SOLAR THERMAL DRIVEN DEHUMIDIFICATION AS A STRAGEGY TO IMPROVE SOLAR THERMAL FINANCIAL PERFORMANCE

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ABSTRACT

Solar thermal systems have a proven and cost-effective record for meeting domestic hot water heating loads especially where it replaces electricity and propane. But hot water heating is a small portion of total residential and commercial energy consumption. Solar thermal systems can be upsized to meet space heating loads, but the extra capacity and high efficiency of solar thermal equipment is poorly utilized in warmer summer months. In temperate climates, air conditioning loads often have a high latent heat component. Additionally, many basements in temperate climates require dehumidification equipment to maintain acceptable humidity levels. This suggests that using a solar thermal driven dehumidification unit might be a good strategy to use excess solar thermal capacity in the summer. A commercially available solar dehumidification unit is examined a complement to solar thermal system and the potential financial performance of this combination is analyzed.

1. INTRODUCTION

Solar thermal technologies used in residential and commercial buildings demonstrate high solar collection efficiency relative to the dominant solar electric technology, photovoltaic panels. Despite this technical advantage, several factors have worked together to limit the spread of solar thermal technology:

1. In the temperate North American climates, the predominant thermal energy load is for space heating. This load occurs in the winter months when sun angles and short day length decrease the solar resource. Solar thermal array size can be increased to provide a significant fraction of winter time heating load, but as a result there is excess, unused capacity in the summer when the only residential thermal load is domestic water heating.
2. Many locations, particularly upper Midwest urban areas, thermal loads are met by utility supplied natural gas that is currently very cheap. Even with a long system life, the up-front capital costs of solar thermal cannot compete with the cheapest natural gas costs. The situation is better where the alternative fuel is electricity or propane, which is more commonly used in rural areas where there are fewer residences and hence fewer potential installation sites for solar thermal systems.
3. When customers consider the environmental benefits of renewable energy, the focus is often on carbon emission reductions. When solar thermal systems are replacing propane and natural gas, carbon emission reductions are lower per dollar of investment as compared with photovoltaic technology supplanting electricity from the electric grid with significant coal generation.
4. While day-to-day storage of solar thermal energy is technically and economically feasible, it does not have the same flexibility in energy use patterns as afforded by net metering of solar electricity.

These factors have tilted the renewable energy market towards electricity generation where it is possible, and the recent dramatic drop in photovoltaic costs have accelerated that trend—to the point that in some markets a combination of photovoltaic panels and a heat pump water heater is being marketed for water heating.

Despite these challenges, solar thermal technology has some attractive features. Its overall collection efficiency is far superior to photovoltaic technology; for example, a recent analysis of two large solar thermal systems showed total system collection efficiencies in excess of 50% [1]. Additionally, the technology is relatively easy to manufacture as evidenced by the numerous "do-it-yourself" approaches [2]. Manufacturing durable, long-lasting solar thermal panels does not require semi-conductor clean room technology.

But to capture these advantages, it is clear that the aforementioned challenges need to be overcome via two strategies:

1) Identifying summertime thermal loads to extend the solar thermal season.
2) Finding ways to use solar thermal energy to supplant more costly and carbon-intensive electricity

An obvious target that fits these specifications is air conditioning. Air conditioning load peaks during the summer and is typically met by electricity. To date, however, the primary technologies for are complex and expensive, as in the case of absorption or adsorption refrigeration units, and require high temperatures in the thermal energy source for effective operation

Another contender for a summer time thermal load is desiccant dehumidification. A majority of summertime cooling load in the central and eastern U.S. consists of the dehumidification, or latent, load [3]. In desiccant dehumidification a solid or liquid desiccant material absorbs humidity from the air, and then thermal energy is used to heat an exhaust airstream which dries the desiccant in preparation for absorbing more moisture. An example of this technology is an enthalpy wheel which uses solid desiccant on a spinning wheel to move humidity from incoming ventilation air to outgoing exhaust air.

In addition to latent cooling loads met by electric powered air conditioning, many homes in the Midwest use electric dehumidifiers to deal with high humidity conditions in basements[4]. This represents a smaller, but significant load that could be met by some form of desiccant dehumidification

The forgoing discussion suggests that combination of a year round hot water heating load with a summertime desiccant dehumidification load could improve the economic performance of solar thermal technology. The work presented here was undertaken to assess that potential.

