NON-REVERSING, 100% OUTSIDE AIR HEAT PUMP FOR HEATING AND COOLING

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Traditionally, a heat pump has relied on a reversing valve system design to achieve the bi-directional requirements of heating and cooling. Unfortunately, the limits of performance using a reversing valve have made applying it to a dedicated outside air system (DOAS) not possible or requires significant preheating which makes the unit non-efficient. A new innovative concept will be explained that will change how all Geo/WSHP projects are designed. It will give consultants the opportunity to expand heat pump uses into projects that were not possible before. The new heat pump design will allow the heating, cooling, and dehumidification of outside air without the use of any auxiliary heat source with EER values above 14 and COP exceeding 6.0. The unit's flexibility and how it integrates into a variety of loop systems will be explained as well as its total system operation.

Key words: ***water source heat pumps (WSHP), non-reverse cycle WSHP, dedicated outside air systems (DOAS), Hot Gas Reheat (HGRH), heating/cooling/dehumidification, Energy Recovery Systems, Four–Element WSHP***

1 INTRODUCTION

Water source heat pump (WSHP) systems are considered to be one of the most efficient ways to heat and cool a small to mid-sized commercial building. In most of the world, operating cost (energy usage) is the primary concern of a building owner assuming a reasonable installed cost. In the USA, this is not the case, but things are in a state of change. With the cost of energy increasing, consumers and HVAC consulting engineers in the USA are finally looking at operating cost as the more important variable over first cost. Electrical utilities are finding it difficult to build new power plants and with the ever increasing demand for electricity, some are starting to renew rebate programs to reduce the connected load for their grids.

This paper will describe a unique methodology to apply a heat pump system for use on 100 percent outside air and allows it to operate efficiently utilizing ground loop water systems, boiler/tower (Building Loop) systems, and hybrid systems.

A heat pump essentially performs just as its name implies, by "pumping" energy from a hot source to a cold source. For HVAC applications, this process must also pump energy from a cold source to a hot source in order to achieve cooling. When this device is in the heating mode it draws energy from the water and transfers it to the air. In the cooling mode, the reverse must occur, thus heat from the air is transferred to the water.

This energy transfer takes place through a refrigeration system with the compressor acting as the energy pump. In the heating mode, the water coil accepts cold refrigerant gas from the TXV valve. The ground source water is significantly warmer and transfers heat from the water to the refrigerant. The refrigerant then circulates to the compressor, picks up the heat of compression, and becomes a hot gas. In this state, it is directed to the air coil where it gives up heat to the cold air stream. The refrigerant quickly returns back to a cool, saturated vapor and the process is repeated. (Refer to figure 1.)

In the cooling mode, the cold gas from the TXV valve is directed to the air coil. The refrigerant cools the air to its dew point and water condenses, giving up more energy. The refrigerant once again flows through the compressor and ends up in the water condenser where it gives it heat to the ground source loop. (Refer to figure 2.)

