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Heat Recovery Water Source Heat Pump System

Water Source Heat Pump (WSHP) systems are considered energy efficient since they can move heat from one location within a building to another location. However, there are two main limitations to this system. The first is that the heating compressors generate additional heat, even though during intermediate seasons there may be sufficient waste heat within the loop to satisfy the heating load. In addition, the compressors consume electricity simply to access this waste heat in the loop. The second limitation is that the fluid loop temperature cannot go above 90º F (32.2° C) for heating compressors to remain operational, or they risk overheating. This limitation may require the operation of a heat sink in order to lower the loop temperature in certain seasons – and operating a heat sink consumes additional electrical energy.

The CGC Group Hybrid Heat Pump System described here combines WSHP and hydronic heating into one operating system. It can heat or cool any space at any time of the year. Heat is either extracted from, or rejected to, the same two-pipe fluid loop just like any conventional WSHP system. The system components (boiler, fluid cooler or cooling tower, etc) form an integral part of the system just like all WSHP designs.

In cooling mode, the CGC Hybrid system operates identically to any conventional WSHP. They are water-cooled air conditioning units, rejecting the building heat to a heat sink through the fluid loop.

For heating, a traditional WSHP absorbs heat from the fluid loop using the refrigeration cycle operating in the reverse mode. Conversely, the CGC Hybrid units operate as simple fan coils, absorbing the fluid heat directly through a hot water coil located inside the unit.

The fluid heat being absorbed comes from two possible sources:

A) From the heat of rejection and compression of the cooling units.

B) From the boiler plant.

Traditional WSHP Operation

A WSHP is said to have a COP (Coefficient of Performance) of approximately 4. For every one unit of energy input, there are 4 units of heat output.

$$COP = \frac{\text{Heating capacity (Btu/hr)}}{\text{Energy input (watts x 3.413 Btu/watt-hr)}} = \frac{\text{Fluid heat + Compressor heat}}{\text{compressor electrical input}}$$

It is not always evident that the total heating capacity output is made up of approximately 75% fluid heat and 25% compressor heat so that the majority of the heat delivered comes from the fluid loop. Once we recognize this, we realize that there are other ways to acquire this heat.

Hybrid System Layout

The architecture of the CGC Hybrid system is identical to any conventional WSHP. It has all the same components, and does not require any additional piping or complicated controls. For heating, instead of energizing a reversing valve to redirect the flow of refrigerant, the hybrid system energizes a simple water valve to redirect the flow of water away from the condenser to a hydronic coil. The coil, valve, piping and controls are all internal to the unit. The installing contractor or the design engineer sees no difference, and the system costs are no greater than a traditional system. The only modification required is an outdoor air sensor, and a larger boiler plant. An outdoor sensor is required since the hydronic heating system is controlled by resetting the fluid loop temperature to ambient conditions, just like any conventional fan coil heating system. A larger boiler plant may be required since the heat normally generated by the compressors will be generated by the boiler plant. This is called fuel switching and is discussed further in this article. To offset the cost of a larger boiler plant, installation cost savings are possible with the CGC system, since the design water flow rate is 2 gpm/ton versus the more traditional 3 gpm/ton. This reduction in flow rate will provide capital cost savings for a smaller fluid cooler, smaller water pumps, and smaller pipes. Of course, lower flow rates will result in lower pumping energy over the entire life of the system.

What about mechanical cooling with elevated fluid temperatures?

Mechanical cooling will always be available up to a maximum fluid temperature of 125° F (51.6° C). However, in most cases, fluid temperatures greater than 115° F (46.1° C) are rarely required, even in very cold climates. Operating cooling units with elevated fluid temperatures in the winter heating season will reduce their energy efficiency. Fortunately, the penalty for operating with elevated fluid temperatures for a limited period in peak heating mode will be minimized if high efficiency models are used. Figure 1 compares the electrical consumption between WSHP's systems operating with 70° F (21.1° C) fluid and hybrid units operating with 110° F (43.3° C) fluid. The only time the hybrid system may require 110° F (43.3° C) is during peak winter conditions when most of the units would be in heating mode, except for possibly interior zones. Therefore, for this example it is assumed that 75% of the units are in heating and only 25% in cooling. This is a very simplified snapshot, but it clearly demonstrates the electrical benefits of turning off the heating compressors even if the cooling units are operating with elevated fluid temperatures.

