WHITE PAPER

BOOSTED AIR-SOURCE HEAT PUMPS

a.k.a.

Acadia™

By

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ABSTRACT

This paper describes a new and improved air-source heat pump system specifically designed for use in colder climate areas where present day systems are found to be seriously lacking in performance.

Present day "air-source" heat pumps are by far the most prevalent type of heat pump used in the world today. Included in this category are: Individual room type units, residential splits, ductless splits, potable water heating units, and many varieties of commercial systems.

Although the general air-source concept has a very high application potential in most of our world-wide climates, its popularity to date has been greatest in only the milder climate zones. This is because the compressor-derived heating capacity of today's systems declines very rapidly as the outdoor ambient temperature falls. This fall in heating capacity is exactly opposite to the increasing heating requirement as colder air temperatures are encountered. When a typical heat pump operates below its realistic balance point (about 32ºf today), supplemental heating from some other source of energy is required. The most prevalent supplemental source in use today is electric by utilization of large electric resistance heating coils located within the units themselves. In other than milder climates, this use of electric resistance heat puts the air-source heat pump at an economic disadvantage to the typical consumer as compared with the other common sources of heating energy available today such as natural gas and oil.

However, these same electric heat pumps are now the dominant form of heating in the south. Because of this, some electric utilities located there are now experiencing "winter peaking demand loads" that have them very concerned. Even in the south, the use of electric resistance heating must be reduced.

When operating at the lower outdoor ambient temperatures, homes heated by present day heat pumps require just as much power input from the electric utility as does a home heated only by electric resistance.

TECHNICAL DISCUSSION

In order for air-source heat pumps to become serious contenders for use in colder climates, significant changes must be made for them to realize their true potential. Fundamental Carnot Theory thermodynamic principles unquestionably show that electric powered air source heat pumps indeed do have very significant potential in cold climates. In fact, the theoretical Carnot C.O.P. (coefficient of performance) limit for a room temperature of 70ºf and an outside air temperature of 0ºf equals 7.566 units of thermal energy delivered to the room for every 1.000 units of work energy supplied to the compression process.

Carnot C.O.P. = $T_2 \times \Delta S \div (T_2 - T_1) \times \Delta S$ where T_2 is the delivered energy's sink temperature in absolute degrees (the 70ºf room temperature in "absolute degrees" = 529.6º) and T_1 is the supplied energy's source temperature (outside air temperature in absolute degrees) and ΔS is the constant change in entropy utilized for this theoretical isentropic cycle. Therefore, executing the equation, the ΔS's cancel out and the final equation is simply: $T_2 \div (T_2 - T_1) = 529.6 \div 70$ = a Carnot limit of 7.566 C.O. P.

It is realistic to expect that with this new system, an actual heating C.O.P. of at least 2.0 will be reached at the 0ºf outdoor ambient condition. This represents a Carnot efficiency level of only [(2.0 ÷7.57) x 100] = 26%, which clearly is within the bounds of rational achievability.

In present day systems, the actual delivered C.O.P. is only about 1.0 at this condition (70°f room temperature and 0°f outside air temperature) because most of their delivered energy comes from electric resistance heating coils at this 0ºf condition and, these electric resistance coils operate with a C.O.P. = 1.0 (1 unit of delivered thermal energy for every 1 unit of supplied electric energy). Also, with these present day systems, the very low delivered energy that does come from their refrigeration circuit may even come with a C.O.P. of less than 1 at these low outdoor ambient temperatures. This is because a significant energy loss occurs between the outdoor and indoor portions of the unit when operating with the extremely low refrigerant weight flow conditions common to these systems.

The heating energy output of any heat pump system is closely proportional to the weight flow of its refrigerant entering the system's indoor unit. Approximately 4 times the amount of heat is required at 0°f as is required at 45°f. This means that approximately a 400% increase of refrigerant weight flow is required at 0°f ambient as compared to 45°f ambient in order to adequately match the heating energy requirement. However, the density of the refrigerant vapor generated in the system evaporator when operating at 0ºf. ambient is only about 33% of that generated when the outdoor temperature is 45ºf. Therefore, when approximately four (4) times the weight flow is required when only 33% of the vapor density is generated, it becomes very obvious that significant changes must be made in order to make a viable heat pump for cold climates. This new Heat Pump first allows for a very large increase in refrigerant weight flow that is inversely related to the drop in outdoor temperature. This refrigerant weight flow increase is then combined with a method of extracting more energy from the still warm liquid refrigerant leaving the system condenser.