2. METHODS

To assess the technical and economic feasibility of this combined solar water heating and desiccant dehumidification approach, the physical capacity of a combined solar water heating and desiccant dehumidification unit were specified based on available data, and then assessed for capacity to meet the loads, subsequently the daily operating costs were computed, and finally a comparative present value calculation of economic performance was performed.

2.1 System operating specification

2.1.1 Desiccant dehumidifier

A commercially available desiccant dehumidifier (DDH), manufactured in the more humid southern U.S. was identified as pre-engineered "drop-in" desiccant dehumidification option for solar thermal system. The Comfort Dry 250 unit, manufactured by Novell Aire Technologies[5], uses a desiccant wheel coupled with a water-to-air heat exchanger in the exhaust air stream to drive dehumidification. Operating specifications for this unit were determined from manufacturer provided data [6]. The unit has a minimum dehumidification capacity of 27.4 L/day with 49°C water entering the heat exchanger and a 9°C temperature drop with a water flow rate of 0.063 L/s (assuming the air stream used to dry the desiccant wheel enters the DDH unit at 23.9°C). This represents a thermal power input of 2.3 KW. Under the same conditions, increasing thermal input power to 2.6KW increases the dehumidification capacity to 32.1 L/day. Blower fan and pump energy consumption is 0.37 KW.

2.1.2 Conventional dehumidifier

Since the minimum capacity of the DDH unit is similar to that of a typical residential dehumidifier (DH), the residential dehumidifier performance capacity and typical utilization data of Swager and Lee [4] are used. They analyzed data from various sources, focusing on Wisconsin to determine typical size and operating hours for a residential dehumidifier. Since they used latent cooling load data to develop their analysis, and Harriman III et. al. [3] report that latent cooling loads are similar in upper Midwestern states, their analysis is assumed to be representative for the upper Midwest. The typical dehumidification season (>99% of operating hours) lasted from May to September (153 days) comprising 917 hours of operation or 5.2 average operating hours per day. During the peak month, July there were a total of 343 operating hours or 11.1 average operating hours per day. Using the midrange of dehumidifier sizes and assuming an ENERGY STAR™ unit, the base case DH is assumed to be a unit capable of removing 23.7 L/day of moisture and drawing 0.61 KW when operating. These values were used to calculate the DDH operating hours based on its minimum capacity to perform the same amount of moisture removal.

2.1.3 Base case solar thermal water heating system (SHW)

On the solar thermal side, a basic two panel solar thermal system (5.95 m^2 collector area) with water storage to collector area ratio (WSCAR) on the order of 50 L/m^2. This system is sized to economically meet a fraction of the domestic hot water heating load for a family of 4 (265 L/day of water heated from 7°C to 49°C) [7]. Cassard et. al. present analysis [8] claiming annual solar fractions (SF) for domestic solar water heating of 50 to 60% for the upper Midwest, but that was for a WSCAR of 56 L/m^2. Their analysis showed that the SF increased as collector area decreased, so the SF values they report can be taken as a minimum for this system.

2.1.4 Base case water heating system (HW)

Conventional tank water heating systems were assumed with efficiency depending on the heating source: electric, 90%; natural gas, 65%; and propane, 65%. Thermal energy calculations for base case water heating were done including efficiency losses in the total water heating energy. Efficiency losses for the solar water heating system were assumed to be captured in the SF value.

2.2 System operation and capacity

Table 1 outlines the dehumidifier operating parameters for both dehumidification options. In terms of desiccant dehumidification using solar thermal heat, the key parameters are the average and peak thermal energy requirements. Based on the hot water load specified above and assuming a solar thermal fraction of 70%, the average daily solar thermal production would be about 9 kWh. Recognizing data [8] suggesting that the average SF value masks a lower wintertime SF and a higher summer SF value, this analysis assumes that summer solar production exceeds the hot water heating load and goes part way to meeting the average and peak thermal needs of the desiccant dehumidifier.

For the remainder of the DDH thermal load, it is assumed that an additional panel (2.97 m^2) can be added to the solar thermal system with minimal design impact. Examination of a typical flat plate performance SRCC rating sheet [9] for a flat plate collector of this size indicates a daily summer (Category C) clear sky production of 10 kWh. Coupled with the excess production from the existing panels, the expanded system should have a solar fraction, SFC serving the combined solar water heating and dehumidification summertime load greater than SF for the smaller system. The remaining thermal supply for the DDH unit is supplied by the back-up water heater at the stated efficiencies. The solar thermal system with the additional panel will be referred to as SWHE. In this analysis, SF was set at 70% and SFC at 90%.

