Leverage Building Energy Diversity in High Efficiency HVAC Design

Water-source heat pumps prove to be more energy-efficient than alternative systems for commercial buildings.

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The first commercial energy code was promulgated in 1975 with the *ASHRAE Standard 90-75 : Energy Conservation in New Building Design.* Since then, subsequent efforts have led to more stringent energy efficiency standards, as shown in Figure 1.

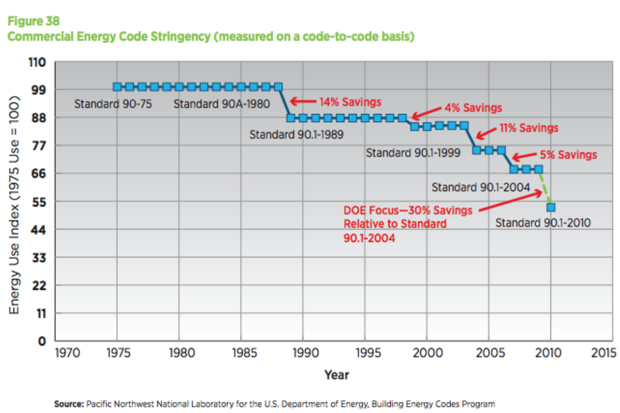

Figure 1: Commercial Energy Code Stringency (measured on a code-to-code basis)[1]. A study conducted by the Pacific Northwest National Labs shows a further 8.5% potential reduction in energy consumption by adoption of the 2013 standard.

A complete and uniform adoption of these energy codes would have resulted in approximately a 50% reduction in normalized energy use between 1975 and 2012. In reality, total energy consumption per square foot in commercial buildings has decreased from 114 kbtu/sq. ft. in 1979 to 79.9 kbtu/sq. ft. in 2012 (Figure 2) – a 30% decrease.

While this is a significant achievement, adoption and enforcement of standards by different states

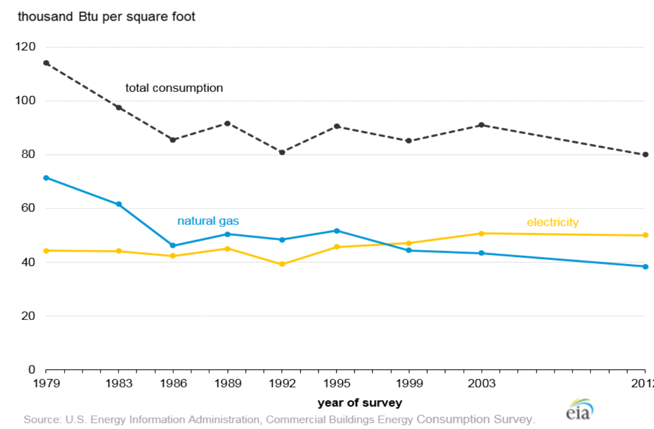

Figure 2: Total energy consumption in commercial buildings (in KBTU/sq. ft) has decreased 30% between 1979 and 2012.[2]

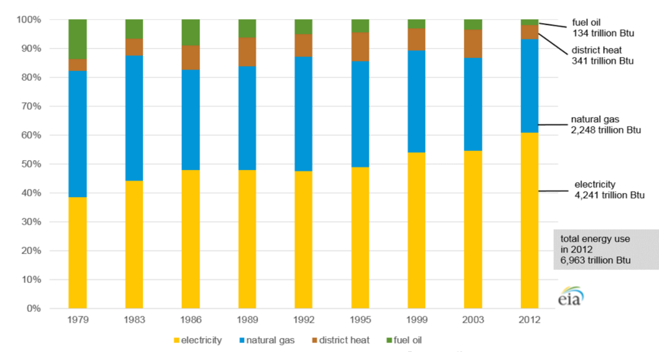

Figure 3: Commercial Building Energy Consumption by Fuel Type. Commercial Buildings consumed almost 7000 trillion BTUs in 2012.

has not been uniform and buildings continue to account for a large percentage of energy consumption in the US. According to the US Energy Information Administration, commercial buildings consumed 7 quadrillion BTUs of energy as shown in Figure 3. (A quadrillion is one thousand trillions – let's just simply say that these buildings consume a lot of energy). Further, HVAC accounts for 44% of the commercial building energy demand (see Figure 4) (includes space heating, ventilation and cooling; excludes refrigeration).

