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COMBINED SPACE-HEATING/WATER-HEATING SYSTEM PERFORMANCE

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Abstract

With increasing fuel prices, various energy-saving techniques have been considered for residential appliances. Space heating accounts for the largest energy use in residential applications. One method proposed by manufacturers to keep operating cost low is to combine residential water-heating and space-heating functions into a single system. This paper presents the field test results of the performance of a combined water-heating/space-heating system under actual usage conditions. The system was installed in an 1187 ft^2 (110 m^2) home (Green Home) located in the Washington DC area. Data were collected for a one-year period. The water-heating performance was established by evaluating the hot water usage data during the test period. Water-heating/space-heating performance was established by using hot water data plus the amount of hot water circulated for space heating during the winter months. Analysis of the data indicated that the system produces hot water at an efficiency averaging 48% for water heating in the summer months and produces hot water at an efficiency ranging between 63.5-69.4% for combined water-heating/space-heating during the winter months. The relative humidity was maintained in the home at substantially lower level than that of the outside air, and the inside temperature was kept at the desired setting.

Introduction

In order to use energy more wisely, buildings have been constructed more energy efficiently with increased insulation and vapor barriers. Tighter buildings may jeopardize indoor air quality levels. They also may develop structure rot from high indoor humidity during the winter. The combined system in this study was equipped with a heat recovery ventilator (HRV). The HRV is designed to provide fresh air into the dwelling while exhausting an equal amount of stale air with minimum energy penalty.

Central gas or electric systems are the primary means for residential space heating. Gas-fired or electric storage-type water heaters that generally have low initial cost and operating cost have fulfilled domestic hot water requirements. With increasing fuel prices, various energy-saving techniques are being considered for residential appliances. One possible method to keep the operating cost low is to combine residential water-heating and space-heating functions into a single system. Typically, storage-type gas water heaters supply residential hot water for approximately two hours per day and store hot water at a thermostatically controlled temperature for the remaining part of the day. The standby losses can be minimized when the storage-type water heater is integrated within an air handler--

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providing residential space heating. Several manufacturers have developed integrated systems for the residential sector. Multifamily dwellings have been considered most suitable for their applications because standard heating and cooling systems are sized for higher capacity than required for these dwellings. There are essentially three integrated systems configurations: 1) Indirect space heating system that heats water for domestic use and circulates hot water through a finned-tube coil, which transfers heat to air by a blower for space heating, 2) Indirect water heating system that heats water for space heating and provides domestic water heating by either utilizing a heat exchanger in the boiler or redirecting the flow of heated water through the hot water tank as necessary, 3) Integrated heat pump system that utilizes a vapor compression cycle to heat domestic hot water while either heating or cooling the space. The indirect space heating system is evaluated in this paper.

A few thousand installations of gas-fired combined systems have been operating satisfactorily and effectively fulfilling the residential water heating and space heating needs in Southern California (Subherwal 1986). Only a few assessments have been done on these systems. Subherwal performed field tests on six combined systems in occupied residences in Southern California during heating and non-heating seasons. Subherwal also tested a system in the laboratory to simulate field conditions and to rate its annual fuel utilization efficiency, seasonal efficiency, and annual energy use. Subherwal data indicated that hot water efficiency ranged from 47 to 58% and space heating efficiency ranged from 51 to 79%. Caron and Wilson (1983) tested combined systems at 24 residential sites in Boston, Brooklyn, and Los Angeles over a two-year period. Energy-conserving and conventional water heaters were installed side-by-side and used and monitored in the integrated systems on alternating weeks. Four sites were occupied residences and were monitored during the non-heating season. Their data revealed efficiencies ranging from 49 to 54% for hot water use and from 49 to 61% for space heating.

The water heater/air handler combination in this study was designed to minimize fuel consumption, thereby lowering the cost of home heating. The combined-system is projected by the manufacturer to achieve an annual efficiency rating up to 90%. Over 100,000 of these units have been installed in North America. In this field test, the water-heating performance of a combined system was measured in an occupied residence for a one-year period. Unlike previous studies, comfort conditions are monitored and standby losses are not evaluated. This paper summarizes the results obtained from using a combined system under field conditions.