TABLE 1: DEHUMIDIFIER OPERATING PARAMETERS

Parameter	**DH**	**DDH**
Average daily operating hours	6	5.2
Peak daily operating hours	11.1	9.6
Operating electrical power, KW	0.61	0.37
Operating thermal power, KW	--	2.3
Average electrical energy use, kWh/day	3.7	1.9
Peak month electrical energy use, kWh/day	6.8	5.9
Average thermal energy use, kWh/day	--	12.1
Peak month thermal energy use, kWh/day	--	22.5

2.3 Financial and greenhouse gas (GHG) emission analysis

Based on the specifications and assumptions, daily operating costs for the water heating and dehumidification options were calculated, and then converted to annual operating costs. Included in the analysis are allowances for maintenance costs, solar thermal pump operating energy, and energy cost inflation as specified in Table 2. Using the annual operating costs, a 25-year present value calculation was done under various assumptions of capital costs and discount rate to compare financial performance. The return on investment (ROI) is the discount rate that makes the present value costs of two options equal. Because the calculations are based on variable data such as energy and capital costs, as well as assumptions about performance, the spreadsheet used to the calculations is available upon request from the author to allow the exploration of different assumptions.

Greenhouse gas emissions factors [10] were determined using the emissions factors also shown in Table 2.

TABLE 2. FINANCIAL AND GHG EMISSIONS ANALYSIS PARAMETERS[1234]

Electricity cost, \$/kWh	\$0.11
Propane cost, \$/kWh equivalent	\$0.061
Natural gas cost, \$/kWh equivalent	\$0.26
Energy inflation rate, %	3
SWH cost, installed	\$7600
SWHE cost, installed	\$8600
HW, installed	\$700
DDH, installed	\$3500 [6]
SHW/SHWE annualO&M cost	\$15
DH annual O&M cost	\$10
DDH annual O&M cost	15
GHG emissions factor for electricity, kg CO_2e/kWh	0.743[5]
GHG emissions factor for propane, kg CO_2e/kWh	0.218
GHG emissions factor for natural gas, kg CO_2e/kWh	0.181

1 These values are used unless otherwise specified. Assumed energy prices based on information about current conditions in Minnesota from http://www.eia.gov/petroleum/.

2 O&M costs are estimates based on pump and glycol replacement for solar thermal, unit replacement for the conventional dehumidifier, and pump and fan replacement for the desiccant dehumidifier.

3 Unless otherwise specified, capital costs are based on author's experience with local market conditions.

4 Water heater/storage tank replacement costs are assumed to be equivalent between conventional and solar water heating system and thus are excluded from the analysis.

5 Calculated from raw emissions data using global warming potential values of 1 for CO_2, 23 for CH_4 and 296 for N_2O.

3. RESULTS AND DISCUSSION

Annual operating costs for various system options, ROI values for the options of first adding just solar hot water heating and then adding desiccant dehumidification, and greenhouse gas emission reductions for the two solar options are presented in Table 3.

Under the assumed system costs and energy costs, it is clear that the addition of the solar dehumidification system has not improved solar thermal financial performance, nor has it changed the overall affect of fuel choice—either solar thermal option performs best when it supplants electric water heating; somewhat worse, but still net positive when it replaces propane; and has a negative return when replacing natural gas at current prices.

For all fuels, the addition of the solar dehumidification option significantly reduced GHG emissions relative to solar water heating only. This reflects the reduction in carbon intensive electricity use. In the event that asignificant tax were applied to carbon emissions, the economic performance of the solar dehumidification option might improve.

TABLE 3. FINANCIAL PERFORMANCE AND GHG EMISSION REDUCTIONS FROM SOLAR DEHUMIDIFICATION

	Electricity	**Propane**	**Natural gas**
Annual operating costs	\$	\$	\$
HW & DH	645	515	256
SWH & DH	279	235	162
SWHE & DDH	151	144	111
ROI compared to HW & DH	%	%	%
SWH & DH	5.1	2.9	-4.4
SWHE & DDH	3.5	1.3	-4.7
25-year GHG reductions compared to HW and DH	tonnes CO_2e	tonnes CO_2e	tonnes CO_2e
SWH & DH	64	24	19
SWHE & DDH	85	35	30

It should be noted that the results presented here are based on current energy prices and system costs. Any more rapid increase in energy prices than the assumed energy inflation rate will improve the financial performance of the two solar options, but the performance of the DDH option will still be relatively less than the SWH and DH option, unless electricity prices rise in disproportion to other energy prices, or as noted above, the introduction of a carbon tax. One way that an electricity price rise might occur would be through the introduction of residential time of day metering.