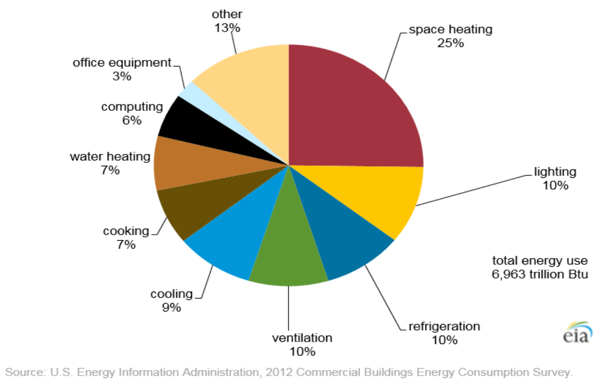

Figure 4: Share of energy use in Commercial Buildings in 2012. HVAC (space heating, ventilation, cooling) accounts for 44% of total energy consumption.[3]

Driving efficiency gains with HVAC systems, which account for 44% of a commercial building's energy consumption, will result in a large positive impact. In this article, we explore how Water Source Heat Pumps (WSHPs) are uniquely positioned to extract energy that is normally wasted and transport it to a place where it is being demanded thus offsetting new energy demand. We also explore other advantages that WSHPs offer such as high efficiency, reduced real estate footprint, improved safety, and better aesthetics in building design compared to alternative systems available in the market today.

Commercial Heat Pumps

A heat pump is a refrigeration circuit that can cool spaces during warm weather and heat spaces during cool weather. With a heat pump, you can cool or heat a space by only using electricity. By not burning fuel for heating, as in a traditional central furnace, a flammability risk is eliminated.

Commercially available heat pumps can be categorized into two broad types:

- An air-source or air-cooled heat pump
- A water-source heat pump (WSHP)

An air-source or air-cooled heat pump is a type of heat pump that operates by rejecting heat to outside air during the summer or by absorbing heat from outside air during the winter. A WSHP is a type of heat pump that operates by rejecting heat to a water-pipe system (or water loop) during the summer or by absorbing heat from the same water loop during the winter. If multiple units of WSHPs are installed, they can all be serviced by a common water loop system (or header).

Advantages of Water Source Heat Pumps (WSHP)

In WSHPs, since heat is transferred via a heat exchanger into a pipe carrying water, the system footprint is smaller since water is more efficient at carrying away heat than is air. In an air source system, the limiting heat transfer coefficient is on the air side and typical forced convection air side heat transfer coefficients are in the range of 25 - 250 W/m^2 K. By contrast, the forced convection heat transfer coefficients on the water side are in the range of 50 – 20,000 W/m^2 K.[4] This results in WSHP equipment being more efficient and smaller in size than air source heat pumps.

Traditional air source units can require each air handling unit to have a separate outdoor condensing unit. For a large multi-unit system, as would be required in a commercial building, multiple outdoor condensing units would be needed that are not only noisy but also present a challenge to install since they require a lot of free space. With a multi-unit WSHP installation, heat exchange can be accomplished with a single central evaporative cooling tower or dry cooler located on the ground or the rooftop. (In one particular version of WSHP, the water loop runs underground and exchanges heat with the earth. Since the loop runs underground, the real estate footprint is minimized. This special version constitutes a geothermal heat pump and is not the focus of this article). The individual WSHP units themselves can be placed in dropped ceilings or hidden away in mechanical rooms or utility closets away from occupied spaces. Placing the units in ceilings, nearer the point of use, also results in less ductwork and less fan energy consumption. Fan energy consumption can be among the largest energy components of a HVAC system[5] and a good overall system design will acknowledge it and attempt to minimize this.

