

The Potential and Challenges of Solar Boosted Heat Pumps for Domestic Hot Water Heating

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Abstract

The use of air-source heat pumps (HPs) for domestic hot water production is well established. These approaches may not be optimum as cold outdoor temperatures can lower overall capacity and COP. An alternative approach is to use a solar-thermal collector to boost the HP's evaporator temperature (and energy input) during cold ambient periods. The HP also cools the solar absorber, reduces heat losses and increases collection efficiency. Various system configurations have been proposed for solar boosted HPs including: "direct" or "indirect"; "series" or "parallel"; and dual-source. To date, the most successful designs use simple, unglazed solar thermal panels that act as an air-source during low-sunlight conditions. These simple solar absorbers reduce costs but have limited solar-boosting capability at low ambient temperatures. The use of high-performance solar panels (with glazed and insulated absorbers), however, limits a unit's "non-solar", air-source capacity; reducing their benefit. Consequently, new systems are being developed that include dual- or tri-mode solar collectors that act as efficient solar- or air-source evaporators and may even include photovoltaic/thermal absorbers. Combined with new system configurations and components (e.g., new variable speed, high-efficiency compressors), fully integrated, high performance, solar/HP hybrid water heaters are possible. This paper describes new approaches to solar boosted heat pumps and discusses their technical potential and challenges.

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1. Introduction

As many groups endeavor to improve energy efficiency and minimize carbon emissions in residences, hot water heating loads remain a significant energy demand. For example, even in heating dominated climates such as Canada, energy use for hot water production represents almost 20% of a residential building's annual energy consumption [1]. Throughout the world, many jurisdictions are imposing, or considering regulations, specifying higher hot water heating efficiencies. EU requirements implemented in 2017 will effectively require the use of either heat pumps or solar heating systems for domestic hot water production [2], and in the USA, for storage systems above 55 gallons (i.e., 208 L) capacity, similar regulations currently apply [3].

Both solar-thermal and air-source heat pumps have the potential of achieving efficiencies above 100% based on their primary energy consumption. Both technologies are well developed, and work well, but have limitations

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in many climatic regions. In particular, colder ambient temperatures lower the performance of these units making them less attractive than alternative, more conventional, water heating approaches. Another drawback relates to the requirement to have an auxiliary heat source to supplement the solar or heat pump unit, particularly, during cold or overcast periods.

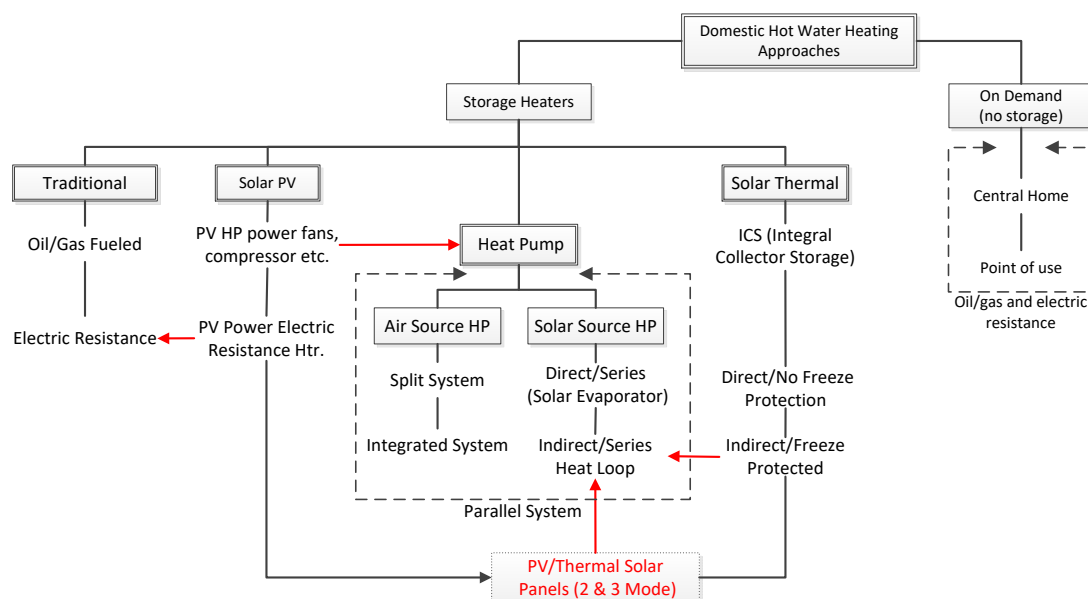
To alleviate some of these deficiencies, researchers have proposed a variety of hybrid systems that incorporate various technologies to improve overall efficiency and seasonal performance. Of these, solar boosted heat pumps have generated significant interest and research. The potential and mutual benefits of combining solar and heat pump systems were identified over six decades ago and various system configurations have been tried since that time. To date, few systems have been widely commercialized due to their apparent complexity and cost relative to conventional energy technologies. There is, however, renewed interest in developing solar-boosted heat pumps for domestic hot water; primarily driven by the need to reduce conventional energy consumption, greenhouse gas emissions and to control electric utility peak demands.

It is also worth noting that there have been technological developments over the past decade that have seen the introduction of new technologies that present significant potential for improving both the energy performance and economic viability of hybrid solar/heat pump systems. Consequently, new systems are being developed that include dual- or tri-mode solar collectors that act as efficient solar- or air-source evaporators and may even include photovoltaic/thermal absorbers. Combined with new system configurations and components (e.g., electronically-controlled, variable speed, high-efficiency compressors, compact condensers, etc.), the development of high performance, solar/HP hybrid water heaters is possible. This paper describes new approaches to solar boosted heat pumps used for water heating and outlines their technical potential and challenges.

1.1. Domestic hot water heating approaches: Competing Water Heating Options

There are currently many approaches for the heating of domestic hot water. These range from a variety of traditional approaches based on the combustion of fossil fuels [e.g. oil, natural gas, propane etc.], to solar thermal and heat pump systems. The latter systems tend to be coupled with storage tanks sized appropriately to meet a household's peak hot water demands. The use of storage tanks compensates for the limits in heating capacity inherent in these units. An alternative approach that is gaining popularity is the use of “on demand” heaters that are able to deliver hot water at the desired temperature and flow rate in a single pass. Consequently, these units require a high thermal capacity that is usually only economically delivered by fossil fuel or large electric resistance heaters. Figure 1 illustrates some of the range of system types available for heating domestic hot water. Existing and proposed concepts are shown, however this paper will focus on the “Solar Source Heat Pumps”, including the relationship between heat pumps, solar thermal and photovoltaics (PV). To understand the synergy between solar energy devices and heat pumps it is worth reviewing some of the basic concepts associated with these technologies.

