ENERGY CONSUMPTION AND DEMAND AS AFFECTED BY HEAT PUMPS THAT COOL, HEAT AND HEAT DOMESTIC WATER

Richard Cawley
Manager, Unitary Technology Systems
Trane UPG
Tyler, TX

ABSTRACT

Products or systems that heat, cool and heat domestic water, which are also referred to as integrated systems, have been available for several years. The concept is simple and appeals to consumers.

This paper presents methods for evaluating the potential savings by using an integrated system that heats water by desuperheating discharge gas in the refrigeration cycle. The methods may be applied for any specific location, and their accuracy will depend on the accuracy of building loads and water usage estimates.

Power demand can also be affected by electric water heaters. The methods presented demonstrate how integrated systems can be of value in reducing daily summertime peaks.

INTRODUCTION

A need for descriptors to evaluate systems that condition space and heat domestic water has been recognized for several years. The HVAC community has not been idle in trying to devise test methods and industry standards (1, 2, 3, 4). To date, however, manufacturers having products that integrate space conditioning and water heating are left to their own devices to quantify energy savings for the consumer - savings that are intuitively perceived by everyone.

One purpose of this study is to present a method for quantifying energy savings with integrated products for specific locations and applications. The Dallas/Fort Worth area is used as an example for an air-to-air heat pump having a factory-installed water pump and heat exchanger. Heat is extracted from the discharge gas and applied to domestic water (commonly referred to as the desuperheating method). The heat transfer characteristics, fluid flow rates and cooling and heating capacities for the integrated system are measured quantities.

Increasing demand on the power generating facilities of some electrical utilities is a well-documented problem that has stimulated activity in thermal storage systems, electronic load management and technologies such as geothermal heat pumps. This study attempts to show how simple integration of space cooling and domestic water heating can favorably impact the demand profile for a residence on an extremely warm day when a summer peaking utility can be strained.

METHOD OF DETERMINING SAVINGS FOR WATER HEATING

Data from the USAF weather data manual (5) may be used for selected regions. This manual is a comprehensive source of temperature data for three portions of a day each month of the year. With this format, more accurate estimates of hourly cooling or heating loads and compressor operating times can be determined than with the more familiar tables showing annual hours in various temperature bins. Another advantage for using tables from the USAF manual is that the months which do not normally require space conditioning (October and April in Dallas/Fort Worth) can be identified. These are months during which the heat pump does not contribute to the hot water requirements.

The following procedure is being used for calculating energy savings in a specific application:

1. A typical day is fashioned for each month

   A. Using temperature bin midpoints, the average outdoor temperature for each of the three eight hour ranges in the month are determined.

   B. The average temperature for an eight hour range is assumed to be at the mid point of the period. If the average for hours 0 to 8 is 68 F, for example, a time-temperature plot will show 68F at hour 4.

   C. Maximum temperature is assumed to occur at 3:00 p.m. (hour 15) and minimum at 6:00 a.m. (hour 6).

Proceedings of the Eighth Symposium on Improving Building Systems in Hot and Humid Climates, Dallas, TX, May 13-14, 1992

D. Having defined average times, average temperatures and maximum and minimum times, which are used as points on two linear time-temperature curves, extreme daily temperatures are found. One curve is assumed to fall with constant slope from hour 15 to hour 6, and the other rises with constant slope from hour 6 to hour 15. Average temperatures occur at hours 4, 12 and 20. The linear time-temperature assumption will result in conservative estimates of water heating contributions from the refrigeration cycle.

2. In general, building load equations prescribed in Department of Energy procedures (6) for calculating Seasonal Energy Efficiency Ratio (SEER) and Heating Seasonal Performance Factor (HSPF) may be used in calculating hourly loads for the heat pump. Hourly loads and capacities are used to determine system running times each hour and resulting domestic water heating while running. For a specific application, the actual hourly loads could be used.

3. Hot water draw schedules are imposed. Amounts drawn, as well as rates and times of day may be selected to suit the application.

