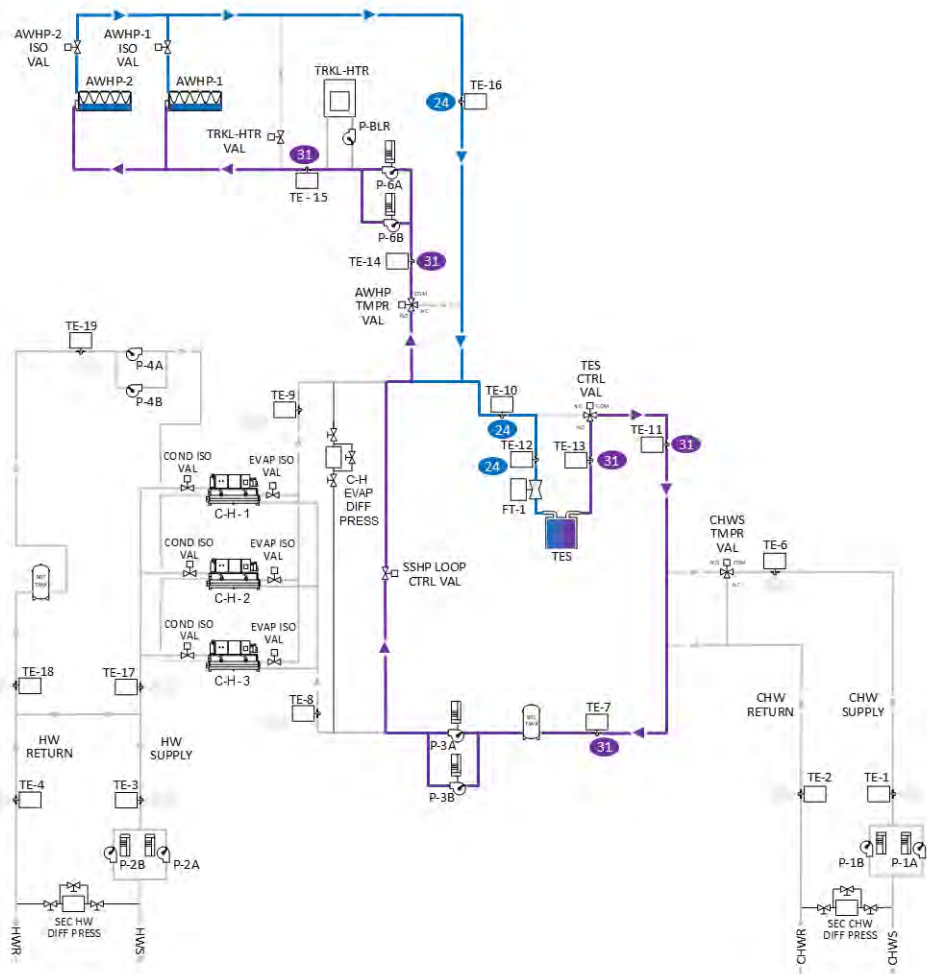


Figure 21 shows the system operating in a TES charging (ice making) mode to prepare the TES thermal batteries to provide cooling at a later time. This is similar to common thermal storage charging operation.

Component control includes:

- Chilled water distribution loop is Off.
- Heating water distribution loop is Off.
- C-H unit(s) are Off.
- SSHP loop pumps speed and staging controlled to provide the TES charging design flow.
- The SSHP loop control valve is 100 percent open, bypassing the C-H units.
- The TES control valve directs all SSHP loop flow through the TES.
- Trickle-heater(s) add heat to the SSHP loop.
 - Units are staged on per the system design intent and the required energy collection rate determined by the BAS.
- AWHP loop/unit pumps are controlled to constant heat pump unit ice making mode design flow rate, depending on the number of units operating.
- AWHPs operate in the ice making mode.
 - AWHP units are staged on per the system design intent.
 - Ice making operation is terminated by the BAS when it determines the tanks are sufficiently charged to meet the next day's cooling and heating loads.

