Optimized Design of Solar/Air Collection and Storage Systems for HVAC

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Abstract

A variety of hybrid or multi-source heat pump systems have been described in patents and academic literature, and are now beginning to be seen as commercial products. These systems often use solar thermal or related technologies. We describe here a comparison of several different methods to combine solar thermal collection with the collection of cold by means of convection and possibly night sky thermal radiation. Some of these cold collection methods are

- the use of conventional unglazed solar thermal collectors;
- a modification of the glazing surface designs of multi-pane windows;
- the use of air to liquid heat exchangers (dry coolers).

Another cold collection method (which is geographically restrictive) is the use of cold water deep in a lake, stream, river or ocean. This collection could be open loop or closed loop (heat exchanger in the water). We also describe herein several improvements in lower cost, long term storage of heat and cold underground. Extending the storage duration to six months will provide cost-effective seasonal storage. To gain the greatest advantage of what is described above, an optimized system of pumps, valves, and sensors will be used, along with computer control.

Objective

- This paper aims to introduce and demonstrate the optimized design and the combined use of above-mentioned energy-saving measures for building heating and cooling. This optimized design contributes to the use of renewable energy, maximizing system efficiencies and entirely eliminating fossil fuel use in buildings.

- Additionally, this paper is intended to explore the best practices in the integrated design of building Heating, Ventilating, and Air Conditioning (HVAC) systems.

Solar Thermal Collectors

- Glazed flat plate collectors - these usually have a metal absorber plate with fluid channels spaced several centimeters below a glass window or glazing surface.
- Evacuated tube collectors - these use an array of glass cylinders within which is a vacuum for insulation and an absorber surface to allow for heating of either water or other specialized heat exchange fluid.
- Unglazed collectors - these consist of black plastic absorber surfaces or cylinder arrays that have water or antifreeze fluid flowing in small diameter channels but no glass window.
- Concentrating collectors - these generally use moving reflective surfaces to maintain an optimum pointing angle relative to the direction of the sun. The most common types use moving parabolic cross-section reflectors.