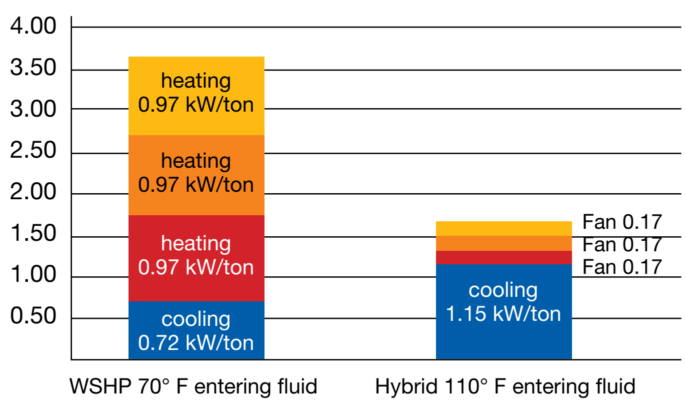


Fig. 1, Electrical energy kW/ton for peak winter operation

A traditional WSHP is very efficient in cooling mode (0.72 kW/ton) with 70° F (21.1° C) fluid serving the condenser, but less efficient in heating mode (0.97 KW/ton) with the fluid serving the evaporators.

What about pipe insulation?

The concern over the requirements for pipe insulation stems from Section 9.4.8.2 of the ASHRAE's Standard 90.1-1989. This standard has been set up to minimize the energy consumption of building systems.

WSHP systems operate with fluid temperatures between 55° F (12.7° C) and 105° F (40.5° C) and according to this standard are exempt from requiring pipe insulation. Another exception is found in ASHRAE 90.1-1989, section 9.4.8.2 (d): "...where it can be shown that the heat gain or heat loss to or from the piping without insulation will not increase building energy costs."

It is repeated in ASHRAE 90.1 – 2007, section 6.4.4.1.3 (c): "... or where heat gain or heat loss will not increase energy usage."

In the winter, the hybrid system fluid temperature is not elevated above 105° F (40.5° C) until the ambient temperatures fall below 15° F (-9.4° C). Most designers who have used the hybrid system have concluded that any heat loss associated with the fluid being above 105° F (40.5° C) for a very short period of time during the peak winter mode is quite minuscule, to the point of being very difficult to quantify. They have therefore relied on the exceptions noted above to not insulate the pipe. Another common thought process is that any heat radiated from the pipe would be radiated to the building structure, so it would not be lost at all.

Making use of ALL the heat generated within the building

Since the CGC Hybrid system does not have a maximum fluid temperature limit of 90º F (32.2° C) in heating mode, the system can actually conserve and reclaim **ALL** of the heat rejected to the fluid loop by the cooling units.

During intermediate seasons, there are often times when there is sufficient heat within the fluid loop to satisfy the heating demand. By turning off the heating compressors and using the hydronic coil, the building can be heated without additional heat input from compressors.

Figure 2 compares the two systems operating on a 40° F (4.4° C) ambient intermediate day. In this example, there should be sufficient heat within the loop to satisfy the heating demand. However, the WSHP cannot allow the fluid loop to climb beyond 90º F (32.2° C) and therefore must operate the fluid cooler in order to reject excess heat. A WSHP cannot operate in heating mode with fluid above 90º F (32.2 °C) since this fluid serves evaporators and the resulting condensing temperatures and pressures would be too high. The heating compressors generate additional heat even though extra heat should not be required on an ambient day of 40° F (4.4° C). The WSHP does not provide part load heating since full compressor heat will always be delivered regardless of the season.

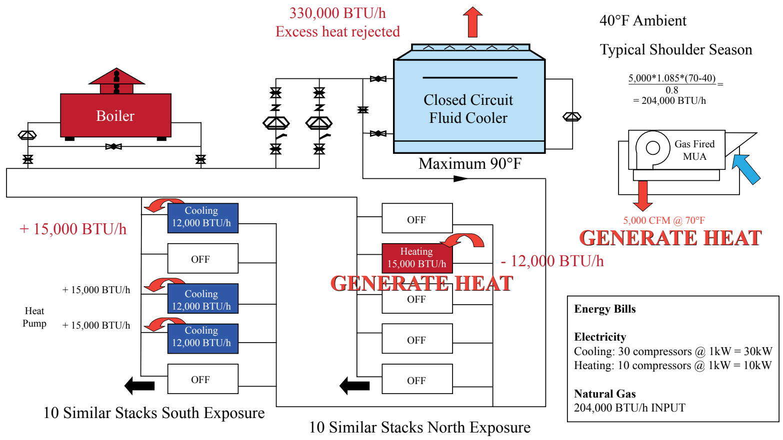
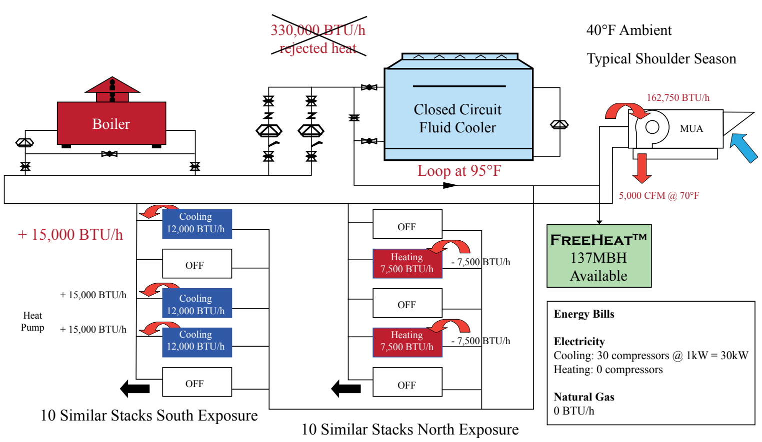