WSHPs also offer some of the highest cooling efficiencies in the HVAC industry. In fact, ASHRAE, the standards setting body for the industry, sets the minimum efficiency requirements for WSHPs to be higher than for traditional air cooled heat pumps and VRF systems. The following values (Table 1) for the most directly comparable units are taken from ASHRAE 90.1 – 2013. This comparison shows that WSHPs meet the highest minimum cooling EER (Energy Efficiency Ratio) requirement. The ClimateMaster TE026 offers an EER of 17.4 at full load and EER of 19.8 at part load at ASHRAE rated conditions which are well above the minimum thresholds.

Table 1:

Mode	Equipment Type	Size Category	Subcategory or Rating Condition	Minimum Efficiency	Reference Source
Cooling	Air Cooled Unitary Heat pump	>= 65,000 btuh and <135,000 btuh	Split System and Single Package, 95 dB, 75 wb	**10.8 EER**	Table 6.8.1-2, Pg. 66
Cooling	Air Cooled VRF Heat Pump	>= 65,000 btuh and <135,000 btuh	VRF Multisplit System, 95 dB, 75 wb	**11.0 EER**	Table 6.8.1-10, Pg. 75
Cooling	Water Source VRF Heat Pump	>= 65,000 btuh and <135,000 btuh	VRF Multisplit System, 86F entering water	**12.0 EER**	Table 6.8.1-10, Pg. 75
Cooling	Water Source Heat Pump	>= 65,000 btuh and <135,000 btuh	86 deg F entering water	**13.0 EER**	Table 6.8.1-2, Pg. 67 **WSHP meets the highest EER requirement**

This table derived from ASHRAE 90.1 – 2013 shows that, under like conditions, the Water Source Heat Pump meets the highest EER requirement in Cooling mode

Table 2:

Mode	Equipment Type	Size Category	Subcategory or Rating Condition	Minimum Efficiency	Reference Source
Heating	Air Cooled Unitary Heat pump	>= 65,000 btuh and <135,000 btuh	47 dB/43 wb outdoor air	**3.3 COP**	Table 6.8.1-2, Pg. 67
Heating	Air Cooled VRF Heat Pump	>= 65,000 btuh and <135,000 btuh	VRF Multisplit system, 47 dB/43 wb outdoor air	**3.3 COP**	Table 6.8.1-10, Pg. 76
Heating	Water Source VRF Heat Pump	<135,000 btuh	VRF Multisplit system, 50 F entering water	**3.6 COP**	Table 6.8.1-10, Pg. 76
Heating	Water Source Heat Pump	<135,000 btuh	50 F entering water	**3.7 COP**	Table 6.8.1-2, Pg. 68 **WSHP meets the highest COP requirement**

This table derived from ASHRAE 90.1 – 2013 shows that, under like conditions, the Water Source Heat Pump meets the highest COP requirement in Heating mode.

WSHPs are some of the most efficient performers even in heating mode when compared with alternative systems. In a furnace unit, the maximum efficiency for heating by burning natural gas is about 98.5% for a COP of 0.985 and by electrical heat is 100% (COP = 1.0). With a water source heat pump in heating mode, not only is the thermal energy from the water loop being extracted and utilized but also the heat of compression in the refrigerant circuit is captured and used as a source of heating. Due to this capability of extracting heat from a heat source (i.e. the water loop) and using the heat of compression, the Water Source Heat Pump can easily provide 4 to 6 units of heating for every unit of energy consumed. Clearly, this is a much more efficient system. Again, WSHPs satisfy the highest minimum ASHRAE COP requirement even in heating mode (Table 2) compared with traditional air cooled heat pumps or with VRF. The ClimateMaster TE-026 model, for example, has a Heating COP of 6.0 at full load and COP of 7.0 at part load at ASHRAE rated conditions which are well above the minimum threshold. In other words, the unit puts out 6 watts of heat for every watt of electricity consumed at full load conditions.