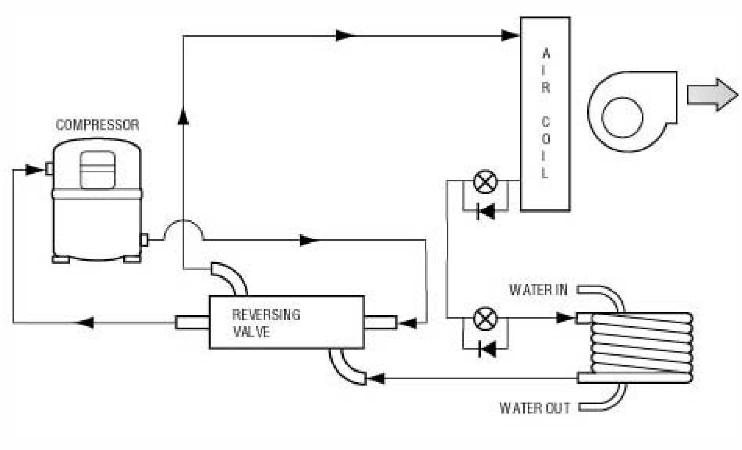


Fig. 1. Heating Mode

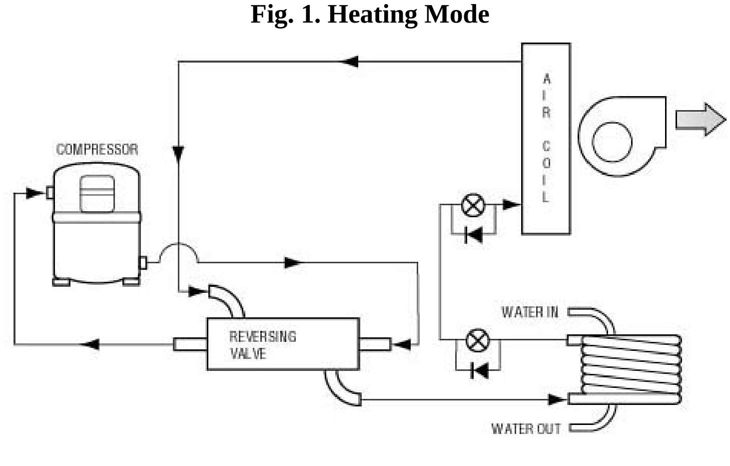


Fig. 2. Cooling Mode

In typical heating or cooling and systems, the return air temperature does not vary significantly. Thus a heat pump system can afford inefficiencies in its design to achieve the heating and cooling loads for the building. When 100 percent outside air is the source to be treated, the range of ambient conditions from 30 degrees Celsius in the summer to -15 degrees Celsius in the winter requires a much more complex and exact heating and cooling system to meet the varying loads at both peak design and part-load design days.

Meeting the ASHRAE 62 ventilation code in existing buildings has become a requirement in the move to improve indoor air quality. The need for consulting engineers and building owners to conform to the code in order to help eliminate "Sick Building Syndrome" has been well documented. According to the general accounting office ([1]GAO 1995, 1996), 20 percent of schools suffer from poor indoor air quality with as many as 36 percent saying their HVAC system was less than adequate. As consulting engineers and end-users implement ASHRAE 62, they must select the appropriate method for introducing outdoor air while controlling the temperature and humidity within the conditioned space.

An interesting paradox is created, however, when this code ventilation is applied to buildings in humid areas. The new or existing WSHP can be modified to bring in more outdoor air to dilute the internal contaminants. However, the modern WSHP cannot remove the additional latent load from the warm, moist outdoor air. Just over sizing the system will cause short-cycling and increase the moisture problem. The air inside the building becomes excessively moist, creating a new indoor air quality problem as mold, mildew and other moisture-loving organisms begin to thrive in this environment. Dealing with one indoor air quality problem gives rise to another. This leads to Dedicated Outdoor Air Systems (DOAS) becoming the standard way to address the IAQ and the SBS issues. “Significant IAQ benefits can be achieved by decoupling the outdoor ventilating air cooling and dehumidification from the space cooling and dehumidification functions.” ([2] Mumma 2003)

If a DOAS is the ideal product for the design, it cannot be overlooked that a compressor based DOAS must have Hot Gas Reheat (HGRH). HGRH is essential to the system design utilizing DOAS to prevent overcooling in part-load conditions and an easy way to meet the intent of ASHRAE 90.1. The standard establishes a need for energy conservation of commercial buildings and provides details on how HVAC equipment can meet the requirements. ASHRAE 90.1 states that some systems cannot use new energy to reheat the air; rather, 75% of their energy must be site-recovered.

1.1 ASHRAE 90.1-2001

To meet the intent of ASHRAE 90.1, you must have controllable / modulating HGRH (e.g. Variable HGRH (VHGRH)) in lieu of stepped or staged HGRH. Stepped or staged HGRH may not control the LAT to the requirements of 90.1 as stated above. With controllable HGRH +/- 2.2º C (+/- 4.0ºF) or better, the LAT can be maintained within the 25% maximum limit of possible new energy usage meeting the intent of standard 90.1 (refer to Figure 3).