Green Home Background

Green Home is an affordable, environmentally sensitive, single-family home built by a coalition of design and environmental professionals in partnership with Washington, D.C. Habitat for Humanity. The Green Home is projected to be greater than 30% (see Table 1) more energy efficient than the EPA=s Energy Star Homes guidelines thereby decreasing monthly utility bills significantly (Leibowitz 1999, http://www.greenhome.org/). The projection is based on taking the details of the house's construction and estimating the annual heating and cooling bills for the house using a model (REM model by Architecture Energy Corporation). The base home has standard construction and insulation materials. Input variables include most of the construction materials, as well as infiltration amounts, the local climate, and the house's orientation. This information was used to determine if the material choices were cost-effective. Numerous design strategies and building products were evaluated before the final design was selected. It minimized the overall wood framing material use. The home was constructed using a large amount of recycled material that included wall sheathing, insulation, roof shingles, nails, wallboard, and ceramic tiles.

Table 1: Predicted Annual Energy Cost

	Base House	Green Home	Green Home Savings
Heating	$424.54	$263.57	38%
Cooling	$111.16	$71.31	36%
Water Heating	$159.20	$99.80	37%
TOTAL	$694.90	$434.68	37%

After the house was completed, a blower door test was performed on the house to determine the air changes per hour (ACH). A typical house has about 0.75 ACH; the Green Home was tested to have 0.16 ACH. ASHRAE standard 62-1999 for natural infiltration requires 0.35 ACH with 15 cfm (0.43 m^3/min) per person to avoid indoor air quality problems. Houses with lower infiltration values may require mechanical ventilation systems to provide enough fresh air. The actual energy cost using the combined system was comparable to that of the base house. The home is certified as an Energy Star home.

Field Testing Method And Instrumentation

A combined space and water heating system was installed in an 1187 ft^2 (110.3 m^2) two-story Green Home. One adult and a child occupy the home. Large southeast facing windows was installed to maximum winter heat gain and minimized the number of north facing windows. A large living room/dining room with an open kitchen was included, to maximize the usage of passive lighting from these windows on the first floor. The house is oriented toward the southeast due to the lot placement on a diagonal street. House construction materials are shown in Table 1a.

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Table 1a. Home Construction Material

Component	*Material*
Walls	Wet-blown cellulose insulation (3.0-3.7 inch), 440 sheathing (5/8 inch), Composite and wood siding
Windows	Double-pane, Argon filled, low-e coating, vinyl-clad wood, U-value =0.32 Btu/(hr-ft^2-F), ALR =0.20, SHGC =0.51, and VLT =0.73.
Roof	Aluminum roofing shingle (dark), Wet-blown cellulose insulation

The combined heating system, shown in Figure 1, has a capacity rating of 40,000 Btu at 600 cfm (11.72 kWh at 17 m^3/min) and 60,000 Btu at 900 cfm (17.59 kWh at 25.48 m^3/min). The system has a heat recovery ventilator that receives heat from exhaust air. This HRV is designed to provide fresh air into the dwelling while exhausting an equal amount of stale air. During the winter months, utilizing the heat recovered from the returned air before it is exhausted to the outdoors warms the entering cold fresh air. During the summer months, the cool outgoing air from the air-conditioned dwelling is used to cool the incoming fresh air. The objectives of using the HRV are to more efficiently and economically exchange the air in the building. This HRV is designed to provide fresh outdoor air without sacrificing the savings of the modern, energy efficient dwelling.

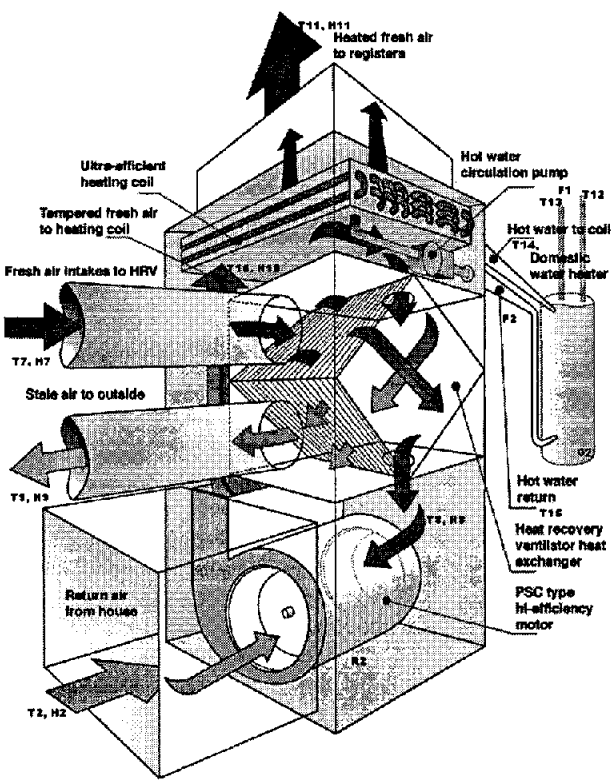

Figure1. Test Equipment (Courtesy of Nutech Energy)

The system's centrifugal blowers bring fresh outdoor air into the dwelling and at the same time, exhaust returned humid air in an equal amount. Both the incoming and outgoing air streams pass through an aluminum heat exchange core(s) where the energy from the exhaust air is transferred to the incoming fresh air. The air duct system supplies the fresh air brought in by the HRV throughout the home. The return air duct brings humid exhaust air back to the HRV.