Fig. 1. Various approaches for heating domestic hot water (DHW).



2. Solar and Heat Pump Water Heater Configurations

The combining of heat pumps with solar thermal systems has been investigated by many researchers in the past [4-7]. Comprehensive review papers, documenting the various approaches and studies undertaken recently been published [8-10]. Many of the studies have looked at combined- or “Combi-systems” intended to provide space heating as well as domestic hot water in residential applications. In a few studies, heat pump systems intended for space and water heating, as well as, space cooling have been published. For the purpose of this paper, the production of hot water for domestic or “sanitary” use will only be discussed. It is of value to review the traditional configurations of solar and HP domestic hot water heating systems to appreciate the features that led to their combination and challenges that still exist.

2.1 Solar Thermal Domestic Water heating (ST-DHW) Systems

Systems designed to heat hot water with sunshine have existed since then mid-19th century. Early units were simple by design but operated on the same principles as modern units. Since that time, the thermal and cost performance of these units has improved; driven largely by advances in materials and manufacturing. Many configurations have been used in the past to facilitate flexibility in design and installation, and to accommodate severe climate conditions. In warm climates where freezing is not a concern, “direct” solar systems may be used where the potable domestic water is circulated directly from a storage reservoir through solar collectors Fig. 2.

In the simplest versions of these units, the thermal storage is installed above the solar collector and use a buoyancy-driven thermosiphon flow to circulate water through the solar collectors. These roof mounted, direct systems, however, are not suitable for cold climates that could result in excessive storage-heat-losses or freezing. In such climates, the storage is usually placed in a heated area and the solar collectors are installed outdoors. Various freeze-protection schemes are used to avoid damage in the piping or solar collectors during cold weather (e.g., “drain-down,” “drain back” or “anti-freeze” circulation loops). Figure 3 shows typical “indirect” solar systems where solar energy is transferred from the solar collector(s) to a heat exchanger via a closed circulation loop charged with a non-toxic anti-freeze solution. The heat exchanger isolates the antifreeze solution from the potable water and may be mounted outside the storage (i.e., “side-arm”) or inside the storage as is the case with an “immersed-coil” heat exchanger. Various solar domestic hot water configurations have been documented in papers and reference books [11-13].

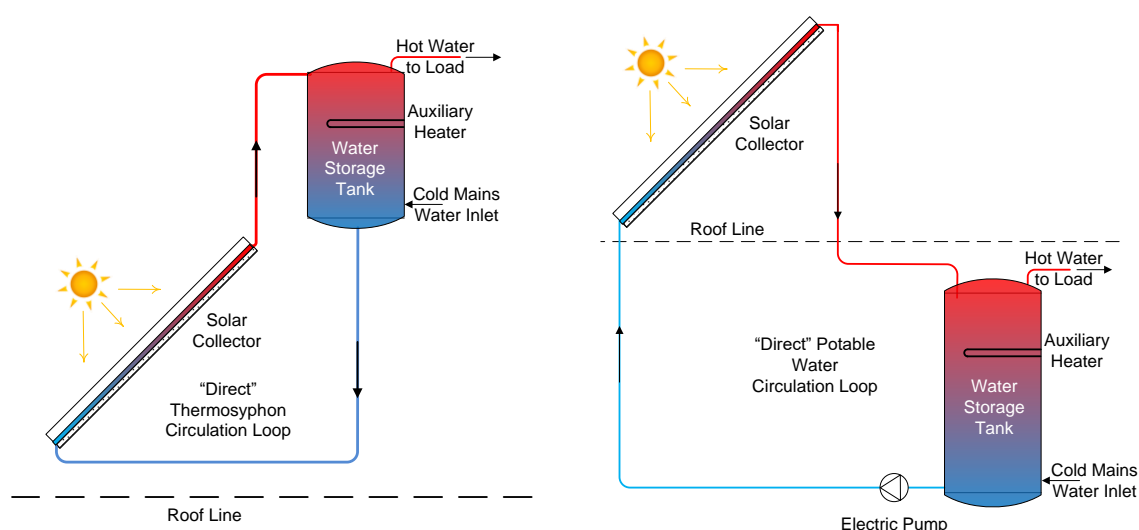


Fig. 2. Schematics of “direct” solar water heaters: LHS - Thermosyphon system; RHS – Pumped circulation.

A modern indirect solar domestic hot water heating system with 6 m² of solar collector and 300 L storage will supply, on average, approximately half of the annual hot water energy load (~7.2 GJ) of an average family in Toronto, Canada (based on 260 L per day heated to 50°C).

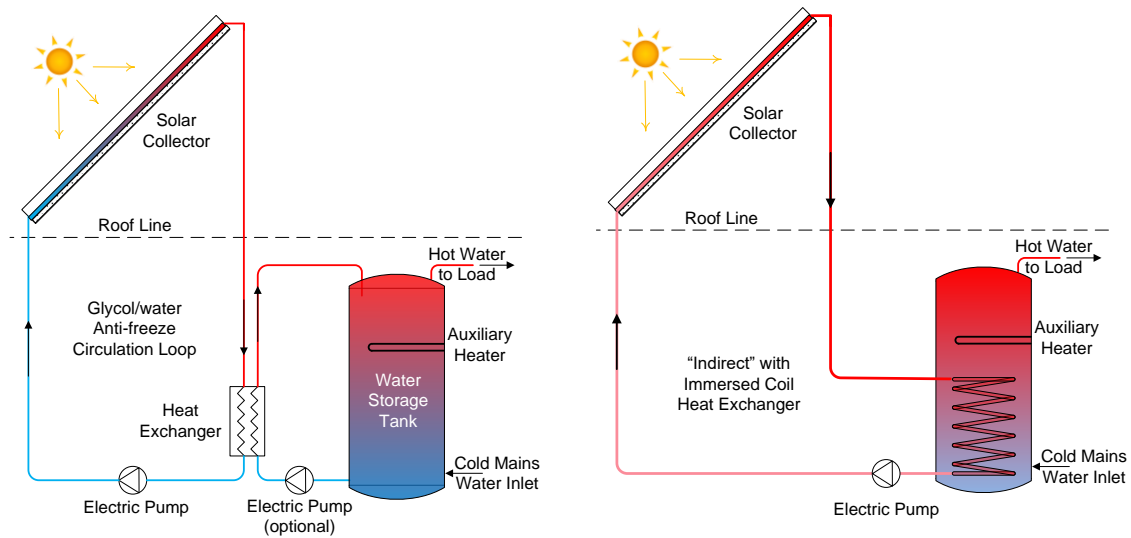


Fig. 3. Schematics of “indirect” solar DHW heaters: LHS - “side-arm” heat exchanger; RHS - immersed-coil.