The poor financial performance of the SHWE and DDH combination is primarily due to the relatively high capital costs of the DDH unit, and secondarily to the fact that its operating electrical energy is not even 50% less than the conventional DH. Sensitivity analysis of the financial model shows that reducing the cost of the DDH unit by 50% would bring financial performance for systems using electricity and propane to parity with the solar alone case, while still preserving the GHG emission reductions. A 50% reduction in DDH operating electrical energy only generated modest changes the ROI--on the order of tenths of a percent.

The choice to model the DDH performance at the low end of it performance range was not simply a matter of conservative analysis, but a reflection of the fact that it is probably oversized as a replacement for a residential dehumidifier—it is primary purpose is dehumidification of make up ventilation air. At the 49°C delivered water temperature, the dehumidification rate can be improved by modestly raising in thermal input via increased water flow rate, or more dramatically increased through higher incoming water temperature. Given the summertime operation of the DDH unit, it is likely that the solar thermal system can deliver higher temperatures on hot summer days.

This excess capacity suggests several avenues to explore in future studies:

1. Design of a smaller, less expensive unit optimized for residential dehumidifier replacement.
2. Use of evacuated tube solar thermal collectors with their higher temperature capability as way to increase performance without the addition of an additional panel.
3. Upsizing the solar thermal array to meet part of wintertime heating loads and summer latent cooling loads.

4. CONCLUSION

For replacement of small residential dehumidification systems, the combination of solar thermal hot water heating and the chosen desiccant dehumidification unit did not improve solar thermal performance under current assumptions of thermal performance and financial parameters, primarily due to the high capital costs of the desiccant dehumidification unit. Sensitivity analysis of the financial model shows that the desiccant dehumidifier needs to be reduced by about 50% to offer financial benefits over a basic solar thermal hot water heating system.

Avenues for improving this picture include cost reductions on the desiccant dehumidification unit and/or solar thermal system, or increasing system capacity to meet additional winter heating and summer latent cooling loads.

5. REFERENCES

(1) Dontje, J. H. Large solar thermal system performance: Domestic hot water and pool heating. Presentation at the Solar Thermal '12 National Solar Thermal Conference, Midwest Renewable Energy Association, 2012

(2) www.buildit.solar.com. Accessed 4 February 2013

(3) Harriman III, L. G., D. Plager and D. Kosar. Dehumidification and cooling loads from ventilation air. ASHRAE Journal, pp. 37-45. November, 1997

(4) Swager, R and L. Lee. Focus on Energy evaluation: Dehumidifiers deemed savings review for targeted home performance with ENERGY STAR. Focus on Energy. www.focusonenergy.com/files/Document_Management_System/Evaluation/Dehumidifiers_Deemed_Savings_Review_for_Targeted_Home_Performance_with_ENERGY_STAR.pdf Accessed 15 March 2013

(5) http://www.novelaire.com/comfortdry-250-dehumidifier.html Accessed 15 March 2013

(6) Janke, S. Private communication. 7 February 2013

(7) Lane, T., Solar Hot Water Systems: Lessons Learned 1977 to Today, Gainesville, FL: ECS Solar Energy Systems,Inc., 2005

(8) Cassard, H., P. Denholm, and S. Ong. Break-even cost for residential solar water heating in the United States: Key drivers and sensitivities. NREL Technical Report NREL/TP-6A20-48986. National Renewable Energy Laboratory, Golden, CO. February 2011. http://www.nrel.gov/docs/fy11osti/48986.pdf Accessed 15 March 2013

(9) Solar Ratings and Certification Corporation. Ratings. http://www.solar-rating.org/facts/collector_ratings.html Accessed 9 March 2013

(10) EnergyCAP, Inc. Greenhouse gas emission factors. EnergyCAP, Inc. 2013. http://www.energycap.com/products/energycap-professional/greenhouse-gas-emission-factors Accessed 15 March 20-13