Case Study - Sustainable Hotel Water Heating - Eliminating Fuel Usage -Puerto Vallarta, Mexico 2006 – 2008

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ABSTRACT

It is estimated that 5% of the world's daily energy consumption is expended on fuel for heating water. An electric heat pump is an alternative to burning fuel for heating water. A heat pump uses a vapor compression cycle to take heat from a low temperature source and raise its temperature to a useful level. Heat pump water heaters or "Heat Machines" using CFC and HCFC refrigerants have been a niche market dating back to the 1970's. HFC refrigerants have been introduced for heat pump water heating but mainly for space heating in cooler climates. The technology herein introduces the concept of using HFC refrigerants, particularly HFC134a, for potable water heating in warmer climates. This heat pump water heating system works to maintain hot water tanks at 60°C while supplying 10 to 30% of the cooling requirement, thereby providing a useful CoP of 6.0 or greater. This system enables the existing water heater fuel valves to be completely shut off, thereby saving fuel and eliminating carbon discharge for water heating. Commercial buildings, such as hotels, have a simultaneous need for heating potable water and comfort cooling. During the period of March 2006 through November 2008, a market test of a heat pump water heating technology was conducted in the hotel resort community of Puerto Vallarta, Mexico. Using a totally installed or "turn-key" approach, seven hotels adopted the new technology which featured special water to water heat pumps using HFC134a refrigerant instead of HCFCs. Each hotel achieved monthly savings in fuel ranging from US$5,000 to $20,000 depending on the degree of the application and the size of the hotel. The savings in fuel quantity and cost as well as carbon discharge were diligently recorded for 32 months. Collectively, over 1.6 million liters of fuel were saved over the period by the seven hotels, representing a value of over US$ 800,000. In addition, over 3000 tons of carbon was saved from discharge and, since cooling was produced simultaneously with the water heating, little or no additional electricity was used. The market test proved the commercial viability of the application on a capital purchase basis or lease with service. HFC134a, while commercially viable, has a global warming potential 1300 - 1430 times greater than CO_2. One of the most important outcomes of the test was the practical experience to design an improved unit with useful CoP's greater than 6.0 that can be applied internationally with double wall heat exchangers to make the same application practical for code compliance and the safe use of low GWP natural refrigerants.

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PREVIOUS SYSTEMS AND REFRIGERANTS

In the 1970's and 80's pioneering projects displaced the burning of fossil fuels for heating water by employing a heat pump vapor compression cycle. Over thirty years ago, one such project was located in Norway at a lake named Mjosa (Norway's largest lake). The lake was polluted and a water treatment facility was erected to clean up the lake. It was proven to be expensive to heat the facility with traditional fossil fuel heating methods. Engineer Emir Chevro with Witt & Borgan and the author, then with Carrier International, proposed a system to modify a Carrier R-12 centrifugal chiller model 19EA to capture heat from the 7^{o}C to 10^{o}C lake water and produce 45^{o}C hot water in the condenser to heat the facility instead of burning fuel. The system was installed in mid 1970's and as of April 2010 is still running.

In the early 1980's, world renowned UK architect Norman Foster directed the building of the headquarters of the HKSB bank in Hong Kong. His team challenged suppliers to develop systems for the 21st century. A space heating system was proposed and adopted whereby the entire building would be heated by a single centrifugal refrigeration machine extracting heat from the adjacent harbor at a CoP of 5. In 2005, the author traveled to Hong Kong to learn that the R-12 system was converted to R134a but is still in operation, providing heat to the building in the 21st century as envisioned.