Simultaneous Heating and Cooling with WSHPs

Depending on the orientation of the buildings and the demands of different kinds of tenants in a multi-use location, it is normal for some of the occupants to be demanding cooling while some others are demanding heating at the same time. Or, there is demand for hot water in a restaurant while the ice cream store next door is demanding cooling. Even within a single office building, for example in winter, there is usually need for heating at the perimeter that is exposed to the elements and cooling needed at the core of the building due to heat given off by occupants and

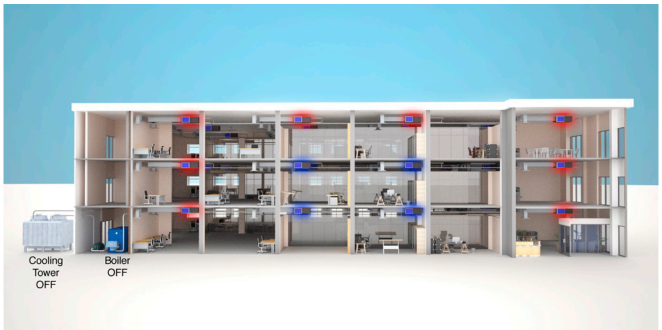

Figure 5: A typical commercial building can have cooling loads at the building perimeter and heating loads in the building core. The WSHP loads at the perimeter (heating demand, shown in red) and in the core (cooling demand, shown in blue) can offset each other.

equipment (Figure 5).

This diversity of energy demand exists everywhere. Wouldn't it be the most efficient use of our resources if we could take the heat out of an area that is rejecting it and use it in another area that is demanding it? This is what Water Source Heat Pumps do and energy recovery and transport is an area where they truly excel. Water is non-flammable, non-toxic and has a high specific heat value of 4.2 KJ/kg C. It is an ideal medium to transport energy without any of the negative consequences of using a synthetic or flammable refrigerant to move energy, especially in the vicinity of occupied spaces. What gives the Water Source Heat Pump this unique ability to achieve this safely and efficiently?

The BTUs of cooling load and the heat of compression in the refrigeration circuit of a traditional air source unit is rejected to the atmosphere through the condensing coil or the outdoor unit. The quality of heat is low and it is not economical in an air source heat pump to recover this energy. This energy is blown into the atmosphere and is thus wasted. In a water source heat pump, these BTUs are rejected into a common water loop and the water loop acts as a reserve of this energy that can be easily transported to the place that is demanding heating. As water is physically moved by means of a water pump to different areas of the same building, or a group of buildings, thermal energy is also being simultaneously transported. Even though the quality of heat is low, it is efficiently captured and transported to where it is needed due to the high heat transfer coefficients achievable with water and due to its high specific heat. The energy that is normally wasted in an air source heat pump is now recovered and used somewhere else, thus offsetting new energy demand. The overall building energy consumption is decreased and no BTU is left behind!

Indeed, this is one of the biggest advantages of a Water Source Heat Pump - *thermal energy can be recovered and economically, efficiently and safely transported to wherever water can be pumped*. Since moving water is easy and safe, the WSHP can be applied to any situation – from a single condo unit to a large office campus.

The advantages of a WSHP deployment become even more apparent when compared with another system, the Variable Refrigerant Flow system or VRF. The VRF system has limited ability to transport energy over long distances since it uses refrigerant close to the saturation temperature, or with limited subcooling, in copper pipes as the transport medium and also because of compressor power and pressure drop concerns with pumping so much refrigerant. Most VRF vendors place limits on refrigerant tubing lengths such as how far the indoor units can be from the outdoor units; the total length of system piping allowable; the length from the first separation tube or branch controller to the farthest indoor unit; or the total vertical pipe length.

In addition, there are also a large number of copper pipe connections that have to be made in the field in a VRF system. If there is a refrigerant leak anywhere along the path, it is extremely difficult to detect, isolate, re-braze, re-vacuum and re-commission the system. In a WSHP, all refrigerant lines are contained within the unit, and installed and leak-tested in a controlled factory setting. The energy in a WSHP system is moved by water in normal plumbing systems that every HVAC contractor is familiar with. This is much safer and easier to maintain and there are no piping distance limits.

A further advantage of Water Source Heat Pumps is its ability to achieve highly efficient operation and perform heat recovery while operating with a limited amount of refrigerant charge. High system refrigerant charges are a potential safety hazard since refrigerant can displace oxygen in closed rooms and cause asphyxiation without warning. ASHRAE Standards 15 and 34 (Safety Standard for Refrigeration Systems; and Designation and Classification of Refrigerants) defines the refrigerant concentration limit (RCL) and oxygen deprivation limit (ODL) for different refrigerants, and these can be used to calculate the smallest-sized room where a refrigeration system can be safely installed. For the most commonly used refrigerant, R-410A, the RCL is 26 lbs. per 1000 cubic feet and the ODL is 140,000 ppm. For institutional buildings such as hospitals, the threshold is only half of the nominal value (Institutional buildings defined as where occupants cannot readily evacuate without the assistance of others).