4. Tank temperature is not allowed to exceed a preset maximum value. This means that at certain times during the constructed typical day more heat is available from the refrigeration system than the water system can store. When this happens in the calculations, the integrated system is not given credit for its excess capacity.

5. Months are chosen, and savings applied, only when it seems likely that the heat pump would be used by the homeowner for comfort. In general, months with mean outdoor temperatures between 55 F and 70 F are regarded as months not requiring heat pump operation.

6. A simple 24 hour calculation is performed using energy balances and logic that will not allow the tank to overheat. These calculations determine the maximum, minimum and average daily water temperatures in the tank and the amount of heat added to and used by the water from the desuperheated refrigerant - heat normally provided by the electric water heater's resistance elements.

DESCRIPTION OF EQUIPMENT

The system considered for this study is best described by U.S. Patent No. 4,747,273 (7), which covers an efficient assembly of heat pump, desuperheater, water pump and water heater. Controls that provide integration of space conditioning and water heating are also taught in the patent. The characteristics of therefrigerant to water coaxial heat exchanger are shown in Figures 1 and 2 with a water pumping rate of 1.3 gallons per minute. The heat pump ratings, independent of domestic water capacities or inputs are as follows:

Cooling Capacity @ 95 F:	36,200 BTU/HR
Cooling Capacity @ 82 F:	39,500 BTU/HR
SEER:	10.00 BTU/W-HR
Heating Capacity @ 47 F:	36,000 BTU/HR
Heating Capacity @ 17 F:	20,600 BTU/HR
HSPF:	7.00 BTU/W-HR

FIGURE 1

DESUPERHEATING CAPACITY WITH 100F WATER

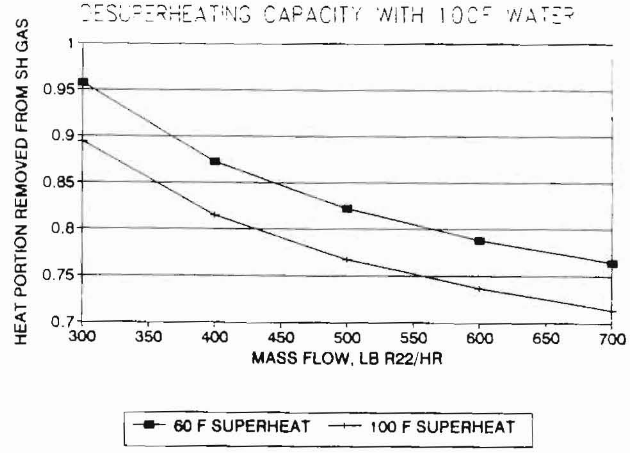
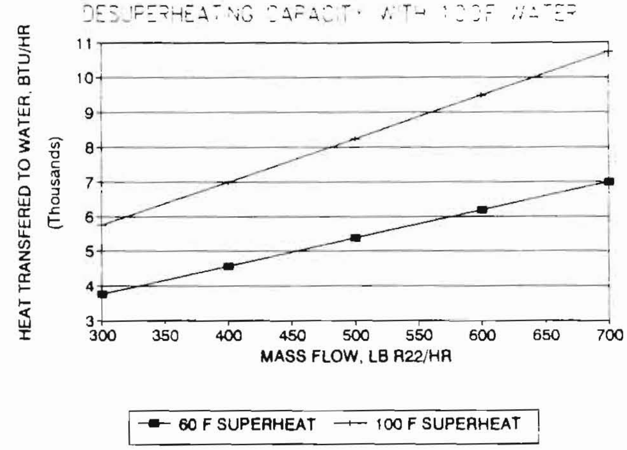


FIGURE 2

DESUPERHEATING CAPACITY WITH 100F WATER



It should also be noted that the compressor is located in the indoor unit. The primary reason for this is to minimize losses from the discharge gas before transferring heat to the water, but other advantages for having the compressor indoors should be apparent to those interested in compressor reliability and service.