1980's reciprocating chillers using CFC's and HCFC's modified to heat water

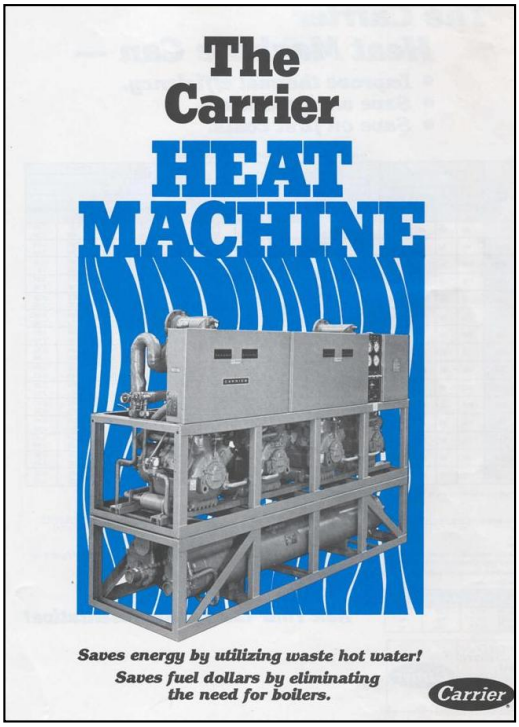

Figure 1 - *In the 1980's air conditioning manufactures such as Carrier developed vapor compression machines using HCFC22 and CFC12 that produced hot water thereby recovering a buildings internal heat instead of burning fuel in boilers.*

In the 1980's these "mega projects" opened up a niche market for what was named "Heat Machines" by one brand, as seen in **Figure 1,** and "Templifiers" by another brand. These were generally reciprocating compressor chillers modified to water to water heat pumps. Different from heat recovery, where the final hot water temperature is not assured, this heat machine concept recovered heat from either the cooling tower or return chilled water and produced hot water at the controlled temperature set point. These heat machines used refrigerant HCFC22 for hot water temperatures up to 50^{o}C, and refrigerant CFC12 for controlled hot water up to 70^{o}C. A market opened up for these machines in large hotels (+100 rooms) in warm climates to provide hot water for guest rooms service instead of using boiler hot water heaters. The Regent Hotel in Bangkok Thailand, the Princess Hotel in Singapore and the Royal Mayan Hotel in Cancun, Mexico installed such machines in the 1980's. The customers appreciated the fuel saved as well as the reduced problems in dealing with the smoke flue discharge of boilers. Soon there after, the Montreal Protocol came to ban CFC's and discourage HCFCs and, coupled with relatively low fuel prices, the heat pump water heating market became largely ignored by major manufacturers.

In the early 1990's, air to water swimming pool heat pump heaters using HCFC 22 were promulgated by niche firms around the world. Following in the later 90's, HFC134a has grown to be an accepted refrigerant for heating water but the application has yet to go beyond a small niche market.

In 1998 a small manufacturer in Mexico named TECSIR (www.tecsir.com) developed and installed some machines they initially called "Co-Therm Chillers" which were water to water heat pumps. These machines used either HCFC22 or HFC134a to produce up to 60^{o}C hot water. Hotels were a particularly attractive application because of the constant need for cooling simultaneous with a large demand for hot water. An article appeared in a hotel magazine, Alta Hoteleria, publicizing

the first initial installation of the Co-Therm Chillers at the Royal Sands in Cancun. Starting in November of 2005 Cotherm of America Corporation, based in Florida, USA, and TECSIR of Monterrey, Mexico teamed up to test market the heat machine concept in the concentrated hotel area of Puerto Vallarta, Mexico.

NEW SYSTEM AND REFRIGERANT

An upgraded design of the 1980's "heat machine" was evolved for the test market in Puerto Vallarta, Mexico. The controls were upgraded to electronic controls with dial up modems to extract two weeks of operating data and enable remote upgrade of the software. A decision was made to steer clear of HCFC's and standardize on HFC134a for hot water and HFC507 for pool water heating. The author and co-author were stationed in Puerto Vallarta to sell a totally installed or "turnkey" concept to the hotels. Moreover, close monitoring of the machines was necessary to resolve issues quickly. An entire "Co-Therm" system would be engineered, manufactured, installed and serviced by one entity to assure the result. A project would start by studying the fuel consumption history of the property and isolating the fuel consumption attributed to the heating of potable water for guest rooms, kitchens and laundry. This data corroborates the theoretical sizing of the capacity of the equipment. All the projects used one or more of two sizes. Model CT-200 yielded a heating capacity of 500,000 BTUs at 60°C hot water while also providing 30 tons of cooling. A "Duplex" model with a heating capacity of 1,000,000 BTUs and 60 tons cooling capacity was also applied. These models used two or four 15 ton reciprocating R134a compressors, either Carlyle or Bitzer. See **Figure 2.**