The small quantity of refrigerant charge needed in a WSHP is contained completely within the factory tested unit. Again contrast this with a VRF system that requires much higher quantities of refrigerant charge. In a VRF system, refrigerant is not only used within the central units and their internal mini-split units but also is present in the extensive pipework and branch controllers between these internal and external units. Some VRF systems require two or three pipe network designs to work and all these pipes carry refrigerant. This complex maze of copper piping presents increased safety and maintenance risks due to the higher refrigerant charge in the system, higher number of connection points that are potential points of failure, and the hazard it poses if there is a leak. As the industry considers moving to refrigerants with flammable characteristics to meet the low Global Warming Potential (GWP) refrigerant requirements driven by climate change concerns, the safety considerations of using VRF become even more acute. In a VRF system, the RCL/ODL thresholds can be easily exceeded in small offices, hotel rooms, bathrooms and utility rooms.[6]

WSHP System Implementation

A typical WSHP implementation in a large commercial building consists of several WSHPs that are installed close to the areas of demand and fed by a common water loop. The cooling tower,

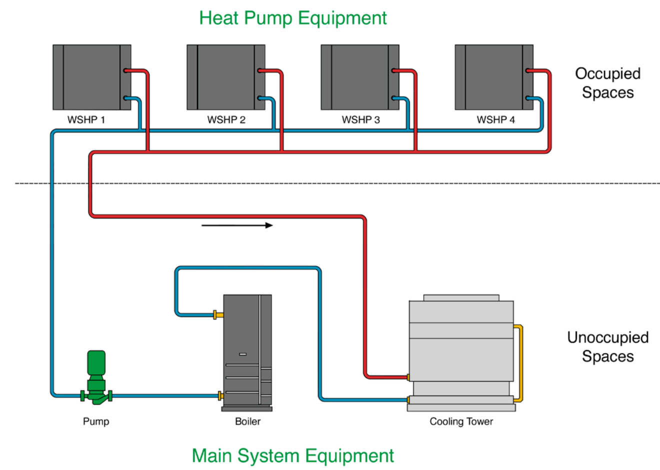

Figure 6: Multiple WSHPs are connected to a common loop or pipe header. This common loop is connected to a boiler and to a cooling tower. Water is then pumped around the loop using pumps. This picture shows a 2-pipe system which is the most common.

pumps and boiler are located away from occupied spaces (Figure 6).

In a WSHP implementation, the control schemes generally limit the water loop temperature to be in the range of 60F to 95F depending on the season. Keeping the water loop temperature in this range is a matter of economics and engineering judgement. The heat pumps can operate with water temperatures outside this range but their efficiency will be lower. For example, the heat pump has to work harder in heating mode with the water loop temperature at 55F than at 60 F. Is it more economical to let the heat pumps work harder at 55 F (consuming more electricity) or using the gas fired boiler to raise the temperature of the loop to 60 F? The answer depends on the relative costs of gas and electricity as well as the relative efficiencies of the boiler and heat pumps at these operating points.

When both heating and cooling loads are present, the WSHPs extract the heat from areas rejecting it and provides it to the WSHPs that are demanding this heat through the common water loop. When the loads are able to offset each other, small temporary imbalances between heating and cooling loads are taken care of by allowing the water loop temperature to float within the 60F to 95F range. In this scenario, there is no need for any net inputs to the system of either heating BTUs or cooling BTUs and both the cooling tower and boiler can be turned off to improve system efficiency (Figure 7). Due to the large specific heat of water in the loops, a 35 degree F range in water loop temperature implies there is a large amount of thermal energy available to take care of demand imbalance. Just one thousand feet of 6” pipe can hold 875 KBTU of thermal energy over a 35 F span of temperature. Over a one hour period, this equates to over 70 tons of refrigeration that can be moved around.