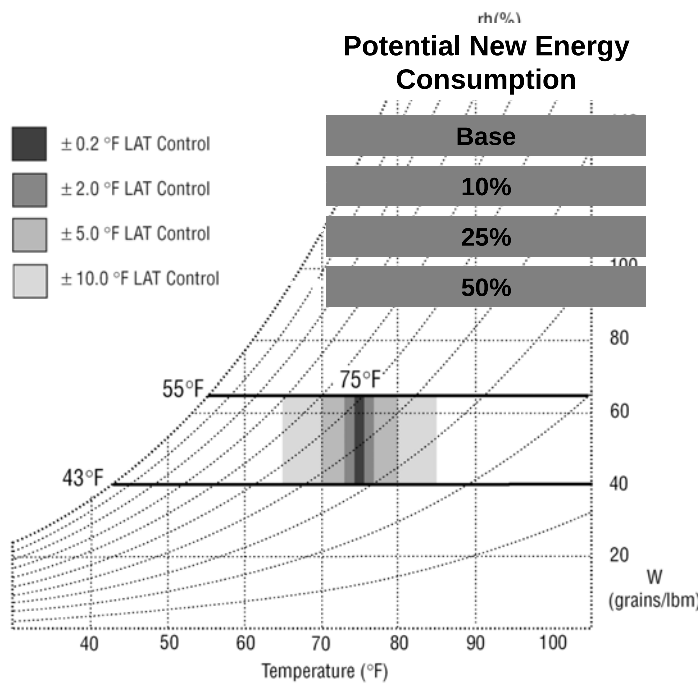


Fig. 3. Site Recovered HGRH Min Requirements

Variable controllable HGRH will allow Leaving Air Temperature Control (LATC). This is a dynamic requirement of a DOAS. This will prevent the DOAS from providing an air supply temperature that affects the space temperature in negative non-efficient way.

1.2 Dedicated Outdoor Air Systems (Doas)

The most energy efficient method for removing moisture in outside air is to use a DOAS that will reduce the dew point of supply air to below 12.7°C (55°F). This approach also helps remove existing moisture inside a facility. A DOAS system design can also be optimized to remove maximum moisture at the lowest electrical consumption rate (Moisture Removal Efficiency, MRE) at both full and part-load conditions.

The DOAS system operates in the heating and dehumidification/cooling modes, and must be designed to handle a wide range of outside ambient conditions. A properly designed system can reduce the total capacity of the required cooling system because the DOAS system cools the outside air in the process of dehumidifying. Under normal operational modes, the unit would reheat the air back up to a neutral temperature. However, it could be set up to reheat to a cooler temperature, thus providing air conditioning and reducing the overall size of the cooling plant. The DOAS can provide part-load cooling and heating during its standard ventilation operating condition.

1.3 DOAS Special Heat Pump Design Requirements

Several design issues must be considered when applying a reverse cycle system to a 100% outside air application. For instance, one must consider the range of conditions that the coil will be exposed to. Plus, it is important to remember that it must function efficiently as an evaporator coil and a condensing coil. This is a very difficult refrigeration design that must accept significant performance degradation in order to operate in all modes under all ambient conditions.

For example, consider a typical air-side coil functioning as a condenser. The majority of the refrigerant passing through its tubes exists either as a superheated vapor or a low quality liquid/vapor mixture. This mixture must flow with a velocity sufficient to "sweep" refrigeration oil back to the compressor to ensure proper lubrication. When the system reverses and this same coil functions as an evaporator, the pressure drop of the refrigerant in the coil becomes much higher. This happens because the majority of the refrigerant passing through its tubes now exists as a sub-cooled liquid or high quality liquid/vapor mixture.

Unfortunately, high evaporator pressure reduces the cooling capacity of a heat pump because its compressor must work harder to overcome the friction between the liquid refrigerant and the tube walls of the evaporator coil. Although one can design a coil to reduce its refrigerant pressure losses when it functions as an evaporator, this same coil may not function well as a condenser. Its refrigerant velocity may then be insufficient to sweep lubricating oil back to the compressor.