Figure 22. Thermal energy storage heat collection (melting): air-to-water heat pump heating (mode 5A)

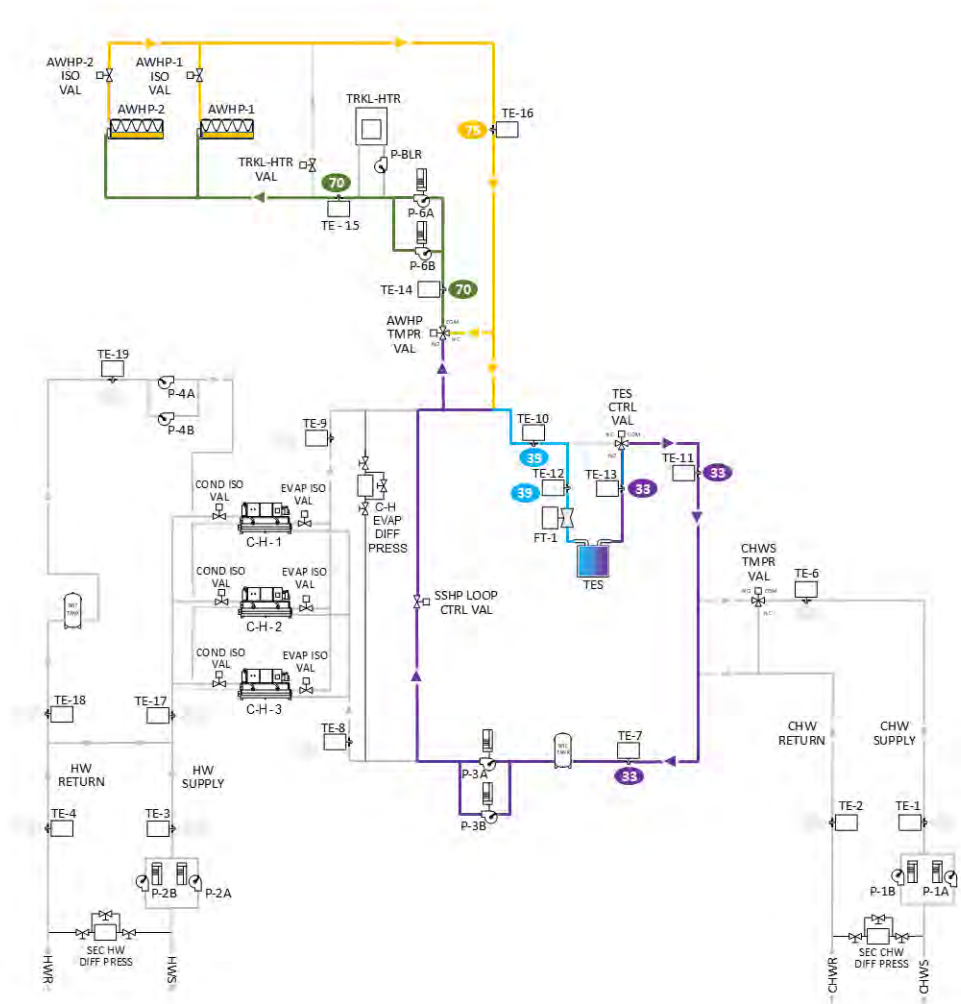


Figure 22 shows the SSHP system operating in a TES heat collection mode.

The AWHPs provide heating for collection into the TES thermal batteries in preparation for later heating needs.

Component control includes:

- Chilled water distribution loop pumps are Off.
- Heating water distribution loop pumps are Off.
- C-H unit(s) are Off.
- SSHP loop pumps speed and staging controlled to provide the TES energy collection design flow.
- The SSHP loop control valve opens to 100 percent bypass the C-H Units.
- The TES control valve directs all SSHP Loop flow through the TES.
- AWHP loop pumps are controlled to the constant heat pump unit heating mode design flow rate, depending on the number of units operating.
- AWHPs operated in the heating mode:
 - AWHP units are staged on per the system design intent and the required energy collection rate determined by the BAS.
- The AWHP tempering valve is controlled to maintain the AWHP return heating water temperature as required by the AWHP heating mode. Consult with the manufacturer for unit operating requirements.