Fig. 2, Conventional WSHP system

Not only is heat being wasted to the fluid coolers, but another source of heat is also required to heat the ventilation air. Gas fired Make Up Air units are required in this example.

With the CGC Hybrid design, we notice that heat is not being rejected to the fluid cooler but rather it is conserved within the loop to allow the loop temperature to reach 95° F (35° C). Since the ambient condition is 40° F (4.4° C), the heating units operating as fan coils will deliver only the required 7500 Btu/h. Essentially, the units are providing part load heating. The Make Up Air (MUA) unit is not consuming a fuel source, but rather is making use of the reclaimed heat. In this example, there is still heat left over for various building heating requirements. At the Frederick Hotel in

Kansas City, this design is using the excess heat to provide towel warming. At the Nelligan Hotel in Montreal, heat removed from the restaurant and suites is used for snow melting as well as garage heating. In the Toronto condominiums, Absolute and 360 ON Pearl, fluid heat is used for under floor radiant heating to combat the cold down draft due to very large glass areas. These “freeheat” examples are possible since heat is conserved within the fluid loop and the temperature is allowed to warm up beyond 90º F (32.2° C). Note that the electrical consumption has dropped to 30 kW by turning off the heating compressors for the hybrid system as opposed to 40 kW for the WSHP. Also, the Natural Gas consumption has dropped to nil from 204,000 Btu/h.



CGC Hybrid system

Under floor radiant heating

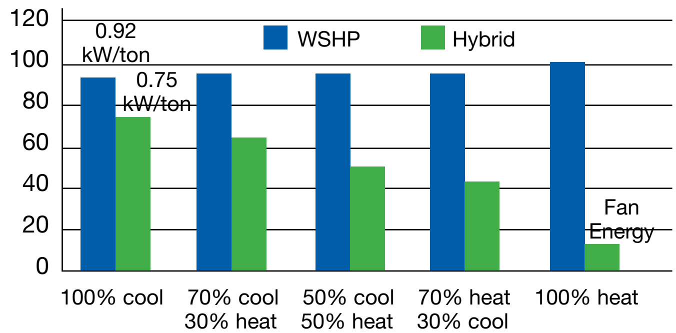


Fig. 3, Heat Pump Electrical Energy consumption , kW/hr

Figure 3 shows simple snapshots in time and compares electrical energy consumed by 100-1 ton heat pumps operating for one hour. A complete energy modeling is required to properly analyze the system with the appropriate amount of operating hours at various load conditions. However, this simple analysis is quite useful to see what happens to the electrical consumption moving from the 100% cooling season, through the intermediate seasons and finally to the 100% heating mode.

In 100% cooling mode, the CGC Hybrid units consume less energy since they are high efficiency models as opposed to simply meeting the ASHRAE standard 90.1 minimum requirement of 12 EER. Using high efficiency models will also limit the energy penalty when operating cooling units with elevated fluid loop temperatures during peak heating mode. Considerable energy savings are achieved in the intermediate seasons when the hybrid system turns off the heating compressors and absorbs the waste heat through a hydronic coil. The traditional WSHP will always require compressor operation regardless of if they are in heating or cooling mode.