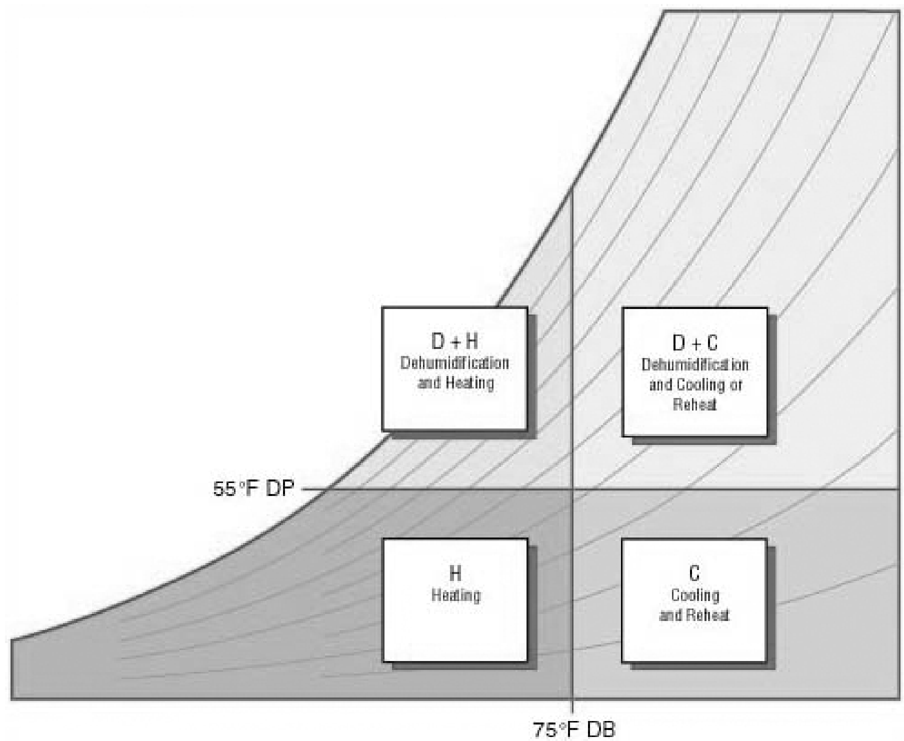
The second major design consideration is the amount of variable heat required to adjust the temperature of outdoor air to the designated space temperature. Only a part of the energy in the heat pump loop is needed to reheat the air, therefore, a second condenser in series with the first is required to reject the total heat of rejection of the system. This further complicates the refrigeration balance and creates the risk of oil return to the compressor. The basic reverse-cycle system does not control the leaving air temperature.

There are four distinctively different load quadrants of an outside air load requirement. (See Fig. 4)

- Quadrant 1 = (D + C) dehumidification and cooling. This is the quadrant that all air conditioning systems are sized for. The problem is that the outside air load is not always at the design peak load.

Therefore, the DOAS system must address the outside air-load during all operating conditions, not just at peak and near peak load. Quadrant 2 = (C) Cooling and actually humidification. The DOAS system is off.

- Quadrant 3= (H) Heating and humidification. This can be approximately 50% of the outside air load operating time. This is where the enthalpy recovery wheel (ERW) can assist in pre-conditioning the outside air prior to the use of the loop to heat the air.
- Quadrant 4= (D+H) Dehumidification and Heating. In the triangular area, there are many bin hours (as much as 25 to 45% of the total) with high to excessive moisture (possibly approaching or exceeding the DB design condition). Typical WSHP will be off, so the DOAS system must dehumidify and heat using recovered hot gas energy.