The water heater is a standard efficiency non-condensing, direct-vented 50-gallon gas-fired unit. The space heating system uses hot water as its heat source. Water is pumped from the water heater to the heating coil. A fan blows the tempered fresh air from the HRV into the heating coil where the circulating water warms the air. Water exits the water heater, flows through the hot water circulation pump to the heating coil, and returns to the water heater where it can be used domestically. As the water flows through the heating coil, air is warmed to the desired temperature and distributed through a system of ducts to registers throughout the home.

The test site was strategically instrumented to continuously monitor the gas and electrical usage, temperatures, and relative humidity throughout the home and on the combined system. Figure 1 shows the locations of instrumentation on the heating system, and Tables 2 and 3 describe the parameters that were monitored and recorded in the house.

Table 2. Electrical, Flow Rate, Time, And Environmental Instrumentation

Sensor	Measurement	Units
R_1	Hot water circulation pump run time	Hours
R_2	Fan run time low speed	Hours
R_3	Fan run time high speed	Hours
E_1	Total electric	kWh
E_2	Air conditioner power	kWh (150 amp ct)
G	Total Gas	ft^3 (1/2 ft^3 per pulse)
F_1	Hot water flow	gpm (151.4 pulses per gal)
F_2	Heating water flow	gpm (151.4 pulses per gal)

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Table 3. Temperature and Relative Humidity Instrumentation

Temperature		Relative Humidity	
Sensor	Measurement (°F)	Sensor	Measurement (%)
T_1	Outside air (OSA)	H_1	Outside air
T_{1a}	Outside air (HRV inlet)	H_{1a}	Outside air (HRV inlet)
T_2	Return air	H_2	Return air
T_3	Living room	H_3	Living room
T_4	2nd floor	H_4	2nd floor
T_5	Attic	H_5	Attic
T_6	Crawl space	H_6	Crawl space
T_7	HRV OSA inlet	H_7	HRV OSA inlet
T_8	HRV OSA to house	H_8	HRV OSA to house
T_9	HRV air leaving HX	H_9	HRV air leaving HX
T_{10}	Mixed return air	H_{10}	Mixed return air
T_{11}	HVAC supply air	H_{11}	HVAC supply air
T_{12}	DHW inlet water		
T_{13}	DHW supply water		
T_{14}	Heating coil inlet		
T_{15}	Heating coil return		

Analysis of Heating Efficiency

The energy supplied for space heating is determined by computing the heat removed from the water circulating through the heating coil (equation 1). The energy supplied for domestic water heat is computed by determining the heat leaving the hot water heater that circulates through the water pipes (equation 2).

$$Q_{spaceheat} = m_2 \cdot C_p \cdot \Delta T_{heatingcoil} \quad (1)$$

$$Q_{domestic} = m_1 \cdot C_p \cdot \Delta T_{waterpipe} \quad (2)$$

$)T_{heatingcoil} = (T_{14} - T_{15})$ and $)T_{waterpipe} = (T_{13} - T_{12})$ are temperature differences of the hot water circulating in the hot water heat exchanger and in the water pipes, respectively. Q, m (subscript 1 for F_1 and subscript 2 for F_2 from Table 2), and C_p, are water energy, water mass, and specific heat of water, respectively. The water heater efficiency is the sum of the space and domestic hot water energy divided by the gas fuel consumption (equation 3). $Q_{gasfuel}$ is determined by multiplying G (total gas use, shown in Table 2) by the heating value of natural gas.