A basic problem in present day systems is that after the refrigerant has been fully liquefied in the heating condenser, there is still a large amount of energy left in this still warm liquid. This remaining energy now evaporates a significant portion of the liquid refrigerant itself during the normal pressure reduction process that is required to develop the necessarily low evaporating temperatures required to absorb energy from cold outside air. As much as 40% of this liquid can be evaporated during this normal pressure reduction process across the system expansion device when operating at the lower outdoor ambient temperatures.

Obviously, if this liquid has already evaporated, it cannot be again evaporated in the system evaporator, and thus cannot absorb energy from the outside air. However, this same vapor passes through the evaporator and is then inducted and fully compressed to the condensing level by the compressor. This is a wasteful process in itself and also, the compressor can now only induct a correspondingly smaller amount of vapor that has been derived from outside air energy thus reducing the heating capacity of the system.

It is unrealistic to consider the use of present day heat pump technology in normally colder climates. This is exactly what has happened in the U. S. marketplace. Air source heat pumps are no longer a real market factor in cold climate areas because of the very high operating cost of the electric resistance supplemental heating requirement.

THE NEW SYSTEM

The new system utilizes a primary compressor that is identical to that used in present day heat pumps and adds a booster compressor and a subcooling economizer. It also includes a means for tapping a portion of the condensed refrigerant liquid leaving the heating condenser and evaporating it within the economizer for the purpose of significantly subcooling the still warm liquid refrigerant before it is supplied to the air-source coil evaporator. The expanded refrigerant from the economizer is then delivered to a point between the outlet of the booster compressor and the inlet to the primary compressor. The significant subcooling of the liquid refrigerant greatly increases the ability of that refrigerant to absorb energy from very cold outside air. Also, the vapor generated from this subcooling process significantly increases the refrigerant weight flow into the heating condenser as it is directly added to the refrigerant flow coming from the booster compressor into the primary compressor. This additional vapor has become akin to an additional energy source supplying vapor to the primary compressor. In fact, it has been generated by the same energy that is entirely wasted in present day heat pumps.

The more important point to be made herein related to maximum system pumping capacity is that the booster compressor has a much larger displacement than that of the primary compressor. Also, whenever the booster is running, it operates at a low compression ratio because the primary must also be running and this causes the discharge pressure of the booster to be quite low. The discharge pressure of a typical booster will rise only until the density (pounds per cubic foot) of the vapor entering the primary compressor times the primary compressor pumping capacity (in cubic feet per minute) exactly equals the pounds per minute of vapor exiting the booster compressor plus the pounds per minute of vapor exiting the economizer. The increased displacement of the booster (compared to the primary) along with its very high volumetric efficiency (because of the low booster discharge pressure) results in a very high booster flow rate. This very high refrigerant flow rate multiplied by the increased energy pickup (Btu per pound) of the liquid refrigerant flowing to the evaporator (because of the low liquid refrigerant temperature due to the economizer), results in a very large increase in the total amount of energy (Btu per minute) absorbed from the outside air into the operating system every minute. This increase also comes about when it is most needed, i.e., at the lower outdoor ambient air temperatures.

The control system includes a transducer which always senses the outdoor ambient temperature. The control always prevents excess system capacity at any outdoor temperature. Whenever the outdoor temperature reaches a predetermined low enough value where more system capacity can properly be allowed, it is called for only if the indoor thermostat senses the need. The control system responds to a two step indoor thermostat which normally steps the system heating capacity between two different levels upon very small variations in indoor temperature. The capacity modes that are allowed are pre-determined from the various outdoor ambient temperatures that are encountered. The initial production systems have four (4) heating capacity modes and two (2) cooling capacity modes.

Heating Operation

The following explanation is intended to show a typical operating sequence that might occur as the outdoor temperature is falling:

Typically, the heating cycle starts when the first step of the two step indoor thermostat calls for heat. Whenever this occurs, only 50% of the primary displacement level is activated until the outdoor ambient temperature drops to 42ºf. At this temperature, 100% of the primary displacement is now activated by that same first step.

No additional heating capacity can normally be brought on line until the outdoor ambient further drops to 30ºf, even if the second step of the indoor thermostat calls for more heat. This is designed to prevent the system from supplying more capacity than is really needed as, if it were to be supplied, it would come about at a low efficiency level because the condenser would operate at an unnecessarily high pressure and the evaporator would operate at an unnecessarily low pressure. When this 30ºf is reached, the booster is now allowed if the second step calls, additionally adding the economizer operation. This combination now becomes the maximum capacity level allowed until the temperature drops further to 16ºf. Then, the first stage of resistive heat provided in the indoor air handler is also allowed in addition to the booster / economizer, but only if the second step of the indoor thermostat calls for more heat.