CITY	D + C	D + H	H	C
Chicago	10%	17%	71%	2%
Wash. DC	15%	22%	60%	3%
Orlando	43%	32%	22%	3%
San Francisco	0%	3%	96%	1%

Fig. 4. Quadrants of Control

2 FOUR-ELEMENT – 100% OUTDOOR AIR SYSTEM

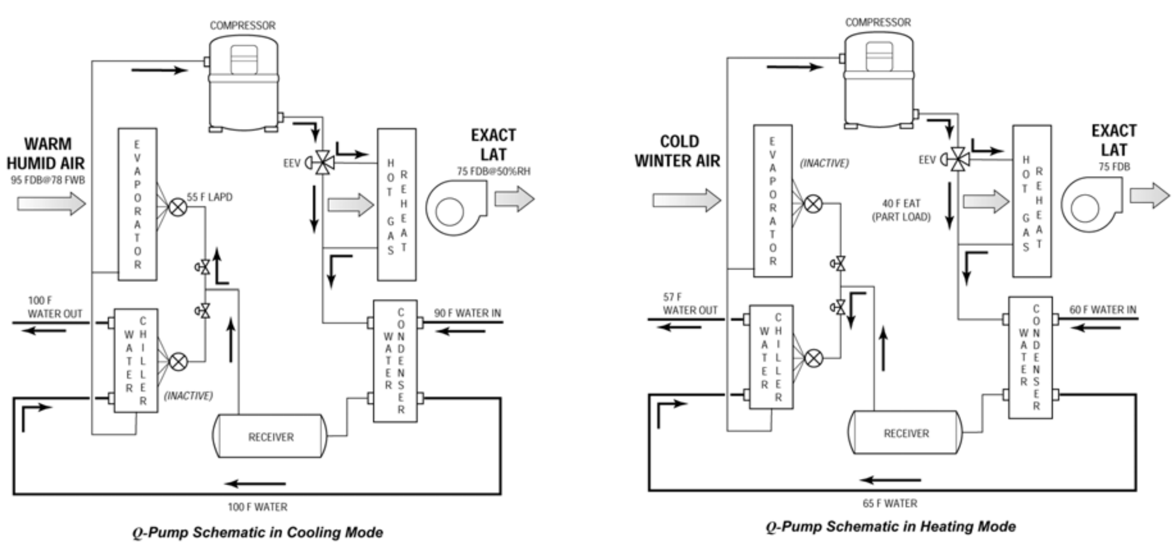
A Four-Element System uses an innovative refrigeration system to overcome the typical problems of a two-element reverse cycle system, including:

1.) Reduced efficiency and performance by design.
2.) Eliminating the requirement of the troublesome "sticky" reversing valves
3.) Reduces the potential for liquid slugging
4.) Reduces the risk of refrigerant suddenly flashing into vapor.

The four-element dehumidifier uses a unique method of heating 100% outdoor winter air without the need for a separate auxiliary heat source such as gas. Our basic system is effective down to -9.44° C (15ºF) winter design temperature without additional auxiliary heat. With an optional enthalpy wheel, the system is effective down to -23.33ºC (-10°F), again, without additional auxiliary heat.

One of the key differences between four-element option and prior solutions is the use of two independent water condensers. One acts as the true condenser for the completion of the total heat of rejection (THR) of the system and the other is the evaporator in the reverse cycle heating mode. Because of the use of the four elements, the hot gas reheat coil can be used in both the cooling and heating modes providing the ability to modulate the leaving air temperature. Its unique design allows for a simple refrigeration design and for the refrigerant itself to be balanced throughout the system.

The hot gas reheat coil is sized to warm up cold air to space conditions, e.g. from -9.44º to 23.88ºC (15° to 75°F) with 15.55ºC (60°F) water. During off-peak times (95% + of operating time), the unused heat of rejection boosts or "supercharges" the water temperature before it is extracted from the loop. This added energy to the water loop increases the system's efficiency. In the summer mode, the water evaporator is inactive and removed from the refrigeration loop by a solenoid valve. In the winter, the air evaporator coil is inactive and the water evaporator will pull energy from the slightly heated ground water loop. The evaporator reduces the water temperature by about -15.0º to -14.44º C (5° to 6°F). Figures 5 and 6 provide a detailed schematic of the Four-Element System in the summer and winter modes.



Figs. 5 & 6. Title?