Figure 23. Thermal energy storage heat collection (melting) with air-to-water heat pump heating in defrost cycle (mode 5B)

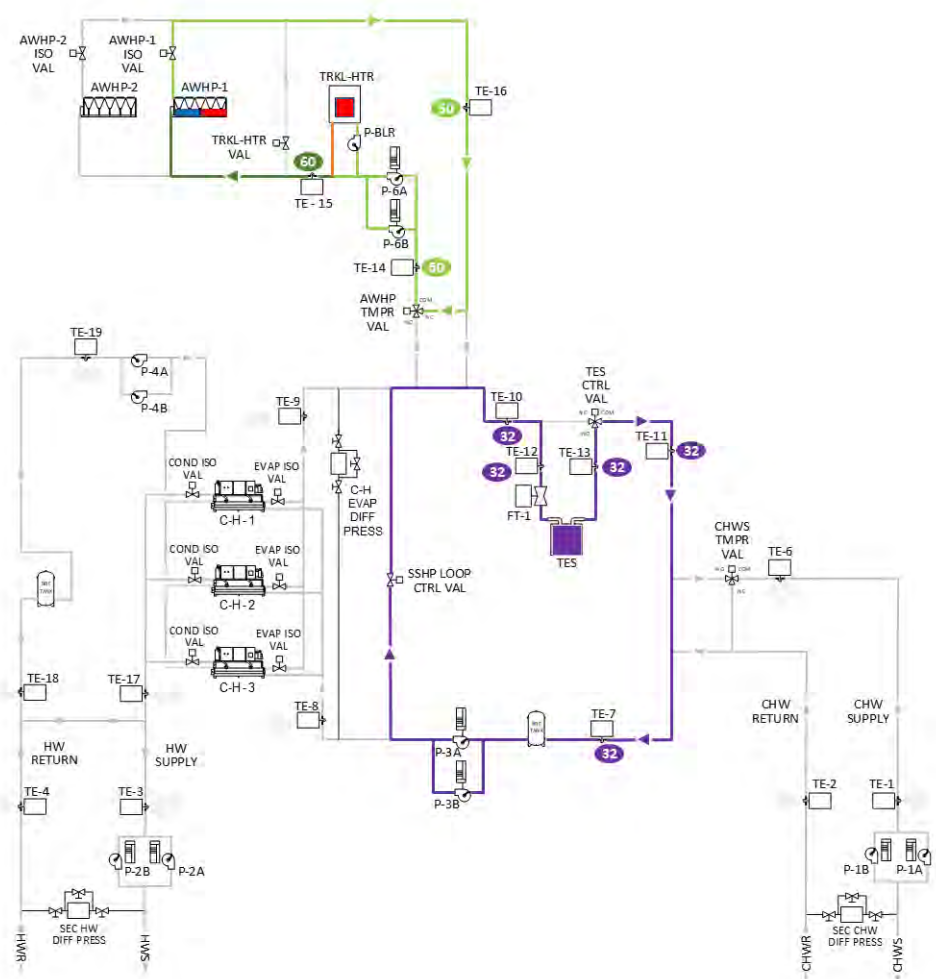


Figure 23 shows the system operating in the TES heat collection mode with one AWHP unit running in a defrost cycle.

The AWHP controls determine when one of its circuits has accumulated enough ice on the outdoor coil that defrosting is required. It provides a signal to the BAS that defrost is required and then initiates the defrost process. The unit controller will only allow one unit circuit to be in defrost at a time.

Defrost can be considered a sub-mode of the system as it can be initiated in any mode that the AWHP will be heating. The only components affected by the defrost cycle are the AWHP and the trickle-heater. The system continues to operate its other components as required for the initial system mode.

There is a minimum allowed entering fluid temperature to the AWHP fluid heat exchanger during the defrost cycle. To maintain at least that entering temperature the BAS activates the trickle-heater boiler. The boiler controls its stages of heating to maintain the required temperature.

Note: The defrost cycle is a highly dynamic mode of system operation. Depending on the unit heating load and number of units operating the system can swing from net heating to neutral operation. The conditions shown in Figure 23 represent the system operation in the middle of a defrost cycle. Unit defrost cycle time is typically limited to six minutes or less.

Component control includes:

- As the supply water temperature from the AWHPs falls the AWHP tempering valve increases the recirculation of the supply water to maintain the return water temperature to the units.
 - The valve may modulate to 100 percent recirculation.
 - As recirculation flow increases the flow to the SSHP loop decreases.
- If the AWHP return water continues to fall after the flow has reached 100 percent recirculation the trickle-heater is enabled and controlled maintain the AWHP return water temperature.