Cooling Operation

In this embodiment, the 50% displacement level of the primary compressor handles most of the cooling requirement except for those periods where 100% of the primary displacement may also be required. This would typically be used only for parties, quick pull downs, or some other abnormal requirement only, and is called by the second thermostat step.

1. Some Boosted Air Source Heat Pump Advantages are as Follows:

2. Excellent comfort levels in both cooling and heating modes.

3. Installed cost equal to that of gas heat plus electric cooling.

4. Efficiencies similar to geothermal systems without the added installation costs.

5. No carbon monoxide risk.

6. No gas explosion risk.

7. Chimney, fuel storage, or fuel deliveries are not required.

8. Energy ratings qualify for energy efficiency incentives and rebates.

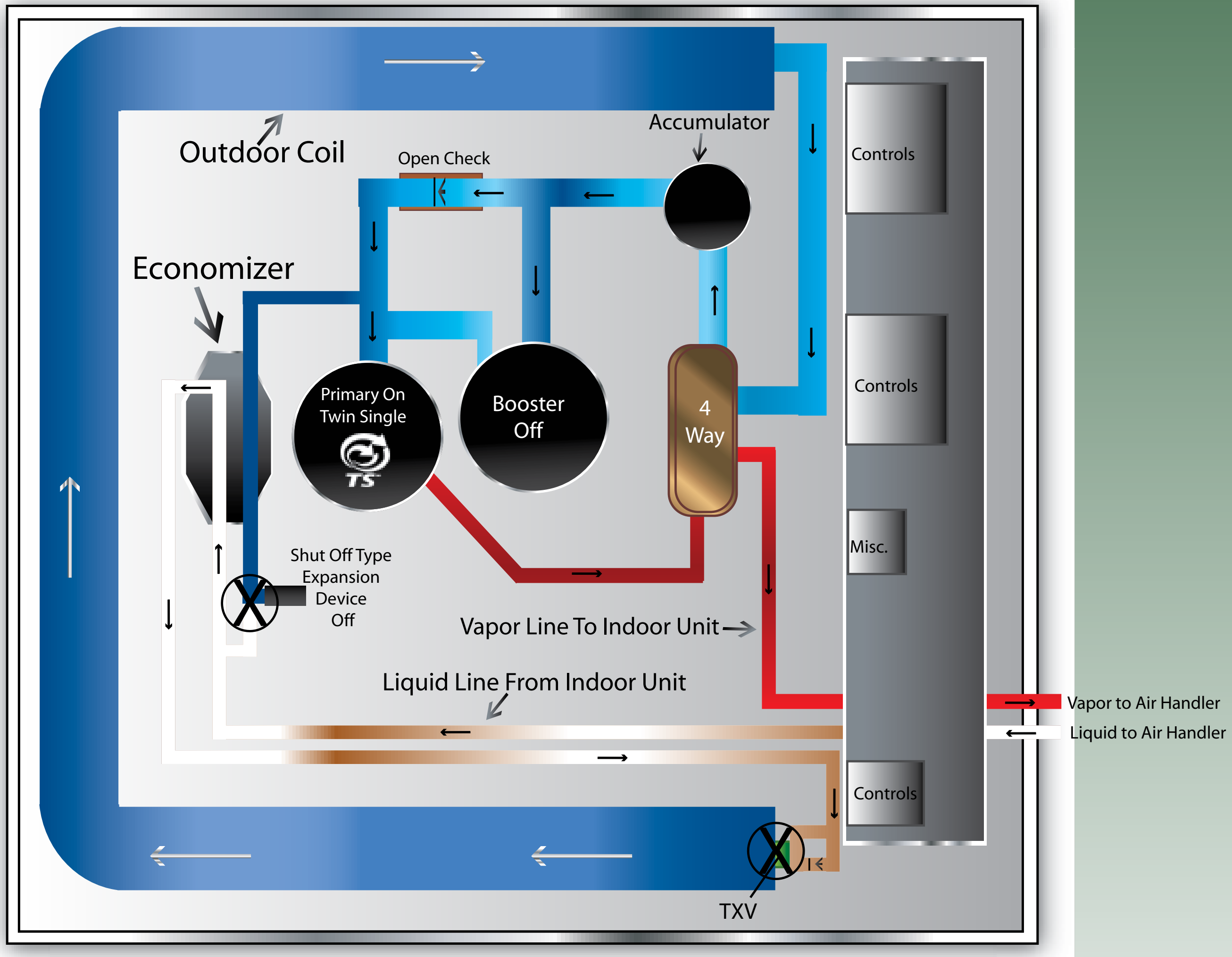
9. Significant financial assistance available from the electric utility.