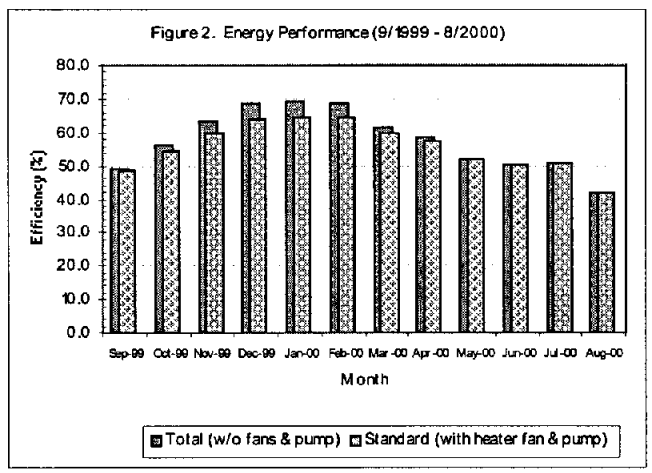
$$\eta_{total} = \frac{(Q_{spaceheat} + Q_{domestic})}{Q_{gasfuel}} \bullet 100 \quad (3)$$

To calculate the overall system efficiency, the additional hot water circulation pump (used for space heat coil) and fan electrical inputs must be included and are incorporated in equation 4. The electric power usage is computed by multiplying the fan and pumps runtime (R_1, R_2, R_3) by the wattage of the units.

$$\eta_{overall} = \frac{(Q_{spaceheat} + Q_{domestic})}{Q_{gasfuel} + (E_{pump} + E_{fan})} \bullet 100 \quad (4)$$

Field Test Results

During the heating (winter) season, the system supplied hot water for domestic hot water and space heating requirements. The total hot water use is the sum of domestic and space heating hot water demanded. During the non-heating (summer) season, the system supplied domestic hot water requirements, and the water heating efficiency is equivalent to the overall system efficiency (Figure 2). The water heating efficiency of the combined system increased as the use of hot water increased. During the peak heating months (November 1999 to February 2000), the average monthly system efficiency is 67.6%—total (63.3%—overall). The total efficiency does not include auxiliary pump and fan power usage. The standard efficiency includes both fan and pump power consumption. The auxiliary pump and fan slightly diminishes the system performance. As shown in Figure 2, the combined operation of the system increases the hot water system efficiency on average by 33 percent over that of the domestic hot water efficiency. The domestic hot water average monthly efficiency ranges from 42.1 to 50.8 percent. The lowest efficiency occurs in August 2000 where data is not for a complete month (data up to August 7, 2000).



The monthly water heated for space heating in Figure 3 ranges from 7047 to 21, 495 gallons (26.7 m^3 to 81.4 m^3) during the heating season (Nov – Feb). The monthly water used for domestic hot water use ranges from 820 to 1198 gallons (3.1 m^3 to 4.5 m^3). Comparing monthly usage and efficiency data (Figures 2 and 3) reveals how water usage affects the system efficiency during the study. The water usage and heated profiles substantiate that the efficiency increases as water heating volume increases, as seen Figure 3. This is partially attributed to standby losses being held to a minimum.