The performance of solar thermal systems depends on the local weather conditions including: the “mains-water” and ambient air temperature; and the available solar radiation. Both seasonal and diurnal variations in available sunshine mean that there is considerable variation in system output at various times of the year, and an auxiliary source of heating is usually required to ensure a consistent supply of hot water.

2.2 Compact Air-source Heat Pump Water Heaters (HPWH)

An air-source heat pump water heater, typically uses a refrigerant-charged fan-coil evaporator, compressor and condenser, to deliver ambient energy to a hot water storage tank, Fig. 4. The use of air-source heat pumps (HPs) for domestic hot water production is well established and many units are commercially available. When used in locations with favorable climatic conditions they may achieve energy savings approaching 70% when compared with conventional electric-resistance water heating. The most common configurations, include an air-source evaporator (usually mounted on a hot water storage reservoir) and an immersed-coil or wrap-around condenser. These “close-coupled” units are an easy to install, water heater and storage unit combined into a compact package. They require a fan-coil to source heat from the surrounding environment and are best suited for mild climates where heat will not be drawn from a heated interior building space. In relatively warm (e.g., Mediterranean) climates, the units may be placed outdoors or in an unheated garage.

While these features have propelled HPWH market growth in many locations, they limit market penetration in colder (e.g., Continental) climates where outdoor installations result in high tank losses or freezing. In such regions, the units must be installed indoors in heated spaces where they may source energy from the building’s primary space-heating system. In effect, transferring the hot water load to the space heating load [14]. On a positive note, the potential benefits of summer cooling and dehumidification have been suggested, although the noise associated with fan-coil evaporator units has been identified as a deterrent to placing some units near or in living spaces. These systems have been studied and performance rating procedures developed [15, 16].

To alleviate the above disadvantages, “split systems” with outdoor fan-coil evaporators can be used, or alternatively, outdoor-air can be ducted through an indoor unit from the outdoors. These approaches are not optimum, however, as cold outdoor temperatures can lower overall capacity and heating coefficient of performance (COPh). It has also been proposed to exhaust building-air through the evaporator of a compact HP water heater unit but this depends on building ventilation requirements and competes directly with “make-up air” heat-recovery heat-exchange units.

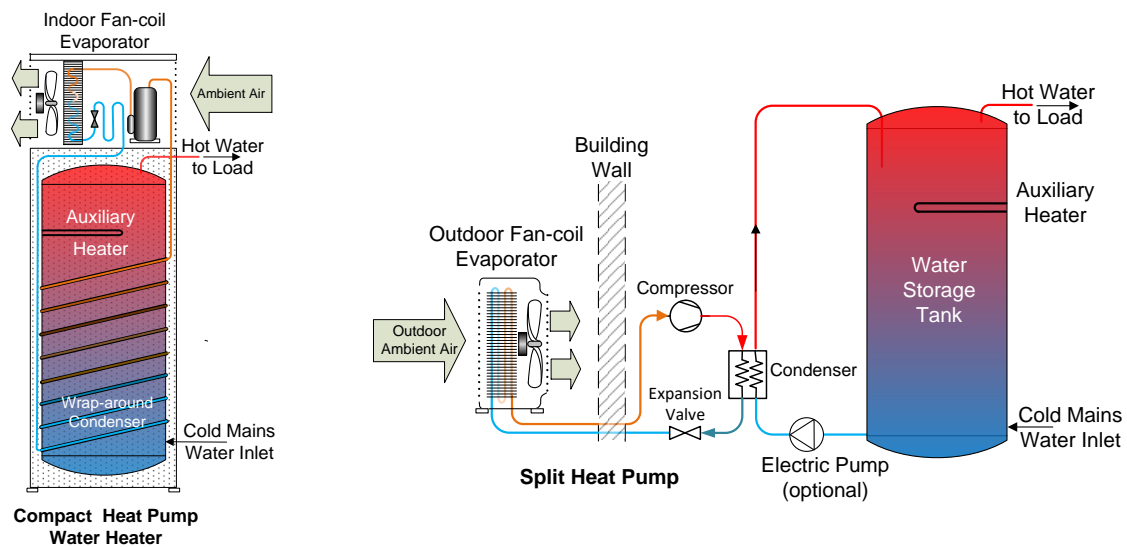


Fig. 4. Air-source HPWH configurations: LHS - Compact HPWH; RHS – “split system”.

3. Solar Boosted Heat Pump Water heater (SB-HPWH)

By placing the evaporator of an air-source heat pump water heater outdoors, the unit is (indirectly) sourcing solar energy, however, to avoid confusion with current discussion, a more appropriate terminology would be to say the heat pump is sourcing “ambient” energy (i.e., energy from the outdoor ambient-air). While, developments in “low-temperature” heat pumps have resulted in improved low-temperature performance, sourcing energy from the outdoor air during the winter will lower COP_h and output.

In addition, the recent significant reduction in the cost of photovoltaic modules has seen many heat pump manufacturers provide an option whereas the power consumption of the heat pump unit can be augmented by the electrical output of a solar PV panel. While this will reduce the consumption of grid supplied electrical energy, it does exploit full potential of a solar boosted heat pump. In a solar augmented HP, solar energy is converted to electricity at an efficiency of approximately 15%; the balance of the solar energy is lost to the environment as heat. There are, however, a variety of alternative configurations that can use this, otherwise wasted, solar thermal energy. I refer to these systems as “solar boosted heat pump water heaters” (SP – HPWH) and these will be discussed in the balance of this paper.

3.1. Why Solar Boosted Heat Pump Water Heaters

A more efficient (and direct) use of solar energy consists of using solar thermal collectors to efficiently collect incident solar energy as heat to boost the HP’s evaporator temperature (and energy input) during cold ambient-air periods. This will solar increase COP_h and seasonal performance, particularly during periods with low ambient temperatures. During operation, the heat pump also cools the solar absorber, reducing heat losses and increasing collector efficiency. The use of a heat pump to drive the heat transfer from a solar collector to the thermal storage allows the operating temperature in the collector to be reduced to near, or below, ambient-air temperatures.