Figure 24. Thermal energy storage collection (melting) with trickle-heater boiler (mode 5C)

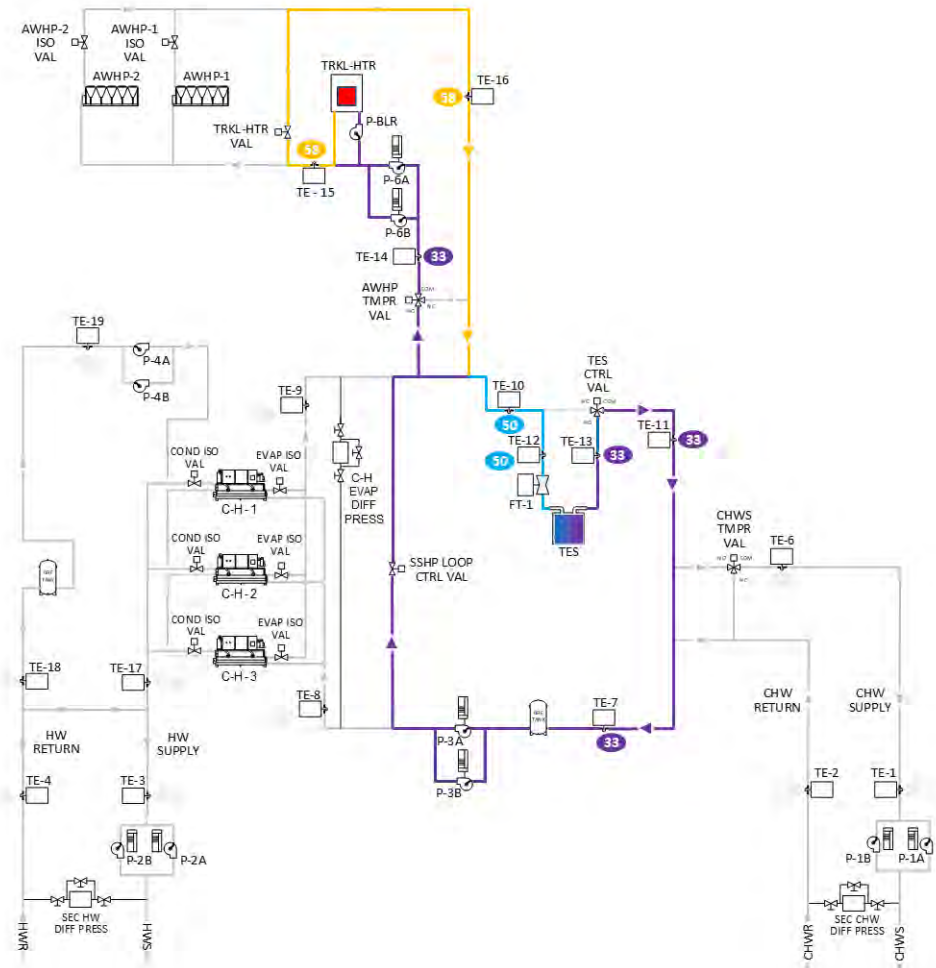


Figure 24 shows the system operating in heat collection only mode with heat energy provided by the trickle-heater. The TES stores energy produced by the trickle-heater for later use by the C-Hs in building heating.

This mode would be used when all the following are true:

- A future need for supplemental heating energy is expected.
- Recovered energy from the building cooling load alone is not expected to meet the future heating requirement.
- The AWHP is not available or does not have the capacity to produce adequate supplemental energy. i.e., during a long period of extremely low OAT, below the AWHP operating range.

There are multiple considerations in sizing the trickle-heater. The key concept behind the “trickle-heater” electric boiler is that it would be sized relatively small and operate up to 24 hours in a given day. This enables the system to meet the peak heating load without causing high electrical demand peaks during the day. Conceptually the boiler capacity would be sized to meet the 24-hour total design heating day cumulative heat energy requirement divided by the number of hours in the day available for the boiler to operate. The trickle-heater could be upsized to operate fewer hours and take advantage of periods of cleaner power or lower electrical utility rates.

The trickle heater is also used to mitigate the impact of AWHP defrost cycles. By locating it upstream of the AWHP it can be used to keep the entering water temperature to the AWHP in an acceptable range during the defrost cycle.

Component control includes:

- SSHP loop pump(s) speed and staging are controlled to provide design TES collection flow.
- The TES control valve directs SSHP loop flow through the TES.
- AWHP loop/unit pumps are controlled to constant design trickle-heater flow.
- The boiler is controlled to the desired heat output or electrical demand.