This graph only represents the energy consumed by the heat pumps themselves. It does not address the boiler plant output. With either system, boiler plant output will not be required until there is insufficient heat of rejection and compression from the cooling units. The hybrid design will require more boiler plant output than the traditional WSHP, since it does not generate heat with compressors. Typically, the incremental cost to install a larger boiler plant is relatively low and is offset by very short payback. The CGC Hybrid system simply shifts the compressor heating load to the boiler plant, where a lower cost fuel can be used – typically Natural Gas. It must be noted that both systems will deliver **equal amounts** of heat during peak heating mode. However, the WSHP will derive approximately 25% of the heat from electricity. Figure 4 shows the financial benefits of shifting the electrical heat to the boiler plant.

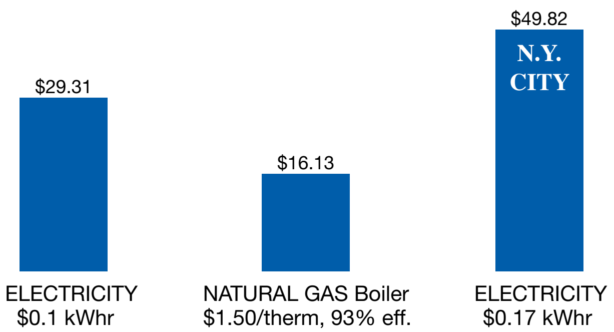


Fig. 4, Cost to generate 1 million Btu of heat

1 million Btu/3,413 = 293.1 kW x 1hr x $0.1 = $29.31
1 million Btu/100,000 = 10 therm x $1.50/0.93 = $16.13

In this example, generating heat with electricity heat costs more than heat provided by Natural Gas boilers (+81.7%).

This analysis clearly demonstrates that heating with electricity costs more than heating with Natural Gas (+81.7%). Of course, the cost of fuel varies from one city to another. In N.Y. City, with electricity at $0.17 kWh, the gap is even larger at +309%.

Geothermal

A variation of the hybrid heat pump system has been applied to geothermal systems. Since the compressors do not operate in heating mode, a method of removing the heat from the ground is required. Water to water chillers are used for this purpose. Substantial energy savings are realized in the intermediate seasons by turning off the heating compressors when there is sufficient heat in the loop, similarly to the closed loop system. Caneta Energy conducted a study on the Springdale Professional Building near Toronto and concluded that a CGC Hybrid system will save 23.8% HVAC energy over a conventional geothermal system.

Energy Analysis

Enermodal Engineering, a well-respected energy consultant, performed a building energy analysis to determine the energy saving benefits of the hybrid heat pump system versus a standard WSHP. Both systems were modeled with identical parameters in terms of EERs, flow rates, capacities, etc. Using the software eQUEST, their analysis conclusions are summarized in Table 1.

A condominium project (located in Toronto, Canada) was selected since this type of building would yield the least favourable results for the hybrid design, due to the limited quantity of operating hours with simultaneous heating and cooling operation. Buildings such as office complexes or schools where there may be more operating hours with simultaneous heating and cooling should yield better results for the hybrid system.

The conclusion reached by the **Enermodal Engineering** analysis is that the process of turning off the heating compressors would deliver a 6% annual **Total building** energy reduction, or a 9% annual reduction in energy when compared to only the **HVAC portion**.

Another major advantage of the CGC Group Hybrid System is fuel switching. This is the process of transferring the electrically generated heat away from the heat pump compressors to the boiler plant, where a lower cost fuel source can be used. In this case, Natural Gas Fired condensing boilers with 93% efficiency were used. Commonly, it is less expensive to heat a building with Natural Gas than it is with electricity. In this case, fuel switching contributed additional financial savings to bring the **Total building** energy cost savings to 11.6% per year, or 20% savings per year when compared to only the **HVAC portion**.

Table 1

HVAC Analysis

	WSHP	hybrid	**Savings**
kWh	2,491,069	1,617,706	873,363 (35%)
Therms 100,000 Btu	121,972	133,672	-11,700 (-10%)
TOTAL energy million Btu	20,699	18,888	**1,811 (9%)**
Building Energy cost	$416,802	$332,761	**$84,042 (20%)**

Total Building Analysis

	WSHP	hybrid	**Savings**
kWh	5,245,304	4,371,941	873,363 (17%)
Therms 100,000 Btu	123,748	135,448	-11,700 (-9%)
TOTAL energy million Btu	30,277	28, 466	**1,811 (6%)**
Building Energy cost	$721,987	$641,882	**$84,042 (11.6%)**

($0.1115 kWhr, $ 1.14/therm, $1.14 CCF)

Note: Extra fan energy was factored in for the hydronic coil (APD= 0.05").