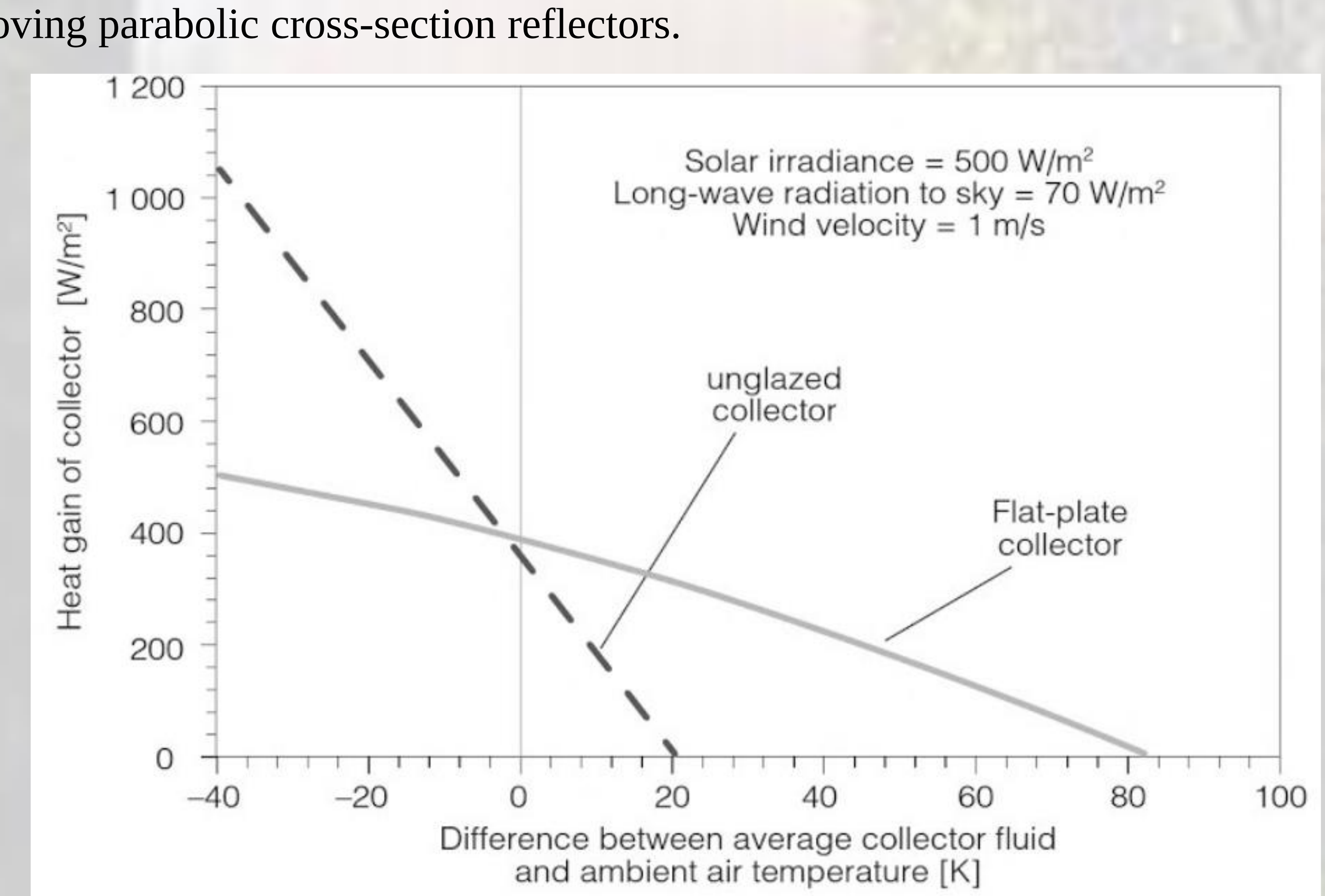

Fig. 1: Solar Thermal Collector Performance (Hadorn et al., 2015)

Design Integration

For the best possible use of solar thermal collection, consideration should be given to the combinations possible in systems also using water source heat pumps (or heat recovery chillers) and underground heat exchange or storage. There have been many versions of these combinations described in books, patents, and actual use over many years (Olson and Yu, 2016; Bottarelli et al., 2016; Jeong et al., 2017). One such combination of technology is shown in Fig. 2.

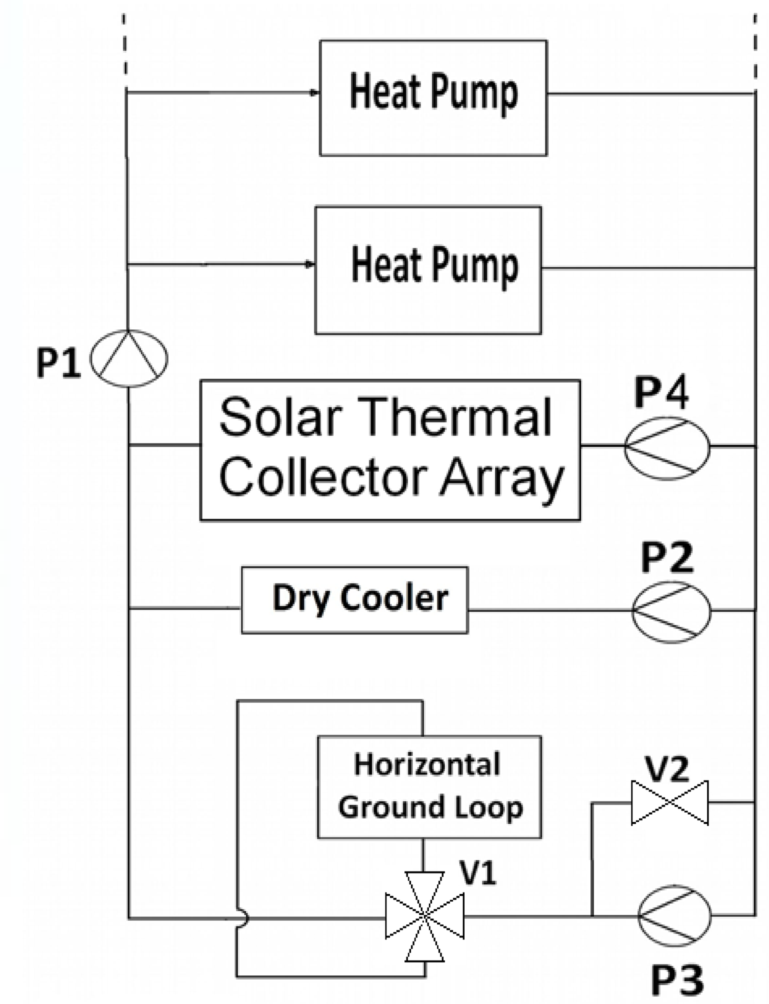

Figure 2: Hybrid or Multi-source Heat Pump System

Benefits of the integrated system:

- The system allows an immediate selection between a ground source mode and an air/solar source mode depending on the temperature from each source. Since air and solar collector temperatures have a much greater variation compared to underground temperature, the average heat pump efficiency is significantly improved.