ASSUMPTIONS FOR ENERGY STUDY

The parameters selected for simulating the interaction of the integrated system, building loads and water heating requirements are:

Supply water temperature	58 F
Hot water supply temperature	140 F
Water storage capacity	50 Gallons
Cooling load base @ 95 F	32,900 Btu/Hr
Heating load base @ 47 F	35,000 Btu/Hr
Min. desuperheating ambient	27 F
Max. tank temperature	140 F
Daily hot water use	62.4 Gallons

Schedule:

6:00 a.m.	15 Gallons
7:00 a.m.	15 Gallons
8:00 a.m.	6 Gallons
6:00 p.m.	5.4 Gallons
7:00 p.m.	6 Gallons
8:00 p.m.	15 Gallons
Water heater energy factor	91 %
Daily water heating energy	13.7 KW-Hr

TOTAL SPACE CONDITIONING AND WATER HEATING ENERGY

Table 1 summarizes energy data in Dallas/Fort Worth for a structure using 3 ton heat pumps with capacities shown earlier. Building loads were computed with DOE methods (6). The domestic water loads were determined using the defined parameters.

Savings are shown relative to a system with SEER of 10.00 BTU/W-HR and HSPF of 7.00 BTU/W-HR. For the unit with 15.00 SEER, a HSPF of 8.50 BTU/W-HR was used.

TABLE 1

DALLAS/FORT WORTH HEATING,COOLING,AND WATER HEATING STUDY
3 TON HEAT PUMPS WITH VARIOUS SEER & HSPF VALUES

HEATING KW-HR

SYSTEM SEER	SYSTEM HSPF	NOV	DEC	JAN	FEB	MAR	TOTAL
10.00	7.00	426	688	918	644	490	3166
15.00	8.50	360	580	769	543	415	2667
	INTEGRATED						
10.00	7.00	489	781	1023	731	561	3585

COOLING KW-HR

SYSTEM SEER	SYSTEM HSPF	MAY	JUN	JUL	AUG	SEPT	TOTAL
10.00	7.00	791	1374	1854	1786	1080	6884
15.00	8.50	462	1026	1590	1497	720	5296
	INTEGRATED						
10.00	7.00	791	1374	1854	1786	1080	6884

HOT WATER KW-HR

	NOV THROUGH MARCH	MAY THROUGH SEPT	TOTAL
NON-INTEGRATED SYSTEMS	2073	2100	4173
INTEGRATED SYSTEM	1632	121	1753

DALLAS/FORT WORTH HEATING,COOLING,AND WATER HEATING STUDY
3 TON HEAT PUMPS WITH VARIOUS SEER & HSPF VALUES

SYSTEM DESCRIPTION	COOL CYCLE		HEAT CYCLE		TOTAL	SAVINGS
	COOL KW-HR	DHW KW-HR	HEAT KW-HR	DHW KW-HR	KW-HR	KW-HR
10 SEER/7 HSPF	6884	2100	3166	2073	14223	0
15 SEER/8.5 HSPF	5296	2100	2667	2073	12136	2087
10 SEER INTEGRATE	6884	121	3585	1632	12222	2001
INTEGRATION SAVIN	0	1979	-420	441	2001	

The energy consumed annually for heating domestic water is seen to be 2420 KW-HR less for the integrated system than for both non-integrated systems (4173-1758). This, of course, is due to the heat extracted from the superheated discharge gas. During the cooling cycle the heat reclaimed for water is normally waste heat dissipated to the ambient, or "free". In the heating cycle the heat is added to the water when the heat pump has excess capacity. It is not quite "free", but it is provided with the COP leverage of a water heating heat pump - with energy consumption at about 38 % of a high efficiency water heater. Annual water heating savings with the integrated system amount to 48.3% in the Dallas/Fort Worth area using the parameters defined for this study.