2.1 Control Schemes

A WSHP DOAS design must have the ability to adapt to the varying conditions of the outside air temperatures; just unloading compressors will not be adequate. The system must have a HGRH component (as stated above) which must have a means to vary the LAT. With the proper refrigeration system design balance, the controls finalize the LAT control allowing LATC with true Variable/Modulating HGRH. There are number of DOAS air temperature control strategies. Three popular control variations are room control, leaving air temperature (LAT) control and room reset of LAT.

1. Room Control

This strategy uses a single wall-mounted sensor to maintain the desired temperature in the conditioned space. Heating or cooling is energized when the space air temperature moves away from the set point. Because of the large mass of air in the room, the supply air temperature may need to be much warmer or cooler than the actual room temperature to drive it closer to its set point. This is a standard understanding in comfort heating and cooling, but with 100% OA modulating control of heating (HGRH or Auxiliary heating) may be required for room control without swings in temperature.

Because LAT may swing widely, supply grilles must be installed where they won't blow air directly on any occupants. Room control is most economical for comfort conditioning purposes in spaces where the system provides less than five air turns per hour. The large room volume (mass) acts as a buffer to quick changes in room temperature.

2. Leaving Air Temperature (LAT) Control

A LAT approach uses a single duct-mounted sensor to maintain the desired temperature of the supply air. Because the air mass in the supply duct is relatively low and is moving rapidly, the heating must respond quickly to changes in the set point.

On/off or staged heaters for the heating mode can rapidly cycle because their steps or stages are too extreme for the level of control required (for Reheat it should not be allowed). Modulating controls can make the small incremental changes necessary to maintain tight control without over heating the space.

Using staged or modulating controls on reheat (HGRH only) and auxiliary heaters will help extend the life of the system, while providing more uniform supply air temperatures.

Exact LAT control is not necessary when a makeup air dehumidifier is supplying conditioned outdoor air to an air handling unit. However, the modulating control can save significant "system" energy, and may be preferred over on/off control in this application. When a makeup air dehumidifier is supplying air directly to a conditioned space, LAT control eliminates the drafts commonly felt with on/off systems. Likewise, LAT control is also ideal in industrial applications that require precise air temperatures.

3. Room Reset of LAT

This strategy combines a wall-mounted sensor with a duct-mounted sensor to maintain the desired temperature in the conditioned space. Heating or cooling will be activated when the air temperature shifts away from the set point. However, unlike the room control strategy, the controller varies the LAT within a fixed range to maintain the room set point. This particular system is especially helpful at preventing over-heating or over-cooling of a space that is influenced by other energy sources, such as solar gain or loss through windows.

This strategy works best when modulating controls are used with an auxiliary heat source and a dehumidifier reheat coil, as is the case with a modulating hot gas reheat system.

Room reset of LAT provides the greatest control over temperature and comfort in spaces with more than five air turns per hour. It helps to conserve energy by preventing overheating or overcooling of the conditioned space. Because this method gradually adjusts room temperature, hot and cold drafts are virtually eliminated. This produces more comfortable surroundings for occupants and a more stable environment for temperature-sensitive equipment.

4. OA Reset of LAT

This strategy operates similar to the above Room Reset of LAT, except it operates on a predetermined LAT based on the OA temperature. See the example below:

5. Temperature and Humidity Control (Occupied and Unoccupied operation)

This operating strategy can be added to all the above control schemes if the return air is available during the unoccupied times.

3 SYSTEM EFFICIENCY AND OPERATIONS

When a consulting engineer properly integrates the approach of WSHP's with DOAS into a system design, it can be one of the most energy efficient building designs in existence and at a competitive installed cost $/ton. This is an exceptional idea, but just until the last two to three years, this was very difficult, if not impossible, to accomplish. The reason this achievement was difficult was there was no existing WSHP system that could properly address the total (sensible and Latent) load of 100% OA, dehumidifying / cooling it with energy efficient reheat (to prevent over cooling at part-loads) and heating the air to room neutral when the air is below 12.7ºC (55ºF) dew point without overheating the space at part-load conditions.