System Options

There are a number of possible options for the SSHP system. Depending on the specific building requirements there are options to increase efficiency, increase accuracy of control, and/or improved redundancy. This guide will focus on the following two options:

1. Dedicated heat recovery unit (DHRU)
2. Direct heating backup boiler

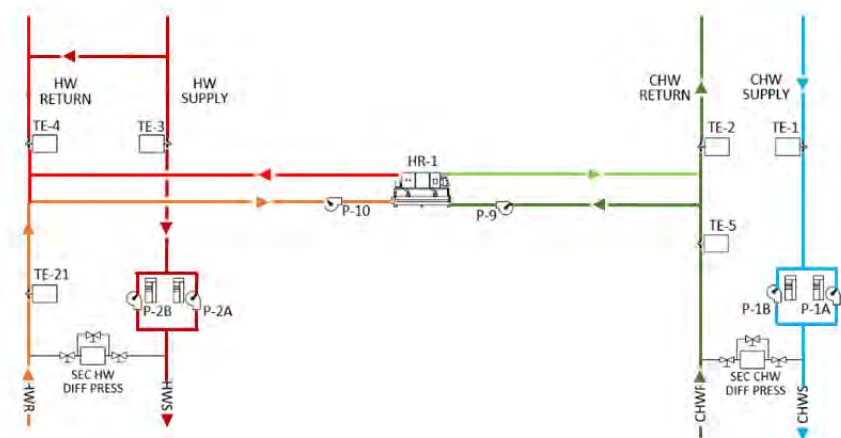
DEDICATED HEAT RECOVERY UNIT

A popular option in electrified systems is a dedicated heat recovery unit (DHRU). DHRUs efficiently move heat energy directly from the cooling distribution loop to the heating distribution loop. DHRU capacity is typically a small fraction of peak heating or cooling load, often ten percent or less.

The application of DHR provides several benefits:

- Increased system efficiency - meeting simultaneous heating or cooling loads more efficiently.
- Reducing the low load cycling and operating hours of other units - reducing maintenance and extending operating life.
- Simplification of overall system operation and control.

Figure 25. Dedicated heat recovery option



DEDICATED HEAT RECOVERY SIZING

Proper sizing of the DHRU is critical to cost-effective design and operation of the system. The amount of energy that can be transferred between the loops is limited to the **lower** of the two loops' simultaneous loads at any moment in time. The result is a substantially lower design capacity of a DHRU unit than the air-to-water heat pump or chiller-heater units. The peak simultaneous load for comfort cooling applications is typically ten percent or less of the peak heating or cooling loads, although some applications could be higher.

The proper way to size the DHRU capacity is by performing an 8,760-hour load analysis for the heating and cooling loads and then extracting the minimum of the two loads for each hour of the year where heating and cooling loads occur simultaneously. This hourly minimum simultaneous data can then be evaluated to determine the appropriate DHRU sizing.

The SSHP system recovers both simultaneous and non-simultaneous cooling energy. A DHRU only recovers simultaneous heating and cooling, however it does so more efficiently because it does not pass the heat energy through the TES loop. For any installation, it's worth comparing the potential efficiency benefit of applying a DHRU versus investing in competing measures such as optimized economizer cooling.

There are benefits beyond system efficiency that dedicated heat recovery provides. DHRU can reduce simultaneous operating hours and low load compressor cycling of the AWHP and C-H, for cooling and heating, respectively.

DIRECT HEATING AUXILIARY BOILER

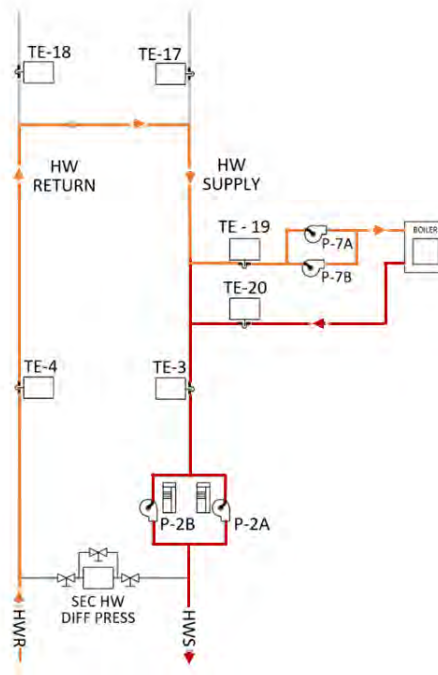
Although a properly sized SSHP system can provide heat to a building at any outdoor air temperature, some owners and engineers include a separate backup heating source. This source will often be non-electric (fossil fuel). Reasons to include this option are:

1. It is an existing building and the boilers are already in the building, so it is free redundancy.
2. Resilient buildings often require backup power generation to maintain building operation through utility power failures. Air-source heat pumps drive the need for large generation capacity and fuel storage. Natural gas, propane or fuel oil boilers may greatly reduce the required generator capacity. The building temperature can be maintained by running only the heating system distribution pumps and the boiler. This reduces the cost of back-up electric generation or electric battery infrastructure.
3. For unit failure recovery, a low first cost alternate heating source, rather than an additional AWHP or C-H unit should be evaluated. If it runs only occasionally, for failure recovery or unit maintenance, the potential impact on the building's carbon footprint may be minimal (see number four below). Of course, the full first cost to the building infrastructure must be considered. Electric boilers may require upsizing of the building electrical service and gas boilers require a gas supply infrastructure and vent piping.
4. A building's life cycle carbon footprint may be reduced by using natural gas or propane for heat during certain times of operation. The carbon impact of generating electricity varies depending upon location throughout the country. Under some conditions heating with a high-efficiency gas boiler could result in lower carbon emissions than heating with an electric heating system. As the grid becomes cleaner, boiler use can be curtailed or eliminated to further reduce carbon emissions.

When auxiliary heat is applied in the hydronic system it is best connected into the heating distribution loop supply line as shown in [Figure 26](#). This position provides stand-alone heating operation with only distribution loop pump operation.

The control of auxiliary heat will vary depending on the installation and the building operating conditions. The design engineer must carefully define the control sequence to ensure the owner's goals are achieved.

Figure 26. Auxiliary heat source in distribution loop supply line



BOILER TYPES AND STORAGE SOURCE HEAT PUMP APPLICATION CONSIDERATIONS

Hot water boilers are a common source of heat for building heating systems. They commonly use electricity or fossil fuels, typically natural gas, as an energy source. Boilers have been in use for decades and therefore influenced heating system design based on their capability and limitations.

Electric Boilers

Electric boilers will be a popular choice in SSHP systems both for trickle-heating and backup heat. Although historically avoided because of the high electrical demand and relatively high utility cost, they feature several advantages in SSHP systems. Perhaps the most attractive advantage is they produce no on-site emissions and as the electrical distribution grid becomes clean, they have a low atmospheric carbon impact. Their carbon impact and annual utility cost is also greatly reduced since they are only used to augment the heating normally produced from the SSHP system air-to-water heat pump and chiller-heater units. They also benefit from low first cost and relatively simple installation. Finally, in locations where fossil

fuel heating is not available or allowed by regulations, they will be the go-to source for auxiliary heat.

Electric boilers use electricity as an energy source. Electric heating elements are used to heat the water with resistance-based heat. They offer nearly 100 percent efficiency (COP=1) and no site emissions. The efficiency remains high at all operating conditions.

Electric boilers are compact for the heating capacity provided and relatively inexpensive. They are simple to install as natural gas lines, flue gas pipes, or condensate pipes are not required. Maintenance is simple without burners, blowers, and combustion related safety controls. They offer tremendous operating range and application flexibility lacking the return hot water temperature limits of gas boilers. Electricity use and demand should be carefully considered in any electric boiler project.

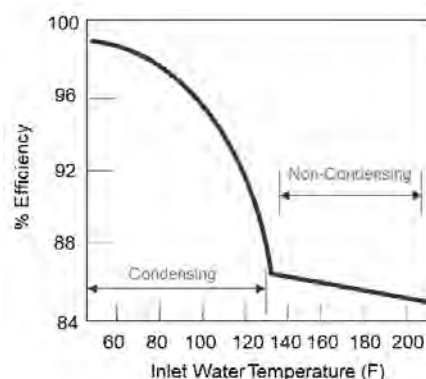
Condensing Boilers

Condensing boilers will likely be the next most popular choice, after electric, for auxiliary heat in SSHP systems. Three of the top reasons for this include:

- They have a very high heating efficiency resulting in low carbon emissions as well as utility cost.
- For best efficiency they require low supply and return heating water temperatures, the lower the better. This makes them a natural partner in an SSHP compressor-based heating system.
- They are in common use today and many codes will require the use of condensing boiler technology when fossil fuel heating is applied.