Pre-Cooling Chilled Water And Producing 60°C Hot Water… TURNING THE BOILER OFF

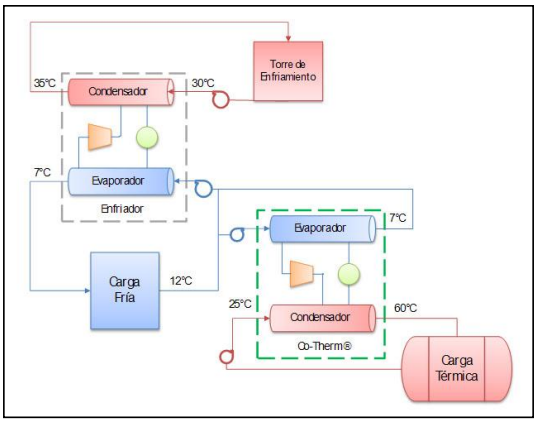

Figure 2. - *This diagram depicts a typical interface of a Co-Therm machine with an existing chiller. The Co-Therm Fluid Heater developed and manufactured by TECSIR of Mexico is a machine using either HCFC22 or HFC134a that maintains 60°C water in the hotel water tanks. This machine replaces the duty of boilers and gas water heaters. The 2006-2008 market test in Puerto Vallarta Mexico had the machines installed in eight hotels using HFC 134a.*

DOCUMENTED OUTCOME OF SUSTAINABLE HOTEL WATER HEATING TEST MARKET 2006 - 2008

The first three hotels were installed free of charge for three months to demonstrate the savings. After the trial period the hotel had the option to purchase the entire system or lease it. If the performance was not satisfactory the system would be removed at no charge to the customer. After a contract was signed, manufacturing and delivery of the unit was established while a team at the jobsite prepared the electrical and plumbing connections to the location of the prospective machine(s). A process known as "hot tapping" was used to make the plumbing connections. Hot tapping (assuming ductile iron pipe) allows access to the existing piping without interrupting operation of the system. This process involves welding a threaded nipple to the outside of the return chilled water pipes and the hot water piping or tank. After a valve was threaded on the welded nipple, a "hole saw" and drill was used to make the penetrations without having to disturb the chilled water or hot water system. Once the machine and pumps were set and final plumbing connections made, the machine was started up. The shortest time from machine arrival to machine start-up was 11 days with three men performing the installation. Upon startup the condensers produced 60°C hot water and maintained that tank temperature. The fuel valves of the water heaters were turned off and the fuel water heaters became a backup system. Customers experienced remarkable savings of fuel and noted that there was not any appreciable increase in electricity after installation. The efficiency in electricity usage was caused by two system improvements. The first improvement is the arrangement whereby the Co-Therm units pre-cooled a portion of the return chilled water before the existing chillers. The large chillers either reduced power while operating in part load or turned

off completely. Secondly, the incoming municipal water was pre-heated in a special sub-cooler. This Pre-heater /Sub-cooler heat exchanger increased the efficiency of the Co-Therm unit.