3.2. Solar Boosted Heat Pump Configurations

The synergy that exists between solar thermal devices and heat pumps has been identified by many researchers over the years [4, 5, 17-19]. Many system configurations have been studied previously and are described in the literature [8]. These include: “series” or “parallel” connected configurations; “dual-source” (where heat input is switched between a solar thermal collector or an outdoor fan-coil unit); and parallel configurations. A parallel combination of solar thermal systems and a heat pump is usually straightforward as often each system operates

independently [8, 9, 10 and 14]. The feasibility of using a parallel source heat pump then largely becomes a matter of the economics of competing auxiliary energy systems and may be influenced by local climatic conditions. Dual source heat pumps allow that thermal input to be switched between the solar array and another heat source, e.g. geothermal, air source etc. as needed. While effective, these systems will be more complex and include additional hardware, e.g. switching valves etc.

Two approaches to solar boosting that have entered the commercial market are shown in Fig. 5. These consist of “direct-expansion” and “indirect” system configurations. In the direct-expansion approach, refrigerant is circulated directly through the solar collectors [17-22]. In effect, the absorber of the solar collector becomes the heat pump evaporator. These systems have demonstrated improved annual performance over conventional systems, but may require long refrigeration lines and on-site charging. With increased concern related to the leakage of traditional refrigerants into the atmosphere and high installation costs, this approach has not been widely used. Alternatively, indirect systems circulate an intermediate heat transfer fluid through the solar collectors and transfer heat to the heat pump’s condenser, simplifying installation, but requiring additional components.

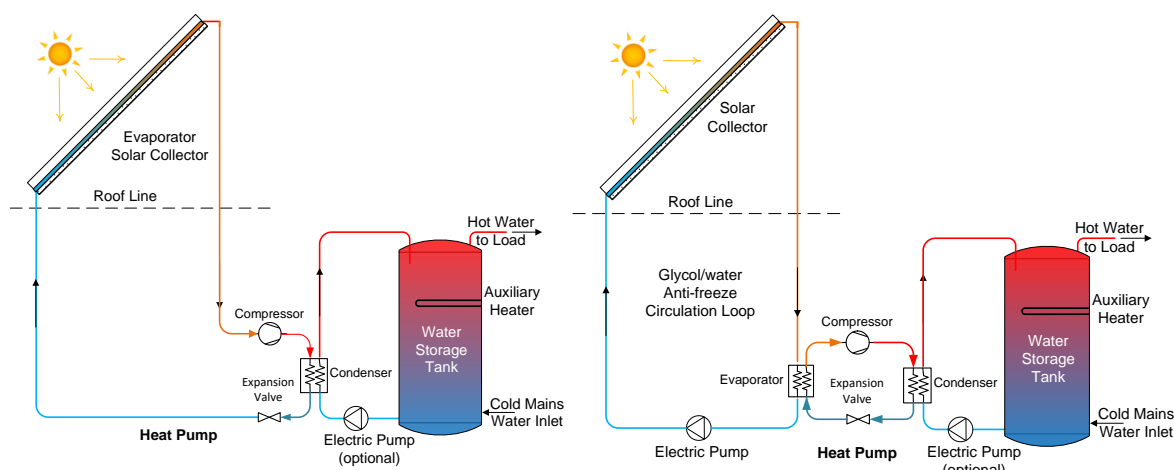


Fig. 5. Example solar boosted HPWHs: LHS- Direct configuration; RHS- Indirect configuration

In indirect SB-HPWHs, similar to indirect solar thermal systems, antifreeze heat transfer fluid is pumped through the solar collectors in a closed loop to a heat exchanger that acts as the heat pump’s evaporator. The heat pump unit then delivers heat to a conventional hot water tank through a condenser/heat exchanger. In the resulting system, the heat pump refrigeration loop may be self-contained, but still provide the benefit of reducing the solar collector operating temperature [23-26].

3.3. Example Performance Comparison for SB-HPWH

Freeman et al., [23] undertook a feasibility study to assess the annual performance of an indirect solar-assisted heat pump hot water heater for three representative Canadian cities: Toronto, Vancouver, and Montreal. The system was evaluated with glazed and unglazed collectors and heat pumps using 325W, 450W, and 650W compressors. Simulations were performed using TRNSYS and typical meteorological year (TMY) weather data; assuming a 239 L/day domestic hot water load. Result indicate that a solar-assisted heat pump (SAHP) system could out-perform a “split” air-source HPWH and a conventional solar hot water system (even with only half the normally required solar collector area using simple unglazed solar collectors). Results from Freeman are shown Figs. 6-9 and demonstrate the advantages of a SAHP (or SB-HPWH) in comparison to a conventional solar-only domestic hot water heater.

The systems were evaluated in terms of the annual and monthly solar fraction and the collector efficiency. The solar fraction is the fraction of solar energy delivered to the load over a specified time period. The collector efficiency is the fraction of available incident radiation that is collected by the solar collectors. The annual solar fraction, as a function of collector area, for the four systems (including an air-source HPWH is) is shown in Fig. 6 for Toronto. The monthly solar fraction for a collector area of 3 m², Fig. 7. The corresponding solar collector

efficiency is shown in Fig 8, as a function of collector area. The solar fraction as a function of collector area for the unglazed SAHP system for each appears in Fig. 9. It may be seen that as the collector area is reduced, the SAHP unglazed solar collectors operate at temperatures lower than ambient increasing their “apparent” collector efficiency to values greater than 100%.

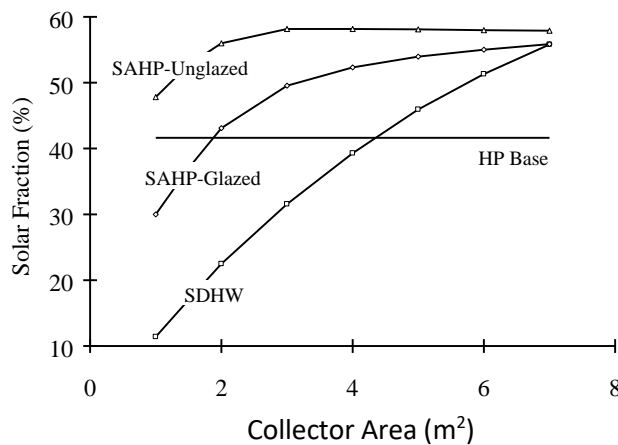


Fig. 6. Annual solar fraction versus solar collector area for Toronto [23].