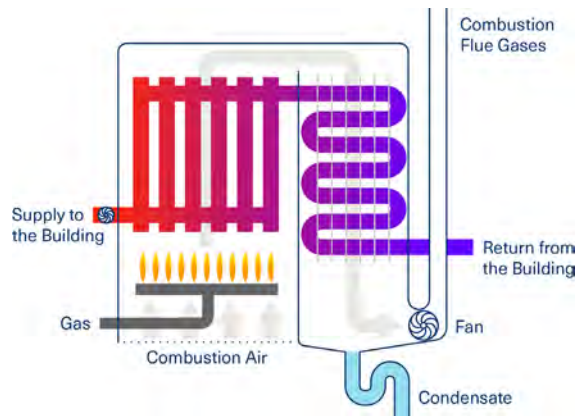
Condensing boilers get their high efficiency by capturing both sensible heat and the heat of condensation of the exhausting flue gas. Lower heating system temperatures enhance their efficiency as a result of greater condensing. Figure 27 shows the opportunity for efficiency improvement as the return water temperature is reduced.

Figure 27. Gas boiler efficiency vs inlet water temperature



The boiler's heat exchangers must be designed to handle flue gas condensate. Figure 28 shows the flue gas being cooled below its dew point temperature thus developing condensate. The heat exchanger and boiler are designed to handle the condensate and its corrosive characteristics. This increases their cost and complexity but is well understood and modern designs are highly reliable.

Figure 28. Condensing boiler



Condensing boilers are in common use today, driven by energy codes and energy cost economics. ASHRAE® 90.1-2019, Section 6.5.4.8.2, *Hot-Water Distribution System Design* essentially requires that hot water return water temperature be 120°F or less, which effects boiler and coil selections.

- Condensing boilers have caused system design hot water supply and return temperatures to reduce considerably. These boilers are commonly specified to produce hot water supply temperatures typically no greater than 140°F with return water temperatures 120°F or less. Condensing boiler efficiency is commonly rated at 99 percent (60°F return) but with higher operating temperature more commonly operate in the low to mid 90's.

- The airside system heating coils and other heat exchangers must be selected for these lower design conditions with the hot water return temperature entering the boilers is 120°F or less. While such low heating water temperatures are historically uncommon, air handler coils are universally available to meet these design conditions. As proof, there are engineering firms in the northeast that have standardized on 95°F (35°C) as their design supply heating water temperature.

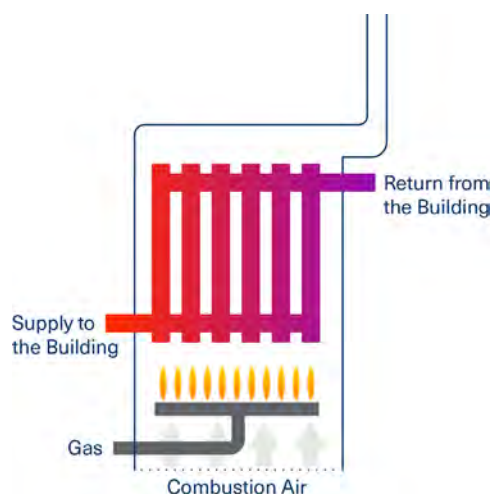
Non-condensing Boilers

Non-condensing boilers may be used for auxiliary heat in SSHP systems. Although their combustion efficiency is relatively low, that is offset by the fact that typical operating hours are minimal to none. As a result, their real operating cost and carbon impact would be very low. The benefit of using non-condensing boilers is the boiler's lower first cost, however this is somewhat offset by the complexity of operating this type of boiler with very low system water temperatures. The boiler piping design will require piping and tempering valves to maintain the boiler operating temperature above the flue gas condensing range (>130°F inlet) to prevent premature heat exchanger failure.

The earliest boilers were non-condensing. They use the heat of combustion to heat water passing through a heat exchanger (Figure 29). The hot combustion flue gas gives up its sensible heat to the relatively cool building return hot water to heat the building supply hot water to a target temperature. The cooled combustion flue gas is exhausted to the outdoors.

The combustion flue gas contains a significant amount of water vapor, and it is exhausted at a temperature above the flue gas dew point temperature (>140°F). This avoids condensing in the boiler. These boilers require a return hot water temperature comfortably above the flue gas dew point temperature to prevent condensation.