The 500 room Marival Resort Hotel in Nuevo Vallarta had four Co-Therm machines installed. Previously the hotel conventional LP fuel water heating technology. The property regularly experienced about 8 propane truck deliveries per month prior to installation of the new technology. After retrofitting to Co-Therm technology, the propane water heaters were completely shut off while the hot water tanks maintained 60^{o}C temperature and the guests enjoyed hot showers. Today the property has three or less deliveries of propane per month. As the Director of Engineering at the Marival relayed to us, the propane gas supplier was dismayed at the dramatic drop in business and offered a lower price. He assumed the customer had changed suppliers, not knowing that a paradigm had been broken. The Marival is leasing the Co-Therm systems with service included. The fuel cost saved every month greatly exceeds the lease payment. It was noted that the applications that used diesel fuel and steam boilers were a bit more difficult to calculate the savings as it depended on the part load efficiency of the boilers and the effectiveness of the steam traps. In one hotel application the steam traps were ineffective, bypassing live steam so the savings were not realized and the customer was not convinced. Seven of eight lead customers are convinced of the value of the application and some have provided video taped testimonials (See http://cothermwaterheating.com/Documentary.html). The applications saving diesel fuel such as the Marriott Casa Magna significantly reduced their carbon footprint as well as their operating cost. The savings with applications that had gas water heaters had much faster fuel cost savings due to the relatively high cost of propane which has a lower heat content than diesel fuel. In just the first month of operation, the Sheraton Buganvilias hotel experienced a savings of 20,000 liters of propane. Several water heating furnaces were completely shut off while the guest rooms and kitchens had plenty of hot water. The Marriott Casa Magna Hotel Director of Engineering, Danny Terry was especially adept at the electricity and fuel savings. In the winter months he heated the pool with his Co-Therm machines and scheduled to run the laundry at night, matching a hot water load with a cooling load. He was able to shut off the main chillers with the Co-Therm units providing enough cooling for the hotel, thereby providing the hot water and chilled water with the same kilowatt. The Marriott Co-Therm hot water system was oversized in capacity. The property used this free hot water to their advantage. In a later room refurbishment, the hotel decided to change out the air conditioning fan coils in all the rooms and add re-heat coils to leverage the nearby hot water in the bathroom for humidity control. This solves a long standing problem in almost all tropical climate hotels. Before humidity control the room humidity was almost always above 75% RH and led guests to turn down the thermostat set point. This situation sometimes leads to guest complaints particularly with the odors that the high humidity may cause and over cooling. After the change to re-heat humidity control, the guest comfort was tangibly improved. In the words of Danny Terry, the humidity complaints after the change were “non existent”. These practices were later documented in a Best Practice document by Marriott. The story behind this test market is featured in an article in Innovation Magazine Titled “Innovation: The Way Through Recession” (Jagusztyn 2009).

The results of each hotel’s fuel and carbon saving were recorded and reported each month from March 2006 till November 2008. **See Table 1** for the summary of results in this period.

ENERGY EFFICIENCY ADVANTAGE

The Coefficient of Performance or CoP is a measure of efficiency. It is the ratio of the output energy to the input energy. A traditional electric hot water heater uses resistance rods immersed in the water tank to heat water. An electrical input of 1000 kW generates a heat output of about 1000 kW or less. Therefore 1000kW Output / 1000kW Input is a CoP = 1. For a gas water heater of say 500,000 BTUH input, the typical output would be less at about 400,000 BTUH or a CoP = 0.8 The efficiency advantage of this Cotherm technology over any existing water heating system is many times greater than either of the aforementioned conventional technologies. In fact, more than six times greater efficiency than conventional water heating. For every 1000 kW of input to the Cotherm Water Heater machine 3500 kW of heat is output simultaneously with 2500 kW of cooling. Therefore the typical Cotherm CoP is 3500kW + 2500kW total output / 1000kW Input = CoP = 6.0. The energy efficiency story is encouraging for engineers but the most desired feature of this technology by customers is the fuel saved.

Over 1.6 Million Liters Of Fuel Saved And 3000 Tons Of Carbon Eliminated
$811,000 Saved
7 Hotels From March 2006 Till Nov 2008