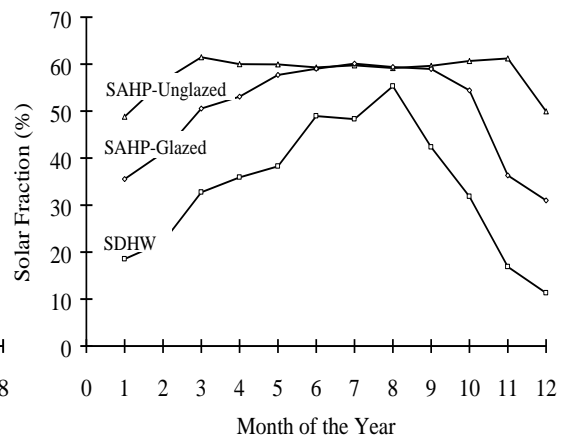


Fig. 7. Toronto, monthly solar fraction for various systems with a solar collector of 3 m² [23].

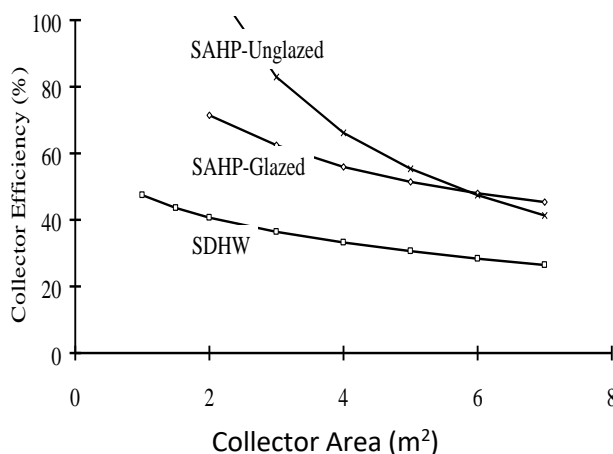


Fig. 8. Monthly solar fraction for a solar collector area of 3 m² in Toronto [23].

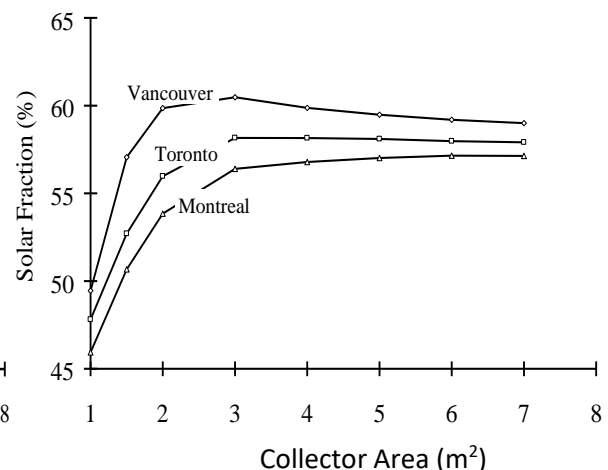


Fig. 9. Solar fraction versus collector area for unglazed SA-HP water heater [23].

The indirect SA HPHW system with unglazed collectors indicated an increase in the solar fraction of between 50-60% for collector areas of 2-4 m². This represents an increase of up to 90% over the conventional SDHW system. The indirect system also demonstrated up to a 40% improvement in ambient energy gain over the split air-source heat pump. For greater collector areas, it appears that the collector capacity exceeds the heat pump's capacity, lowering overall system performance,

Results also indicated that the use of low-cost unglazed collectors provides an additional 25% in energy gains over the glazed SAHP system and greater than 100% improvement relative to the conventional SDHW system. A solar fraction of 50% achieved using a 6 m² collector on an SDHW system could be achieved using under 2 m² of unglazed collectors with a SAHP system. This is an important result as it demonstrates that the additional cost of the heat pump may be offset by reduced solar array area and simpler, lower cost unglazed solar collectors. It must be noted, however, that almost 40% of the energy that was collected over the year by the unglazed SAHP system

was gained from ambient air. Both the SAHP systems were observed to run an average of 30% longer each day over the entire year when compared to the SDHW system.

Following on the simulations of Freeman, Bridgeman conducted laboratory tests to verify the performance of an indirect SAHP with a simulated solar input [24]. Simulated solar profile tests found a maximum COP of 3.2 measured at peak solar input and the minimum COP of 2.4 occurred at the end of the charge cycle. System tested use a natural convection side-arm in exchanger/condenser that allowed the thermal storage to achieve high degrees of thermal stratification. The amount of heat transferred through the condenser to the natural convection loop ranged from 1300 2000 W. Compressor power input range from 484 to 635 watts during tests. Other studies have been conducted showing similar results [25, 26].

4. Recent Technological developments

4.1. PV-only DHW

Although this is compelling technology due recent price reductions and significant infrastructure for remanufacturing and installation, various groups have been developing (stand-alone) PV-electric resistance water heating systems. While compatible with PV installation practices, the “solar” efficiency of these devices is low (e.g., 10 to 15%) which is one-third to one-half of comparable solar thermal devices. As such, a PV SDHW water system would require more than 12 m² of roof area to provide a significant portion of the domestic hot water load (4 times the area of a Solar Boosted HP water heater). This solution clearly does not maximize the potential solar energy available nor efficiently use valuable roof space [27]. The rapid growth of PV systems in the market place does offer many opportunities to “piggyback” on existing PV infrastructure (installation and mounting, etc.), potentially lowering the installation cost of SB-HPWH that can be configured to be compatible with standard PV modules.

4.2. Alternate Configurations for a SB-HPWH

As illustrated in Section 3.3, a limit of an indirect configuration for a SB-HPWH is that all the energy capture must be delivered through the heat pump at all times; even when the output temperature of the solar collector is at a high enough to be delivered to the load. Freeman et al., showed that the ISAHP performance could be improved by modulating the compressor capacity during summer months. While not practical at the time of that study, high efficiency, variable speed compressor are now readily available and will improve summer HP COPh.