- If only horizontal pipe arrays are used, the installation cost can be much lower than is the case for borehole heat exchangers.

- With a water connection at the center of the underground pipe array region, the long term thermal storage capability is greater than for the case with connections only at the perimeter.

- The system as described here can force the ground to be rapidly cooled in the spring shoulder season and rapidly warmed in the fall shoulder season. This would be done by using a preconditioning mode with only water pumping and also judicious selection of ground source heat pump mode when the transfer of heat is in the right direction. If the transfer of heat is in the wrong direction, the air/solar mode would be used.

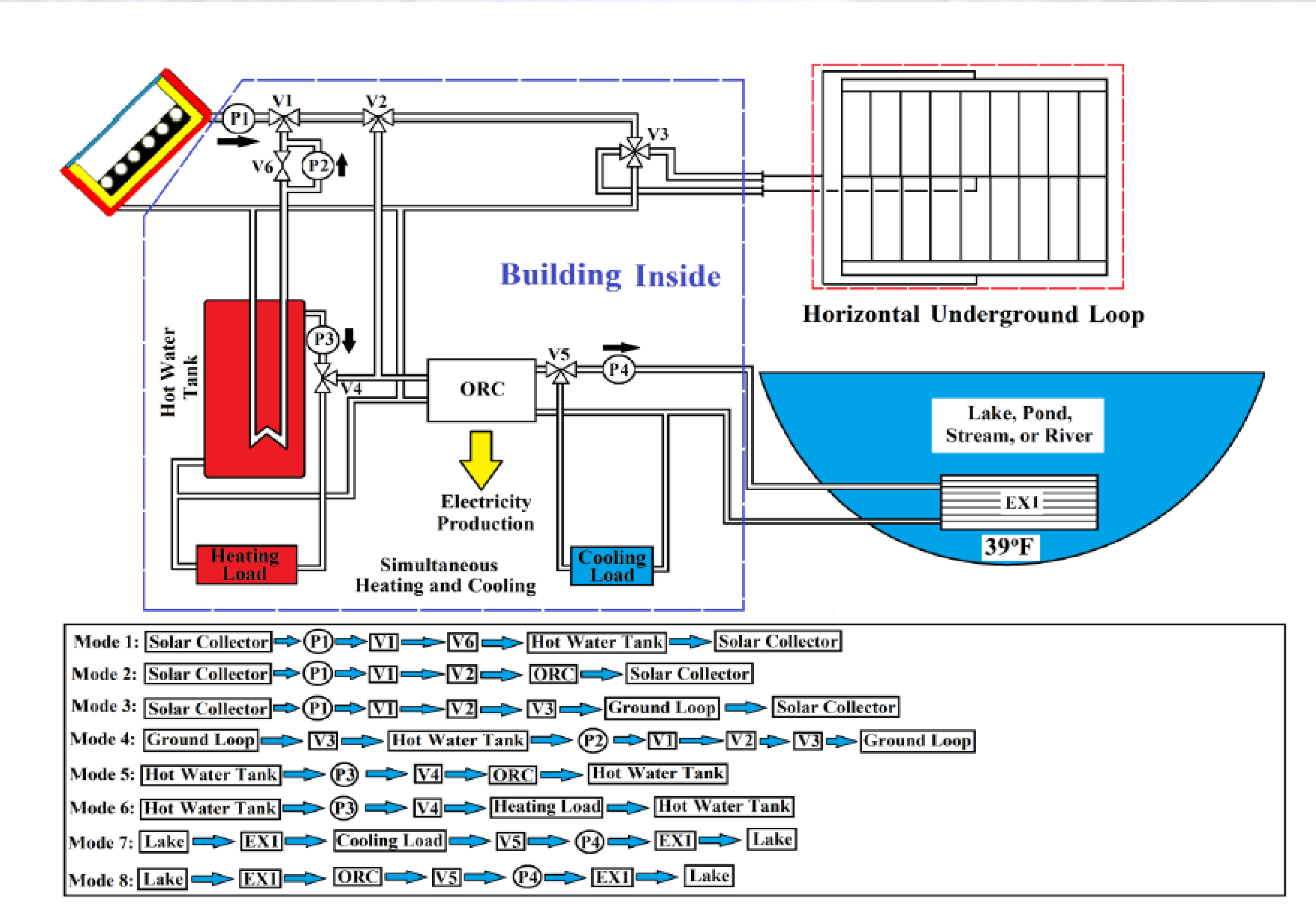

Figure 3: HVAC System with Seasonal Storage and Electricity Generation

Underground Thermal Storage

Underground loops are assumed to be a type suitable for very long term thermal storage in the earth (at least three months). This type of storage will be optimized if there is a fluid connection at the center and one or more connections at the perimeter.