With the cost of Natural Gas at $1.50/therm, the total building annual savings would be $79,829 (10.4%), or 17% for the HVAC only.

Maintenance

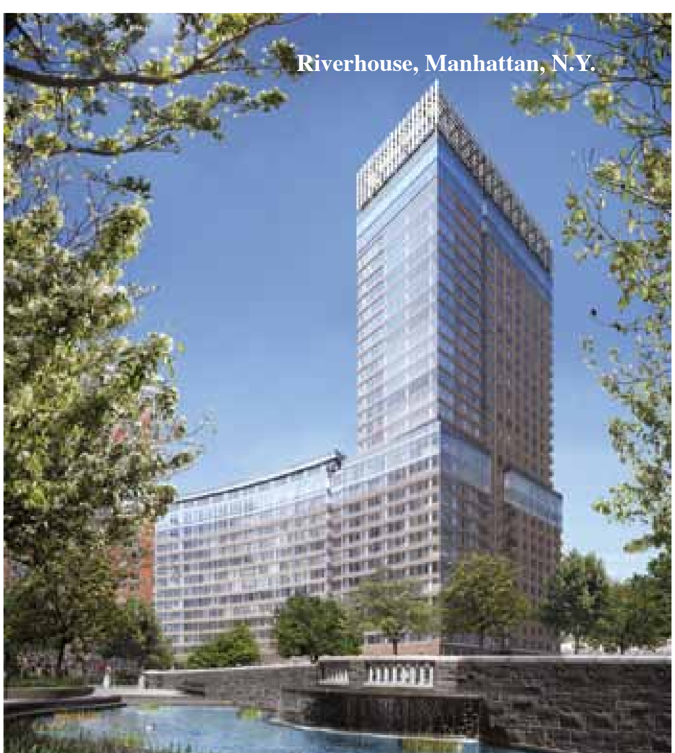
It seems self-evident that if the compressors only operate in cooling mode, they will last longer. Compressor manufacturers rate the useful life by the quantity of start-stop. Eliminating the heating mode operation will drastically reduce the quantity of start-stop and extend the useful life of the compressors.

Retrofit Projects

Ameresco, an energy solution company, has retrofitted many projects, including schools and hotels, using the CGC Hybrid system. It is difficult to determine the exact amount of energy savings that can be attributed solely to the hybrid system since other changes are usually made to the buildings such as lighting and boiler retrofits. However, **Ameresco** in Toronto states that there are significant energy savings achieved with the CGC Hybrid system as opposed to a standard WSHP.

New Constructions

The CGC Group Hybrid Heat Pump System has been used successfully since 1998 in new construction projects such as assisted living spaces, schools, office complexes, hotels and condominiums. Among them are **Hilton Hotels** (Toronto, Montreal), **Marriott's** (Seattle, New York), Manhattan condominiums **RiverHouse** (LEED Gold) & **Trebeca Green**, as well as the one million square foot **Bell Canada** (LEED Gold) office complex in Montreal.


Riverhouse, Manhattan, N.Y.

Summary

A traditional **WSHP** has certain limitations:

A) Compressors must consume electricity to extract waste heat from the fluid loop, and they generate additional heat – even during periods when there should be sufficient waste heat in the loop. Hence, the WSHP may be generating heat and consuming electrical power needlessly during spring and fall.

B) Approximately 25% of the heat delivered is generated from electricity. Typically, heat can be generated less expensively using alternate fuels such as Natural Gas.

C) The fluid loop maximum temperature limit of 90º F (32.2° C) in heating mode limits the amount of heat that can be reclaimed and may result in needless rejection of energy to a heat sink.

CGC Hybrid System

By comparison, the CGC Hybrid system absorbs heat directly from the loop without additional heat generation since the compressors do not operate. Since there is no longer a maximum loop temperature limit of 90º F (32.2° C) the system allows for greater heat conservation.

Energy & Cost Benefits

Reduced Energy & Cost

- Reduced electrical consumption in heating mode by turning off the compressors.
- Switches the compressor generated heat to the boiler plant where lower fuel costs can be used.
- Reduced heat sink operation in intermediate seasons, since heat is conserved within the fluid loop.
- The conserved heat can be used for various building heat, which reduces other fuel consumption components such as Natural Gas fired Make Up Air units.

Conclusion

A CGC Group Hybrid Heat Pump System is a novel design that delivers better heat recovery capabilities than a traditional system, resulting in significant energy savings. It overcomes the limitations of Water Source Heat Pump systems and provides innovative energy solutions that buildings across North America can profit from.

For more information go to www.cgc-group.com