A series-connected solar-boosted heat pump will provide improved performance during sunny cold periods but may limit solar contribution during summer periods. In many locations, a solar-only DHW system or air-source HPWH may offer higher performance and greater energy savings during warm summer months. To alleviate this, the use of parallel or dual-source systems that may switch between a solar boosted evaporator and a separate air-source evaporator unit are possible, but while maximizing operational flexibility, these systems have the disadvantage of increased complexity and cost (e.g., diverting-valves, fan coil units, controls, etc.) and, as such, have not penetrated the DHW market.

As an alternative, Sterling proposed and simulated the performance of a Solar-Side” ISAHP as shown in Fig. 10. This novel configuration used a heat pump to upgrade the outlet collector temperatures with the evaporator removing heat from the collector inlet fluid. This system can only operate in conjunction with the solar collector loop and primarily allows for extended use of the solar collector during periods of lower irradiation. Results suggested a Solar Fraction of 0.66 could be achieved using a complex control scheme to determine optimal use of the heat pump [28].

This system configuration would seem to have a number of features that would eliminate the series effect that restricts the direct transfer of solar energy from the collectors to the thermal storage. With the solar side configuration, it should be possible to operate the system as conventional solar thermal system during warm summer periods. The disadvantage of this configuration is necessity of using an additional heat exchanger and they apparently more challenging control scheme. Further research into the performance and costs associated with this configuration would be of value.

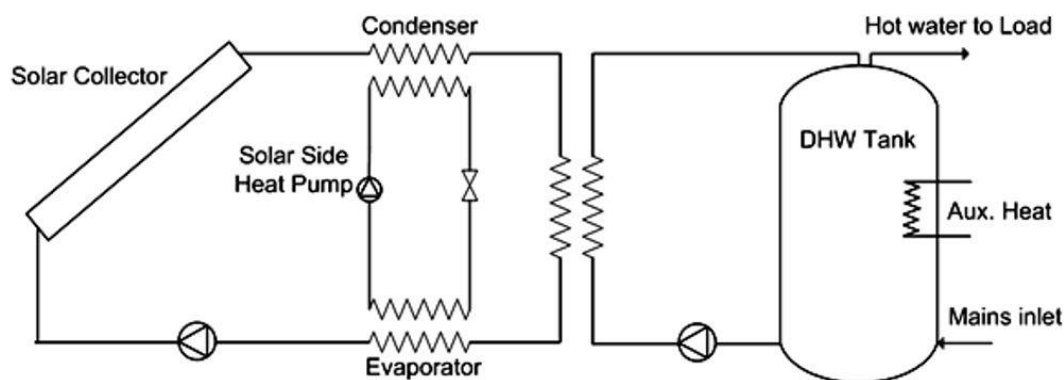


Fig. 10. Schematic of the Solar-side Heat Pump configuration proposed by Sterling [28]

5. New Solar collector Options for Solar Boosted Heat Pump Water Heaters

It was also noted by Freeman that at very low ambient temperatures such as predicted in Winnipeg during the winter, the system performance could be improved by using a glazed solar collector rather than the usual unglazed collectors. Making the switch, however, would lower performance during periods with warmer ambient temperatures.

The effectiveness of solar boosting a heat pump depends on the climate (solar availability and ambient air temperature) and the type of solar collector used. In addition, for applications like domestic hot water heating, load demand may occur at times when sunlight is unavailable due to cloud cover or time of day. It is usually not practical or economical to oversize the thermal storage or solar array so systems must be able to source energy directly from the ambient-air when sunshine is not available. It is typical to use simple, unglazed solar thermal panels that may also source energy from the ambient-air during low solar conditions. These simple solar absorbers reduce costs and stagnation problems but have limited solar-boosting capability at low ambient temperatures.

As a result, it has been common practice to use unglazed collectors in SB-HP systems based on the fact that lower collector temperatures maintained by the heat pump can reduce thermal losses and maintain high efficiency. Additionally, as the unglazed collector has a high heat loss coefficient, it can, under certain situations, absorb more energy from the surrounding ambient air than a glazed and insulated collector.

Maintaining low collector temperatures during cold winter periods will because the COP of the heat pump to decreases, and therefore it may be detrimental to operate the collector near the ambient temperature under these conditions. On a seasonal basis, a SB-HP with a glazed collector has the potential to outperform the unglazed collector in the winter time, with its greater efficiency at larger temperature differences.

5.1. Dual Mode Vented Collector

One approach to alleviating this problem is to use a “dual-mode” solar collector that consists of a modified glazed flat-plate solar collector equipped with an air channel between the absorber and rear insulation, as shown by the cross-sectional side view Fig. 11. The air channel allows the absorber to exchange heat with the ambient air by natural convection like an unglazed collector, while the glazing and insulation limits the heat loss when required. In effect, this becomes a hybrid collector, able to more efficiently absorb energy from solar, as well as, ambient sources. Elliott [29] studied the performance of a SB-HWHP equipped with a dual-mode solar collector. The system performance was evaluated by computer simulation and by experimental field testing under natural atmospheric conditions.

To evaluate the system, Elliott calculated the free energy ratio for the system that represents the fraction of the load energy requirements that is supplied by non-purchased sources (i.e., the useful gain of the collector from the

solar irradiance and ambient air). The total energy delivered to the load is the increase in thermal energy of the water exiting the tank compared to the water entering the tank.