Cumulative Vallarta Area Fuel Savings with CoTherm Technology

Update 16-Dec-08

Project Location	Type of Fuel	Start-Up date	Report Date	Months of Operation	Liters Of Fuel Saved	Pesos* Saved	US Dollars* Saved	Carbon Tons Saved
Marriott PV	Diesel	18-Mar-06	30-Nov-08	32.5	594,777	$ 3,045,689	$ 298,597	1790
Marival NV	LP Gas	11-Nov-06	30-Nov-08	24.7	519,796	$ 2,435,886	$ 238,812	115
Holiday Inn PV	Diesel	21-Jan-07	30-Nov-08	22.3	186,796	$ 932,322	$ 91,404	562
Grand Mayan Laundry NV	LP Gas (Recorded since 06/2008)	7-Jun-08	30-Nov-08	5.8	49,112	$ 238,022	$ 22,039	11
Occidental NV	LP Gas (Recorded since 06/2008)	30-May-08	30-Nov-08	6.0	72,382	$ 350,785	$ 34,391	16
Sheraton PV	LP Gas	2-Sep-08	30-Nov-08	2.9	77,614	$ 383,870	$ 37,634	17
NH Krystal	LP Gas	10-Nov-08	30-Nov-08	0.7	5,886	$ 29,584	$ 2,900	2
Total				114.2	1,691,403	8,285,545	811,012	3,014

* 10.2 Pesos to One US Dollar exchange rate

TABLE 1. *The table summarizes savings in fuel measured in liters, fuel cost in Pesos and converted to US dollars and carbon in tons which were recorded monthly from March 2006 till November 2008. The basis for the fuel savings for the first year was the fuel used per occupied room in the base 2005 month. After this period the machines had software that calculated the amount of fuel saved based on the amount of heat they produced versus the base fuel water heater. The carbon discharge saved was calculated with software based on the amount of fuel not combusted at the normal efficiency.*

LEASONS LEARNED TOWARD THE PATH BEYOND SYNTHETIC REFRIGERANTS

Establishing Validity Among Customers

Prior to entering this market test the US DoE had issued a report in 1997 ("Commercial" 2000) citing that customer awareness was a key obstacle. A follow-up report by New York State "TOWARD MARKET TRANSFORMATION: COMMERCIAL HEAT PUMP WATER HEATERS FOR THE NEW YORK ENERGY $MARTS M REGION" (NYSERDA 2002) confirmed that while the technology was straight forward, customer awareness was lacking. In the microcosm market of Puerto Vallarta we found that after the performance of Co-Therm was verified by word of mouth that new customers were much easier to convince. We found that a critical success factor was a total package installed with close coordination between engineering, manufacturing, installation, service and feedback to the customer. The decision makers liked the choice to either lease the system at a positive cash-flow or outright purchase it. Roughly half the customers chose to lease the system with service. One customer's General Manager who favored leasing was looking at obvious fuel savings averaging $20,000 per month with lease payments per month of approximately $12,000 said "you just have to do the math." We borrowed a concept from the hotels called a "Dash Board" where all the numbers of the investment and saving are visible at a glance. See **Table 2** for one such Dash Board which resulted in a sale. Going forward, the necessity to establish the validity of the fuel savings among customers can not be understated.

CoTherm Technology DASHBOARD 450 Room Hotel

Hotel Guest Room & Laundry Hot Water Heating

SAVINGS	Annual Fuel	Annual Cost Reduction
	(Liters LP)	(US$)
	241,038	$131,079

INVESTMENT	Total Installed Price	Monthly Lease Price (5 Year)	Service/Maintenance Monthly Fee	Annual Lease Expense
	(US$)	(US$)	(US$)	(US$)
	$145,000	$4,300	$700	$60,000

CUMULATIVE COMPARISON		5 YEAR LEASE OPTION		PURCHASE OPTION	
	Annual Savings	Annual Lease Expense	Annual Lease Net Profit	Total Installed Purchase Price	Purchased Return on Investment
	(US$)	(US$)	(US$)	(US$)	(months)
	$131,079	$60,000	$71,079	$145,000	13

TABLE 2. *This table presented to the customer shows an actual sale proposition to a hotel for a 1,000,000 Btu Co-Therm water heater on a capital purchase or 60 month lease. This summarizes the options of a total installed capital purchase of $145,000 or a 60 month leased for $5000 per month with service. With an estimated $131,000 annual savings in propane fuel at current prices the choice was either a 13 month payback or yearly positive cash flow of $71,000. This was fairly easy to sell either option but not until credibility of the fuel savings was established at other hotels in the area.*

A Robust Design

While the Puerto Vallarta market test proved hotel market acceptance of heat pump water heating, certain deficiencies were discovered that would need to be addressed if this technology is to be in the mainstream in the near term. The most common defect was the pumps which were supplied separately from the unit. An integral package with robust pumps would solve this problem and perhaps lower installed cost. Compressor failures were common and the root cause evaluated. A design change would increase the reliability.