10. Energy savings to homes and business's.

11. Supported by an existing aftermarket and trade industry.

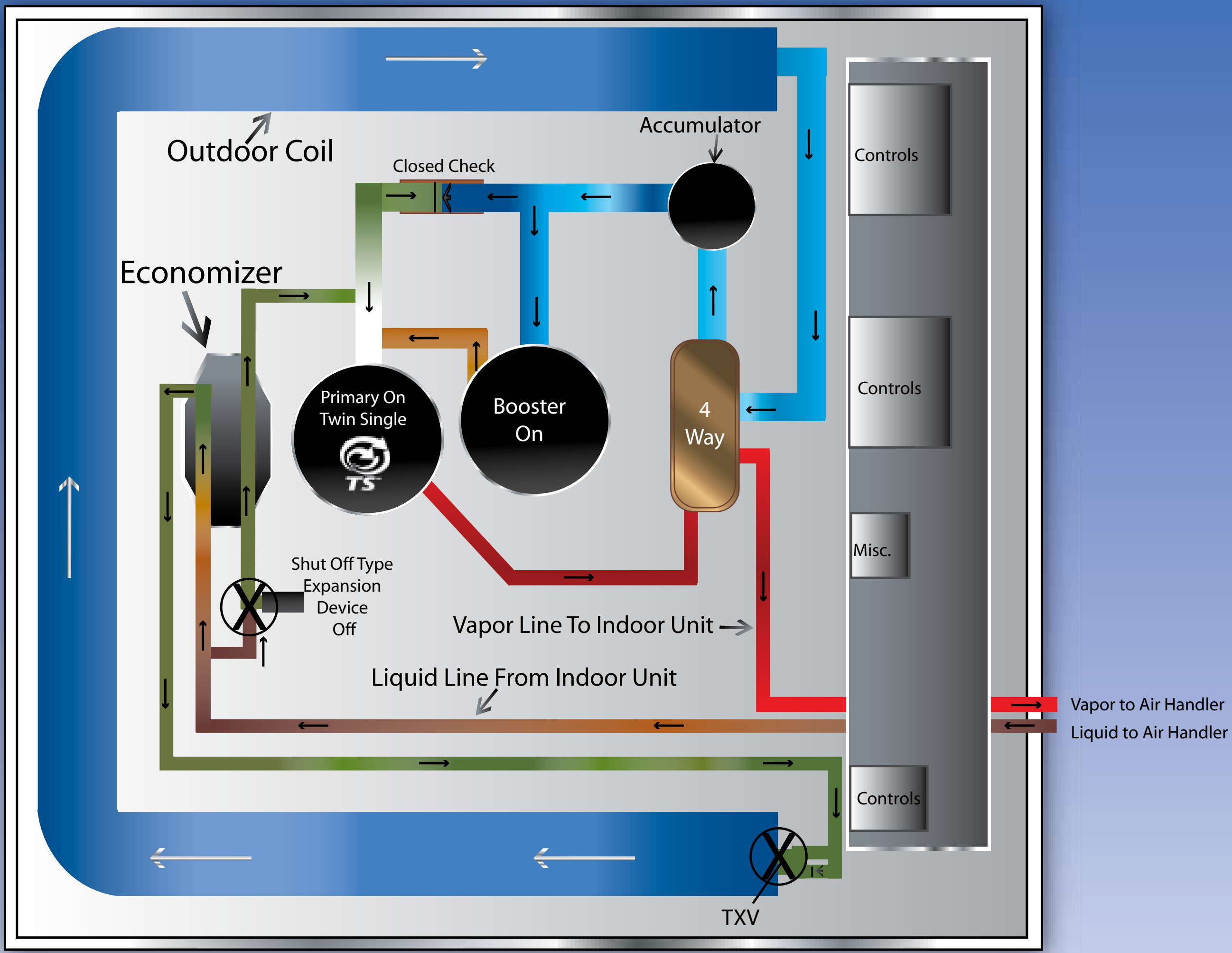
12. Does not directly rely on unpredictable and currently unstable fossil fuel.

Typical Outdoor All Climate Heat Pump
Multiple Level Heating and Cooling



Mild Heating Depicted With Only Primary Compressor Operational
During Mild Outdoor Ambient Temperatures

Typical Outdoor All Climate Heat Pump
Multiple Level Heating and Cooling



Both Compressors Operational During Lower Outdoor Ambient Temperatures For Maximum BTU Output Without Supplemental Heating.