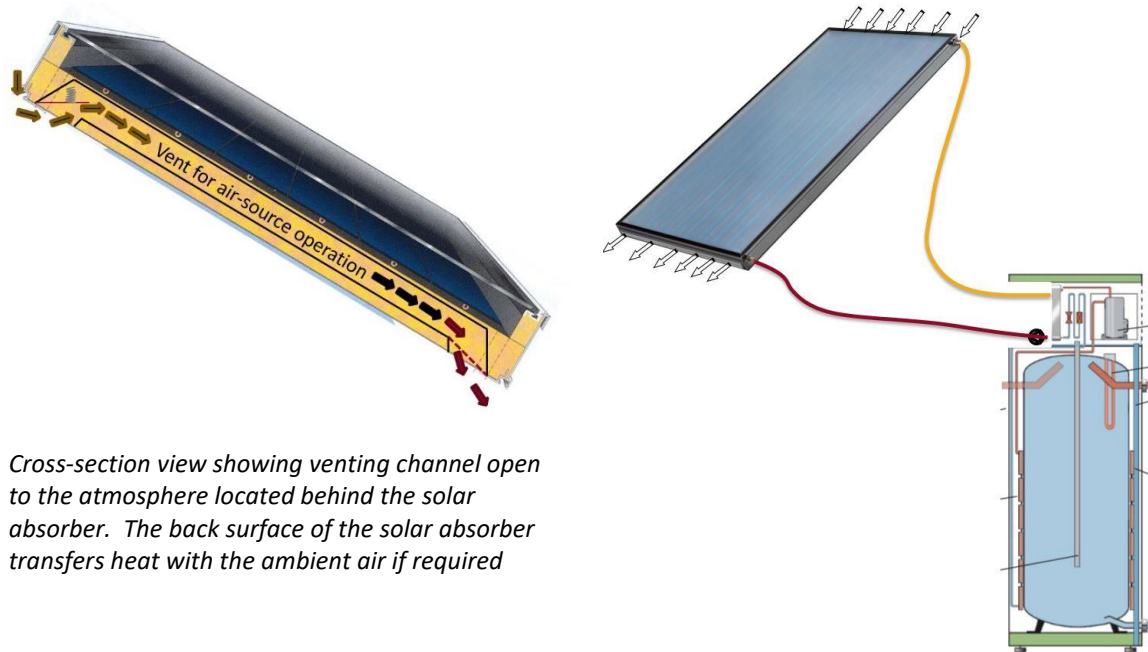


Fig. 11. Dual mode solar collector with venting channel that allows energy collection during low-solar periods (e.g., rear surface of solar absorber acts as an air-source heat exchanger)

Elliott's results showed that on sunny days, the system experienced daily averaged collector efficiencies between 0.47 and 0.88, depending on the flow rate and season. Averaged heat pump coefficients of performance of 2.54 to 3.13 were observed. Overcast days experienced reduced coefficients of performance, between 2.24 and 2.44. However, on overcast days, upwards of 76% of the collected energy gain was from convection with the surroundings.

Based upon these experimental results, a model for the hybrid collector was developed and Annual simulations conducted to compare the performance of the solar heat pump system when fitted with the hybrid collector relative to cases with more conventional glazed and unglazed collectors commonly used in solar thermal systems. The heat pump with the hybrid collector outperformed the other collectors in the Toronto climate, with a free energy ratio of 0.548. Adding a thermally controlled valve to the hybrid collector was proposed to further increase the annual free energy ratio. It was also proposed that additional improvements could be achieved by allowing the collectors to deliver heat directly to the storage tank, by circumventing the heat pump if the conditions were favorable as proposed by Sterling.

A similar scheme was used for Team Ontario's 2013 US Solar Decathlon Entry on a multi-function integrated heat pump system [30]. However, a recent study indicated [31] that a vented collector had little apparent effect on the performance of an ice-slurry heat pump, indicating that its effectiveness may depend on operational temperatures and the overall heat transfer coefficient to the solar array as recently reported by [32]. It is apparent that further optimization of this concept is required to identify suitable applications.

5.2. PV/Thermal HP Water heater

PV/Thermal collectors have been studied in the past [33-35], but only recently are becoming commercially available. Recent studies have shown that combined PV/Thermal devices can significantly improve the overall performance of SB-HPHW.. Solar conversion efficiency of PV/Thermal devices can be very high as solar energy, not directly converted to electricity, is converted to heat and this can be extracted for heating purposes. The addition of a heat pump to this combination allows solar panel operation at low temperatures (even sub-ambient) increasing both electric and thermal conversion efficiency, Fig. 12. The heat pump allows the low-temperature solar heat to be upgraded to a useable temperature improving heat transfer processes. The COP of the Heat pump “leverages” the electrical input of the system while increasing the thermal output of the system. PV/Thermal panels are being produced by a small group of manufactures world –wide but numbers are growing. The most common technology is an extension of standard PV module production, and is compatible with typical PV system installation techniques.

Suitable heat pumps for this application will initially be based on vapour-compression cycles and should use environmentally friendly refrigerants such as CO₂. The successful integration of these systems, their controls and the utilization of the PV generated electricity are areas requiring research and development.

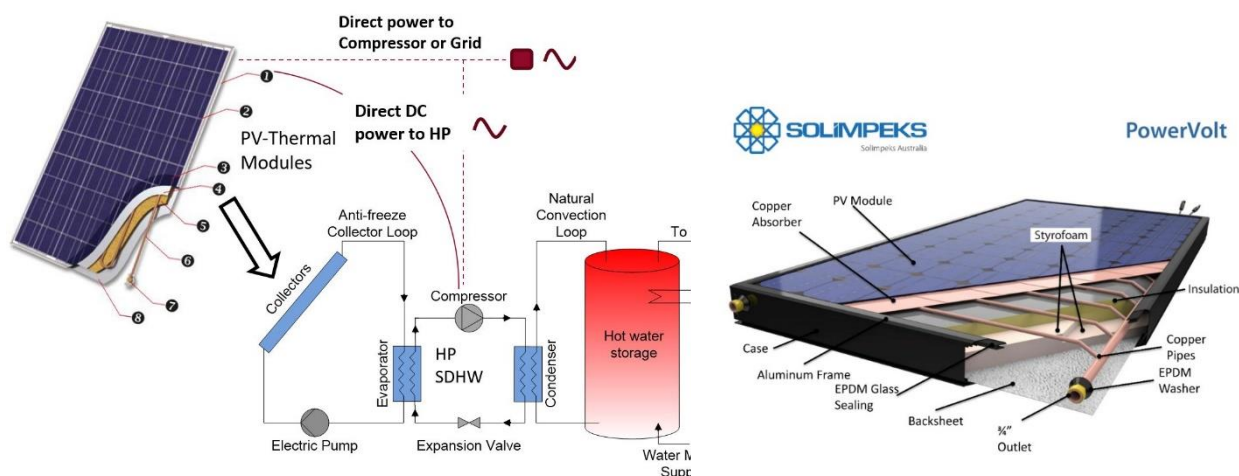


Fig. 12. PVT collector added to a SB-HPWH to provide electricity to the “grid” or to directly power the HP’s Compressor.

5.3. PVT Solar Boosted HP vs Air-Source

To illustrate the benefits of adding PV thermal collectors to a solar boosted heat pump water heater, one can refer to Sankey diagrams illustrating the energy flow during steady-state operation of a PVT SP – HPWH in comparison to that of an air source heat pump supplying the same heat load Fig. 13. These plots illustrated the benefit of the additional solar electric input on the values of free energy ratio and collector efficiency. The true benefit of PV/thermal solar panels is evident for cases in which space is limited.