Figure 29. Non-condensing boiler



Non-condensing boilers are commonly specified to produce hot water supply temperatures in the 160°F to 180°F range and accept return water temperatures not less than 140°F. [Figure 27](#) shows the relationship of return hot water temperature to boiler efficiency. Non-condensing boiler efficiency is less than ≈86 percent given its return hot water temperature limit.

HEATING REDUNDANCY

Redundancy in a heating system is a core requirement. Since this is a hydronic system pumping redundancy is a key requirement and should be addressed with good heating system design practices. There are several ways to provide heating supply redundancy:

- Redundant chiller-heaters
- Redundant trickle charging boilers
- Direct heating backup boilers

Direct Heating Backup Boilers. These are discussed in the previous section. If backup boilers are included in the system no other heating supply redundancy is likely to be required.

Redundant Chiller-Heater Unit(s). Installing N+1 C-H units helps provide all-electric redundancy. The incremental cost of the additional C-H relative to the base system cost varies greatly depending on the number of base units required. demonstrates this concept by showing that as the number of base heat pump units increases there is a reduction in the incremental capacity addition relative to the design system load.

To provide redundancy in a system with a single unit, two full sized units must be installed. The first cost of the heat pump units and infrastructure may be reduced by installing three smaller units rather than two larger ones. And the system will benefit from the more stable control and greater capacity turndown than a single large base unit would provide.

Redundant Trickle Charge Boilers. The trickle charge boilers naturally act as a backup to the AWHPs. Installing N+1 trickle-charge boilers along with C-H units provide all-electric redundancy. The incremental cost of the additional trickle-charge boilers relative to the base system cost may be relatively low compared to other redundancy options.

Summary

An electrified storage source heat pump cooling/heating system does not need to be complex to design or operate. However, careful consideration must be given to the unique system and equipment characteristics and operating limitations that are different from those in chilled water systems. These must be addressed in order to have an effective and reliable decarbonized system.

As covered in this application guide, there are several key points that the design engineer should be mindful of when designing the system:

- Major advantages of a SSHP system include:
 - Heating available at any outdoor air temperature.
 - Warmer heating water available at any outdoor air temperature.
 - Electrical demand management in both cooling and heating.
 - Recovery of all cooling energy for use in heating.
- **Lower design and operating hot water supply temperatures results in more efficient heat pump unit operation.** The target for the central air handler and terminal equipment design heating water temperature should be 95°F to 105°F. One method to enable this temperature range is to changeover the unit cooling coil for use in heating.
- **Proper system/equipment sizing is key to efficient and reliable operation.** Improper equipment sizing penalizes system efficiency and shortens equipment operating life, therefore reducing the benefits of decarbonization of the system. Oversizing also unnecessarily increases equipment installed cost. Some equipment may have limited turndown capability which can result excessive low load cycling.
- **Decoupling of the production and distribution systems' pumping** is the most reliable and efficient method to ensure continued reliable system operation over its full operating range.
- **Air side design, specification and control is key to achieving maximum decarbonization.** In addition to low heating fluid temperature considerations, features such as air side heat recovery should be considered. If AHUs are equipped with airside economizers then load-shed economizer control must be implemented. Recovery/collection of building cooling loads into the TES is key to the SSHP system operation.
- **Equipment selection must account for coldest design conditions** as the outdoor air temperature has a significant effect on air-to-water heat pump unit capacity and available supply hot water temperature.
- **Ensure system will meet project decarbonization goals.** Understand the applicable grid emissions and select equipment efficiencies and system operating temperatures that ensure goals will be met.

- **If waterside heat recovery is considered**, a careful analysis of the full year (8,760 hours) simultaneous load curves is required for right sizing, not oversizing, DHR units, efficient heat recovery operation and operating cost savings estimation.

Taking these key points into account during the design process will ensure the design engineer has greater success in providing a highly flexible, efficient, and reliable electrified heating system.

The products and systems available for commercial building electrified hydronic heating systems are maturing quickly. Contact a local Trane® sales representative for the latest version of this application guide and other decarbonization related support materials.

Resources

- [1] Murphy, J. 2022. "Heating with Lower-Temperature Hot Water". Trane® *Engineers Newsletter*. 51-4.
- [2] ANSI/ASHRAE/IES. Standard 90.1-2019. *Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta. ASHRAE. 2019.
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- [5] Trane®. *Partial Ice Storage: Rules of Thumb* sales brochure. ENV-SLB020-EN. 2014.
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