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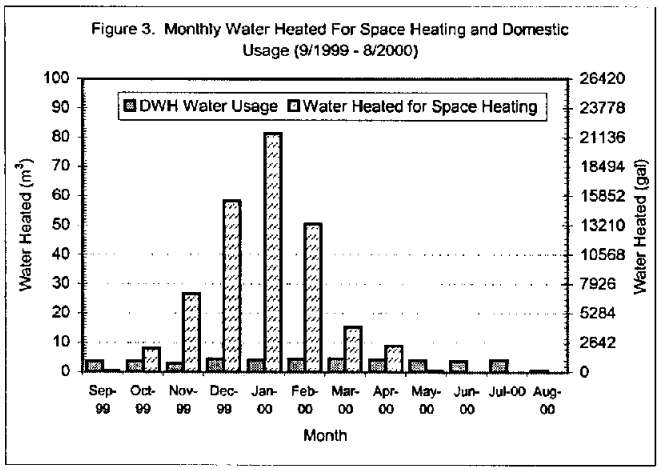
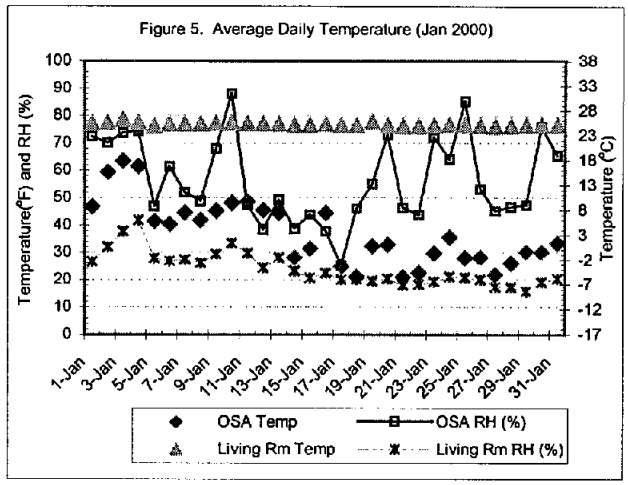
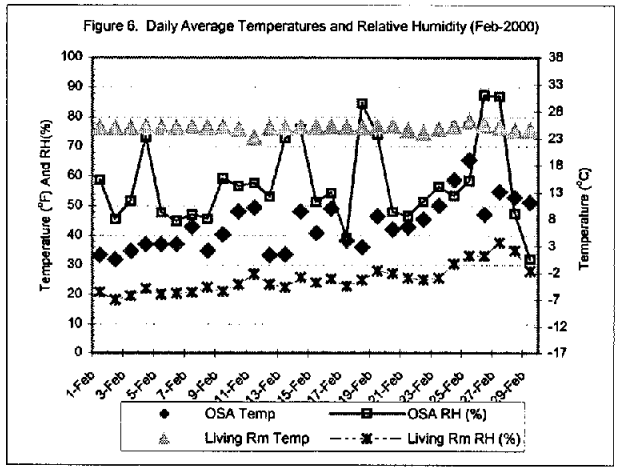
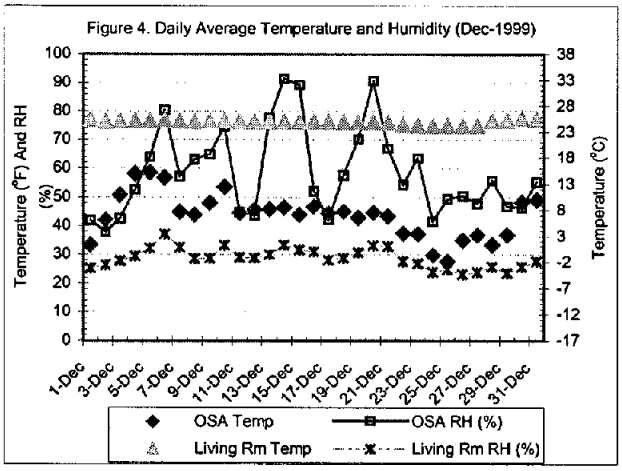




The heating needs of the home are fulfilled by the system. The inside temperature is maintained at the desired set point, and the humidity is held at a comfortable level, as shown in Figures 4 to 6. During the peak heating months, the inside temperature is held at approximately 78°F (25.6°C) even when the outside temperature drops below 30°F (-1.1°C). The relative humidity is kept below 40%. The HRV is attributed for low inside level. The HRV exit flow rates varied from 43 cfm (1.22 m^3/min, low fan speed) to 78 cfm (2.21 m^3/min, high fan speed); the inlet flow rates varied from undetectable (low speed) to 25 cfm (0.71 m^3/min, high speed). The HRV was unbalanced but results were not notably affected. Improper installation of the returned duct system may have caused this imbalance. A balanced system should ensure adequate air ventilation. Future work would be to balance the HRV.





Conclusions

The following conclusions were ascertained from the test results.

- Analysis of the data indicated that the system produced hot water for domestic use only at an efficiency averaging 48% for water heating.
- Data indicated that the combined system produced hot water at an efficiency ranging between 63.5% - 69.4% (total) and 60% - 64.4% (overall) for combined usage during the winter months. The maximum potential water heater efficiency of 80% is not realized, because the effectiveness of the heating coil not 100% and the water during space heating is heated from a higher temperature than that required for rating the water heater (65°F).
- During the peak heating months, the average monthly system efficiency is 67.7 % (total) and 63.3% (overall).
- The combined operation of the system increases the hot water system efficiency on average by 33 percent over that of the domestic hot water efficiency. The domestic hot water average monthly efficiency ranges from 42.1

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to 50.8 percent.

- The results are comparable to that of other studies. Subherwal (1986) data indicated that hot water efficiency ranged from 47 to 58% and space heating efficiency ranged from 51 to 79%. Caron and Wilson (1983) data revealed efficiencies ranging from 49 to 54% for hot water use and from 49 to 61% for space heating.

- The efficiency increases as water consumption increases and are attributed to standby losses being held to a minimum.
- The heating needs of the home are met by the system. The inside temperature is maintained at the desired set point, and the humidity is held at a comfortable level.
- Further refinements of the hot water heat exchanger could increase the system performance. Other system enhancements are needed to make the system comparable to conventional heating systems.

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