Results from simulation studies of the underground storage are shown in Figure 5 by using different shapes (cube/rectangular block/hemisphere/sphere) and simulation tools (LISA/COMSOL). The assumptions going in to this figure are that there is a heated device below a large area surface insulator with ground thermal characteristics as listed at the bottom right corner of Figure 4. To approximate a seasonal time frame, there is a heating (warm-up) time of 60 days followed by a 150 day cool down time. During this 150 day period, a certain fraction of the initial heat will be lost to the surrounding ground.

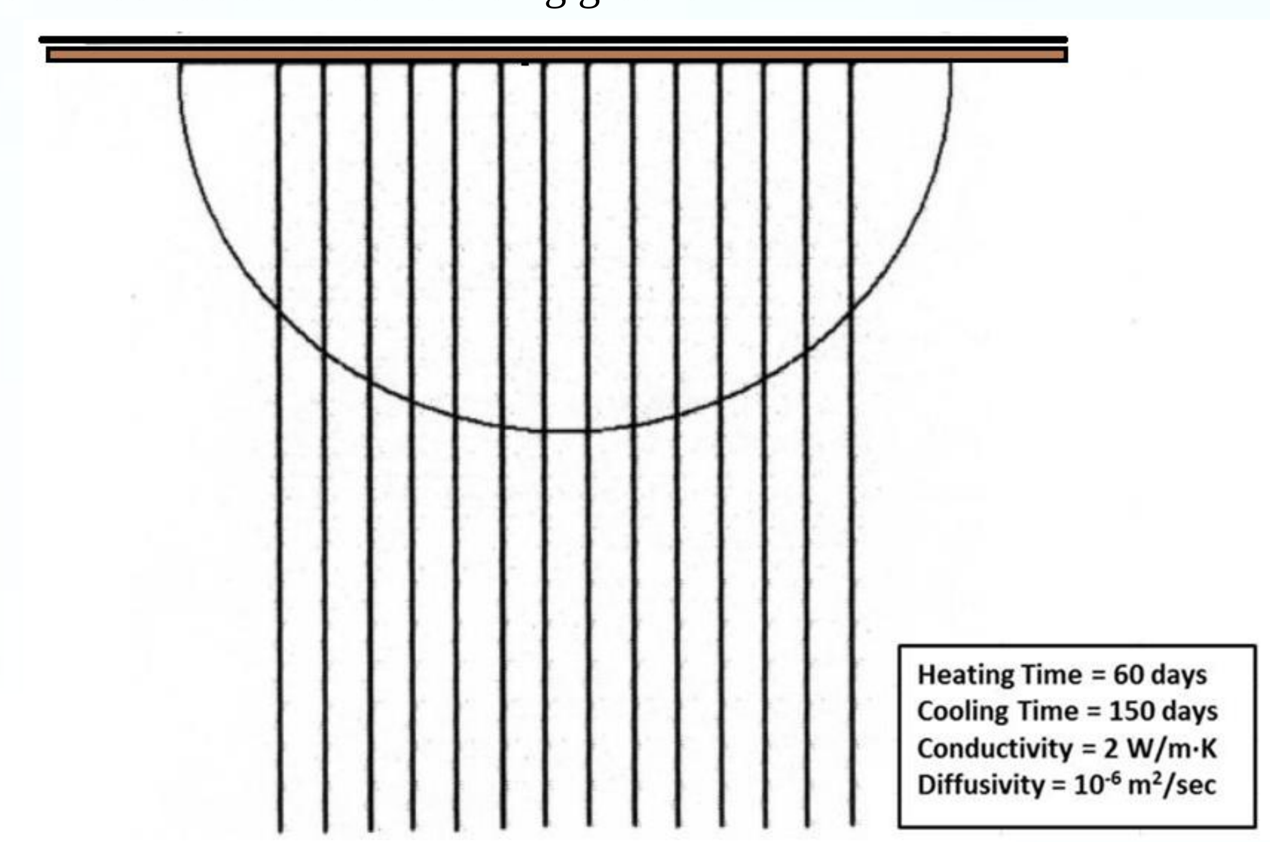

Figure 4: Underground thermal storage simulation

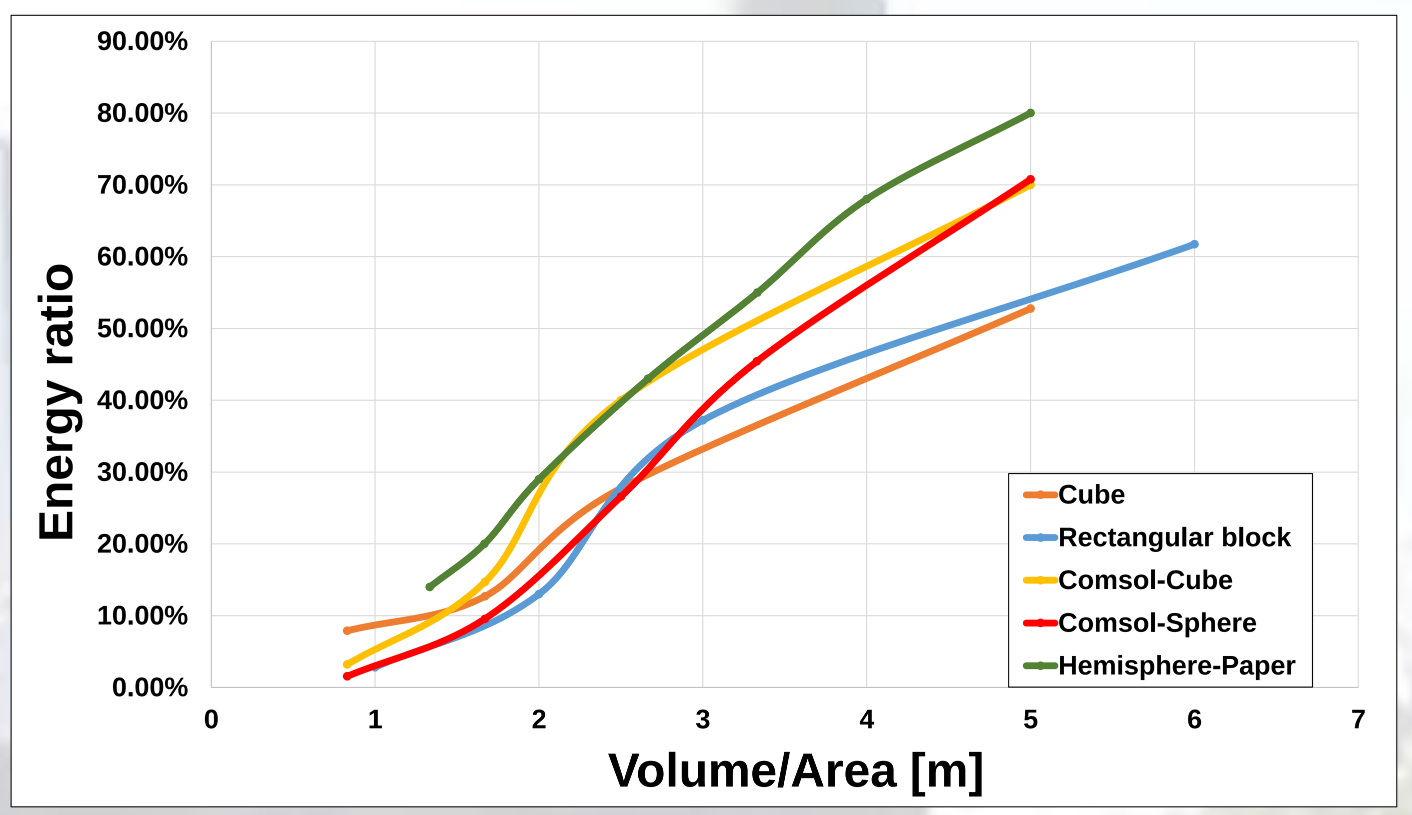

Figure 5: Underground heat/energy retention ratio

Conclusion

In summary, a variety of solar thermal collector types and related technology might significantly reduce fossil fuel energy use in buildings. Over the near term, the best possibility is for buildings that have a large enough roof area or have nearby surface area that is large enough for installation of either a horizontal or vertical ground source heat exchanger. Over the longer term (5 to 10 years), solar thermal collection and air to liquid heat exchange might be extended to any and all buildings that contain windows. This might eventually include high rise buildings in any city.

References

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