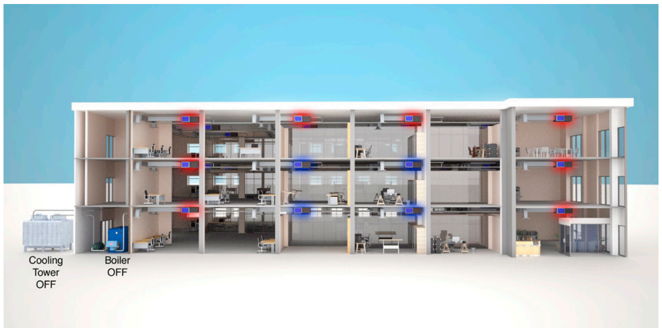

Figure 7: The heating and cooling loads are able to offset each other in this scenario. The heat rejected by units in cooling mode is carried away to the heat pumps that are in heating mode. Both the boiler and cooling tower are turned off.

In cases where there are predominantly cooling loads, in summer for example, a central cooling tower is provided to provide only the net cooling to keep the water loop temperature from exceeding 95F (Figure 8). Alternately, the excess BTUs can simply be used to generate hot water using a water-to-water WSHP.

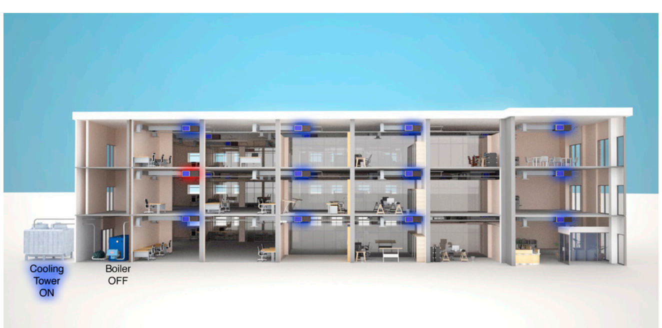

Figure 8: Most of the units are in cooling mode. The cooling tower is on and the boiler is turned off.

The reverse is true in winter when the heating demands exceed the cooling demands: a central boiler is provided to add BTUs to the water loop to make sure that the water loop temperature does not go below 60F (Figure 9). Since the cooling tower and boiler are sized to handle only the maximum net cooling and heating demand, as opposed to sizing for maximum total cooling and heating demand, their sizes can be reduced resulting in cost savings.

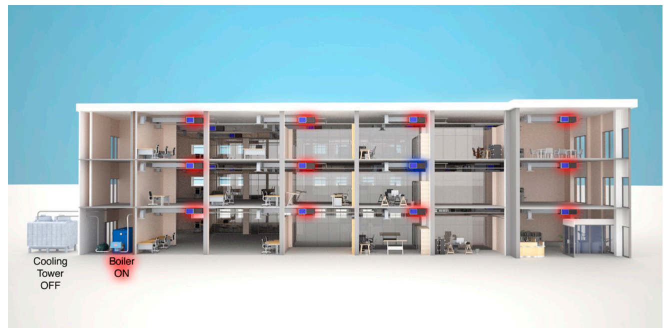

Figure 9: Most of the units are in heating mode. The cooling tower is off and the boiler is turned on.

The WSHP industry continues to make strides in improving efficiency, even at part load conditions. Technologies like microchannel heat exchangers, variable speed compressors, BMS integration, wireless thermostats, and occupancy sensors are being tested or have already been implemented to further reduce energy usage and stay at the higher end of the efficiency spectrum.

Conclusion

WSHPs are a time tested efficient solution that have been successfully deployed in commercial buildings. They are especially effective in reducing energy consumption where there is diversity in energy demand and result in smaller sizes of cooling towers and boilers. By using water as a heat transport medium in a common water loop, WSHPs can move thermal energy across large distances safely and more efficiently compared to alternative solutions on the market. They are smaller and offer design flexibility by allowing the placement of towers, boilers and pumps in locations remote from occupied spaces. WSHPs eliminate flammability risk associated with furnace heating and they accomplish highly efficient operation using much smaller quantities of refrigerant charge compared to VRF systems.

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