The minimum acceptable heat pump EER rating by ASHRAE 90.1- 2001 and ARI/ISO Standard 13256-1 is 4.2 on a building loop system and 3.1 on a geothermal loop system. The Four–Element System's COP range is from 4.5 to 6.5 and is based on an outside air load rather than return air load (this is a much more difficult load to address) without energy recovery wheels (ERW). For a system with an ERW, the minimum standard becomes 12.0 on a building loop systems and an EER of (13.4) on a geothermal loop system. The Four-Element System has a range of 10.5 to 25 plus in EERs and a range of 4.5 to 10.6 in the COP department, all on the more difficult outside air temperature loads (See the tables below).

Four-Element DOAS WSHP Unit EER / COP								
Geothermal Loops								
EAT°C DB / WB (5)	**CFM**	**Comp Nominal HP**	**Total Cap MBH**	**Unit LADP**	***EER*** **/** COP	**MRE (2)**	**EWT°F(4)**	**GPM / GPM Ton (3)**
35/25.55 (95/78)	3500	25	346	48.0	***15.9***	7.2	77	84 / 2.91
35/25.55 (95/78)	8000	56	748	50.2	***15.7***	7.0	77	186/2.98
< -12.22ºC (10°F) **(1)**	3500	25	324	NA	5.4	NA	41	84 / NA
			276		4.6		32	
< -12.22ºC (10°F) **(1)**	8000	56	724		5.5		41	186 / NA
			618		4.9		32	
Building Loops 60°F to 90°F								
35/25.55 (95/78)	3500	25	307	52.9	***10.6***	4.8	86	70 / 2.74
35/25.55 (95/78)	8000	56	664	54.2	***10.4***	4.6	86	155/2.80
< -12.22ºC (10°F) **(1)**	3500	25	437	NA	5.3	NA	68	70 / NA
< -12.22ºC (10°F) **(1)**	8000	56	972		5.4		68	155 / NA

Four-Element DOAS WSHP Wheeled Unit EER / COP									
Geothermal Loops									
EAT°C (5)	**Suppl y CFM**	**Return CFM**	**Comp Nominal HP**	**Total Cap MBH**	**Unit LADP**	***EER*** **/** COP	**MRE (2)**	**EWT°F (4)**	**GPM / GPM Ton (3)**
35/25.55 (95/78)	3500	3100	10	304	52.7	***24.7***	11.1	77	34 / 1.35
35/25.55 (95/78)	8000	7200	25	695	52.7	***25.5***	11.4	77	84 / 1.45
< -17.77ºC (0°F) **(1)**	3500	3100	10	364	NA	10.6	NA	41	34 / NA
				342		10.1		32	
< -17.77ºC (0°F) **(1)**	8000	7200	25	822		10.4		41	84 / NA
				774		9.9		32	
Building Loops 60°F to 90°F									
35/25.55 (95/78)	3500	3100	10	287	54.9	***18.3***	8.1	86	28 / 1.18
35/25.55 (95/78)	8000	7200	25	654	54.9	***19.1***	8.4	86	70 / 1.29
< -17.77ºC (0°F) **(1)**	3500	3100	10	414	NA	9.0	NA	68	28 / NA

< 0°F **(1)**	8000	7200	25	935		9.3		68	70 / NA

Notes:

1. The Four-Element System will control the LAT to 23.88º C (75ºF) in the heat pump mode with an EAT -12.22 to -9.44º C (10 to 15ºF) or below and adequate EWT.
2. MRE is Moisture Removal Efficiency.
3. The GPM/Ton is GPM per actual performance ton.
4. The EWT is calculated based on the rating points of the proposed ARI/ISO Standard 13256-1. This standard will replace the current ARI standards 320, 325 and 330.
5. At the time this article was written, ARI/ISO Standards do not address 100% OA units. Therefore, an EAT that relates to 100% OA loads was used in the efficiency calculations.

4 CONCLUSION

The major reason the use of WSHP systems are as popular as they are is the design flexibility, economical installed cost and ideal operating costs. The addition of the Four-Element DOAS WSHP requires a WSHP system to be considered on all projects. The fact this system design doesn’t just meet the minimum efficiency requirements of ASHRAE 90.1-2001, but that they greatly surpass them is a benefit to the owner and the environment. The loop efficiency becomes a true player in the energy decision. The flexibility of the Four-Element System allows the designer to choose the type of loop system practical for the project/site and then optimize the flow rate of the loop using a DOAS type of system to treat the outside air requirements.