The units in the test market used condensers and sub-cooler heat exchangers that were “single wall.” That means that on one side of the heat exchangers was a fluid mixture of HFC134a and refrigerant oil and on the other side, potable water. If a breach in the heat exchanger was to occur, say by corrosion, one side would “cross-connect” to the other. Internationally recognized plumbing codes specify “cross-connection” prevention measures that preclude the potential for non-potable fluids such as refrigerant oil to enter a potable water stream. Some international hotel chains also include cross-connection prevention in their codes of practice. One remedy would be to engineer an isolation loop but that would increase complexity and cost and reduce efficiency.

To make Cotherm Water Heating more efficient and practical for international application, including the safe use of natural refrigerants, an international patent application was made. A US Patent was published on 11 Feb 2010 (Jagusztyn 2010) which incorporated the lessons learned by this market test. As shown in **Figure 3**, the prototype unit has been on test since January of 2009.

Prototype Unit Under Test Incorporating Lessons Learned From The Puerto Vallarta Market Test Of Cotherm Water Heating

Figure 3. *Blissfield Manufacturing Company of Blissfield, Michigan USA cooperated with the inventor of US Patent 7,658,082 to build and test prototypes of units incorporating the knowledge gained from the market test. Above is the second prototype with tanks simulating the operation of both the hot water and chilled water systems. This CoTherm unit was tested in an adjacent industrial application that needed hot water as well as cold water which proved to be yet another viable application. The unit features web based controls, integral pumps and double wall heat exchangers for cross connection prevention and the possibility of application with natural refrigerants.*

NATURAL REFRIGERANTS

While the system is currently designed to use HFC134a, it is envisioned to move towards natural refrigerants such as HC600a (isobutene). This modification would increase overall system efficiency while decreasing the detrimental environmental effect of synthetic refrigerants. This modification requires additional research and development to innovate low-cost, double-wall heat exchangers and safety systems that are designed specifically to operate with these natural refrigerants.

CONCLUSION

A paradigm has been broken in understanding that fuel no longer needs to be used to produce hot water in tropical climates (as long as you have a chilled water system.) In its place, electric Cotherm machines are used to transfer heat rather than producing the heat while utilizing a cooling benefit. The current paradigm for producing hot water has accepted a CoP of less than 1.0. The demonstrated system described herein outperforms this current paradigm by achieving a CoP of 6.0. Commercial viability of the technology has been established on either a purchase or a lease basis. An improved unit design capitalizing on the experience from this market test and conforming to international codes is in development. Interested stakeholders or customers can contact the authors for more information.

REFERENCES

"Commercial Heat Pump Water Heaters: Technology for Efficient Electric Service Water Heating in Commercial Buildings." Federal Technology Alert. New Technology Demonstration Program, May 2000. Web. May 2010. <http://www1.eere.energy.gov/femp/pdfs/FTA_HPWH.pdf>.

Jagusztyn, Tadeusz. "Innovation – The Way Through Recession." V I E W P O I N T. Innovation Magazine, 1 Nov. 2009. Web. <http://www.innovationmagazine.com/volumes/v9n1/preserved-docs/60_61.pdf>.

Jagusztyn, Tadeusz. "Heat Transfer System and Associated Methods." United States Patent: 7658082. USPTO, 9 Feb. 2010. Web. May 2010. http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=/netahtml/PTO/srchnum.htm&r=1&f=G&l=50&s1=7,658,082.PN.&OS=PN/7,658,082&RS=PN/7,658,082.

Sachs, H.M. 2002. Toward Market Transformation: Commercial Heat Pump Water Heaters for the New York Energy $mart^{SM} Program. American Council for an Energy–Efficient Economy. Washington, D.C.