There currently are very few studies that fully analyze potential of PV thermal panels used in conjunction with pumps. There are even less that identifies potential spec to heat pump water heaters. This is an area requiring further study. Current PV/Thermal cost are approximately 3-5 times that of standard PV modules, however it is expected that these prices will drop as volume and competition increases in the market place.

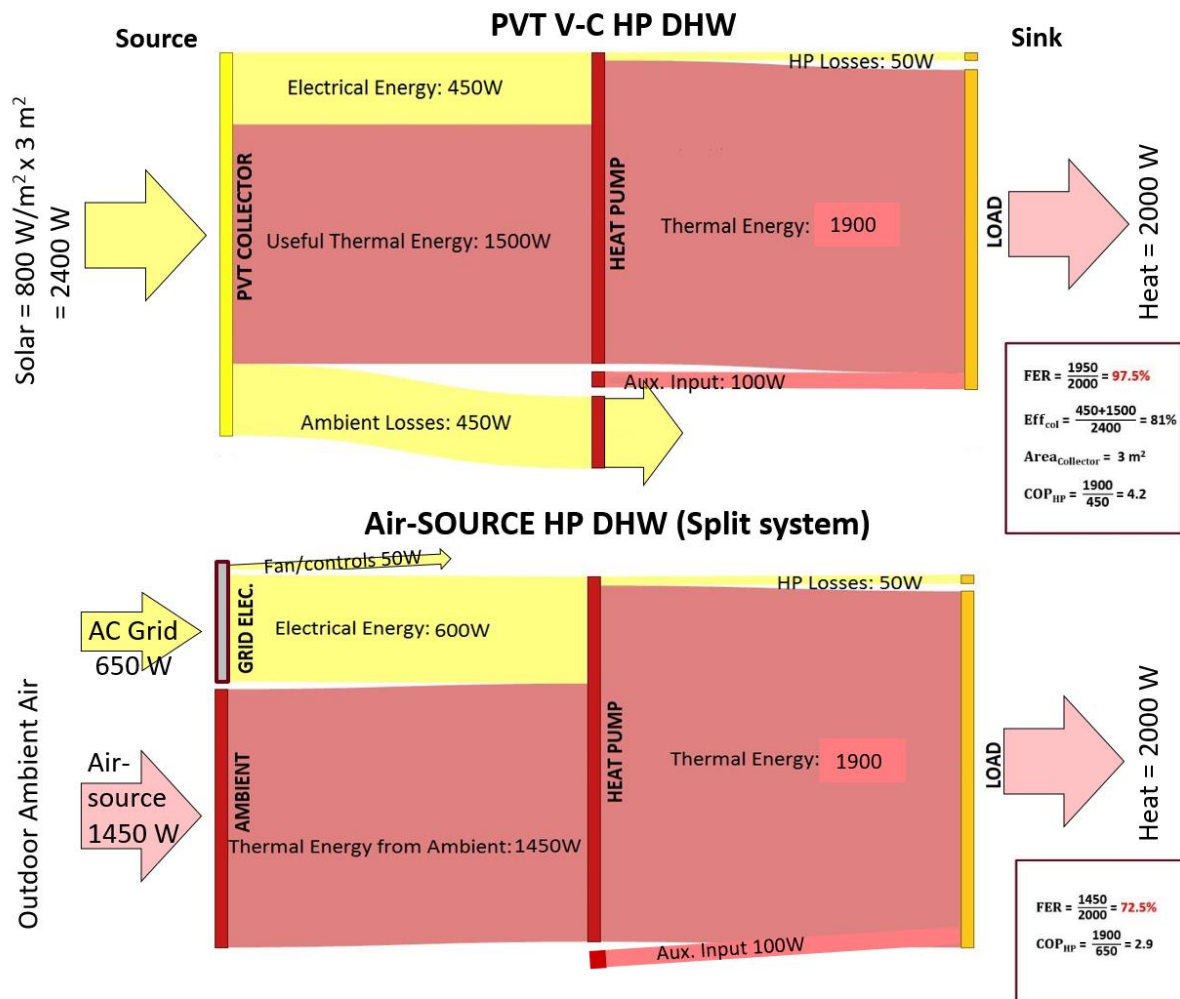


Fig. 13. Sankey diagrams illustrating the energy flow during steady-state operation of a PVT SP-HPWH in comparison to that of an air source heat pump supplying the same heat load.

6. Conclusion and Recommendations

The use of air-source heat pumps for domestic hot water production is well established and many units are commercially available. The most common configuration, includes an air-source evaporator and an immersed-coil or wrap-around condenser. An alternative approach, to use a solar thermal collector to boost the evaporator temperature (and energy input) during cold ambient periods. The heat pump is able cool the solar absorber, reducing heat losses and increasing its efficiency. This has the advantage of providing substantial heat gains even under marginal solar conditions. It also allows for efficient operation over a larger range of seasons and weather conditions, and for more hours of the day. In addition, the solar energy input to HP's evaporator, increases COP and seasonal performance. Various system configurations have been proposed in the past however few have gained significant market share.

The use of a heat pump to drive the heat transfer from a solar collector to the thermal storage allows the operating temperature in the collector to be reduce to near or below ambient temperatures. Combining heat pumps with conventional solar systems also has the potential to produce high energy output from low cost unglazed solar

absorber panels. Result indicate that a solar-assisted heat pump domestic hot water system could out-perform a conventional solar hot water system even with only half the normally required solar collector area.

An important issue relates to the use of a SB-HPWH in climates with significant seasonal temperature variations. Unglazed solar thermal panels have limited solar-boosting capability at low temperatures. The use of high performance solar panels (with glazed and insulated absorbers), however, reduces the unit's "non-solar, air-source" capacity making them undesirable in many climates.

Consequently, new approaches to these tradition configurations are being developed based on new system configurations and components. These include dual- and tri-mode solar collectors that act as solar or air-source evaporators and may include PV/Thermal absorbers. New variable speed, high efficiency DC compressors may also offer significant advantages for a fully integrated solar/HP hybrid heat pump water heater. Careful integration of these components may produce units with unparalleled performance [36].

The development of an optimized SB-HPWH has yet to be achieved but is being attempted by various groups. Issues related to system control and operation have yet to be resolved. New technologies, such as PV and PV/Thermal are presenting new opportunities to achieve very high solar energy contributions to domestic hot water heating loads.

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