If you consider the proper outside air design requirements as described by ASHRAE 62, 90.1-2001, LEEDS system designs and other international energy efficient design requirements, a DOAS for 100% outside air is the correct way to solve most types of design challenges. A Four-Element DOAS WSHP can assist in acquiring over 15 points to meet the LEED certification points.

The type of climate impacts the design choices and the severity of the dehumidification requirements. In warm humid climates such as the Southeast USA and the Eastern Seaboard Coastal Area, a DOAS is required for the control of the humid outside air. Introducing air into a standard unit at these dew points at both peak and part-loads can be devastating. In dry tempered climates such as the Southwestern part of the US, there is little need for dehumidification of the outside air . However, in these areas the air conditioning compressor run time is considerably reduced due to the actual cooling load. In a school classroom for instance, this may lead to a possible build-up of moisture because of the heavy occupied space. If the outside air is at or above 15.55º C (60ºF) dew point, the space can have a major problem with IAQ issues. In cool and dry climates such as the Midwest and Northeastern USA, most of the operating hours of a school and office building are at or below the OA design temperature of 18.33º C (65ºF) dew point. With this low of an outside air design temperature, it may be assumed that the standard AC systems can remove the moisture from the OA. However, the low amount of compressor run time can lead to a possible build up of moisture in the space.

A positive design approach for all these areas is the Four-Element System DOAS design with standard WSHP for sensible cooling. In the warm humid climates, the Four-Element System with or without ERW, will dehumidify the OA reduce the space humidity and allow the WSHP to do what they are designed for, sensible cooling and space heating. The Four-Element System will also handle the heating requirement of the outside air.

In the Dry Tempered and Cool and Dry Climates, the Four-Element System with ERW will allow the system to be designed as a complete WSHP loop, with the major heating load of the outside air to be tempered and controlled without adversely affecting the standard WSHP's. A Four-Element System with ERW and a wheel bypass damper can perform building morning warm-up [at 40.55º C (105ºF) plus LAT] in any climate. The building owner and the occupants also get another benefit with a system design of this type, and that is the opportunity to control the temperature and the humidity in the space occupied and unoccupied times with energy saving Humidity Control with night set-back.

In building WSHP loop systems (boiler/tower) the system already has the auxiliary heating unit needed to heat the outside air from 0 to 15 C. The boiler should be sized to handle the building block heating load, including the outside air load. With this design, the DOAS could extract the heating load from the loop, and then the system would have sufficient heat pump heating for all possible operating conditions, without the need of DOAS unit mounted auxiliary heat. This will reduce the system installed cost. In a Geothermal Loop system in cold climates, the best design is with a DOAS ERW. Even with an ERW, the loop water temperature may be near freezing or drop below. Of course, all the systems in this design range will be of the non-freeze design. The nature of this design actually reduces the efficiency of the system. However, if the design had a geothermal to building heat exchanger and a small boiler (Hybrid WSHP System), the controls could decouple the geothermal wells from the building during an extended extreme cold operating time, boost the building loop temperature and greatly increase all the WSHP units' efficiencies, while allowing the loop the opportunity to recover and be re-coupled back to the building loop.

Add to the above described designs the opportunity to do the following additional control modes: part-load on demand heating and cooling, temperature and humidity control during both occupied and unoccupied modes, allowing the zone WSHP supply fan to be on only in the space cooling and heating mode and the ability to do morning warm-up after a energy saving night set-back operation, all make the Four-Element DOAS WSHP a dynamic environmental control system.

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[1] GAO (General Accounting Office). 1995, 1996. "Condition of America's Schools" and "America's School Report Differing Conditions.

[2] S.A. Mumma, Ph.D., P.E. "Decoupling OA and Space Thermal Control" in ASHRAE IAQ Applications/Winter 2003.