Proceedings of the Eighth Symposium on Improving Building Systems in Hot and Humid Climates, Dallas, TX, May 13-14, 1992

When incentive programs are offered, considerable emphasis is placed on equipment SEER rating, which affects only cooling cycle energy consumption. Some numbers can be lifted from Table 1 that show an integrated system with SEER of 10.00 BTU/W-HR to be more energy efficient during the cooling cycle, when water heating is included in the analysis, than a 15.00 BTU/W-HR system and high efficiency water heater operating independently. This is illustrated as follows:

SYSTEM	SUMMER COOL KW-HR	SUMMER DHW KW-HR	SUMMER TOTAL KW-HR
SEER=15; WH EFF.=91%	5296	2100	7396
SEER=10; INTEGRATED	6884	121	7005
INTEGRATED SYSTEM SAVINGS OVER			
HIGH EFF. HP & WH	(1588)	1979	391

These numbers are revealing, particularly considering that the consumer's installed cost for a system with SEER of 15 will be from $900 to $1750 more than some simple integrated systems. If the calculated savings are even approximately accurate, integration deserves as much attention as SEER.

Tables 2 and 3 illustrate the methods described for determining energy savings by integrating space conditioning with domestic water heating. For January and July, ambient temperatures are estimated hour by hour along with building load, equipment response to the load and available heat for water. Tables 2A and 3A show how the water tank is responding to heat storage, standby losses and draw schedules in Tables 2 and 3.

TABLE 2

WATER STORAGE CALCULATIONS ALLOWING FOR BENEFIT OF INTEGRATION
(EACH HOUR CALCULATED WITH 3 TON,7 BTU/W HR SYSTEM USING DOE RULES)
8.8 BTU/W-HR IS AVERAGE HEATING PERFORMANCE FACTOR IN 27F TO 62F RANGE

DALLAS/FORT WORTH, JANUARY

	47F	35F	17F
HEATING CAPACITIES :	36000	26500	20600
HEAT DESIGN TEMP	5 F		
DESIGN HEAT REQUIREMENT	35000		

		H20	
MAXIMUM DAILY TEMPERATUR	48.3 F	ENTERIN	58 F
DAILY TEMPERATURE RANGE	12 F	LEAVING	140 F
ENERGY FACTOR	91%	CHARGE	50 GALLONS

HR OF DAY	AMB TEMP	LOAD KBTUH	CAP KBTUH	RUN HRS	AVAILABL BOOST KBTU	DHW DRAIN GALLONS	DHW DRAIN KBTU	STANDBY LOSSES KBTU
0	41.1	10.7	25.5	0.421	2.11	0.0	0.0	0.18
1	40.3	11.1	25.4	0.437	2.16	0.0	0.0	0.18
2	39.5	11.5	25.3	0.453	2.20	0.0	0.0	0.18
3	38.7	11.8	25.2	0.469	2.25	0.0	0.0	0.18
4	37.9	12.2	25.1	0.486	2.30	0.0	0.0	0.18
5	37.1	12.5	25.0	0.502	2.34	0.0	0.0	0.18
6	36.3	12.9	24.9	0.518	2.38	15.0	10.2	0.18
7	37.6	12.3	25.0	0.491	2.31	15.0	10.2	0.18
8	39.0	11.7	25.2	0.464	2.24	6.0	4.1	0.18
9	40.3	11.1	25.4	0.437	2.16	0.0	0.0	0.18
10	41.6	10.5	25.5	0.411	2.07	0.0	0.0	0.18
11	43.0	9.9	25.7	0.385	1.99	0.0	0.0	0.18
12	44.3	9.3	25.9	0.359	1.89	0.0	0.0	0.18
13	45.6	8.7	31.4	0.277	1.49	0.0	0.0	0.18
14	47.0	8.1	31.8	0.255	1.40	0.0	0.0	0.18
15	48.3	7.5	32.2	0.233	1.31	0.0	0.0	0.18
16	47.5	7.9	32.0	0.246	1.36	0.0	0.0	0.18
17	46.7	8.2	31.7	0.259	1.42	0.0	0.0	0.18
18	45.9	8.6	31.5	0.273	1.47	5.4	3.7	0.18
19	45.1	8.9	31.2	0.286	1.53	6.0	4.1	0.18
20	44.3	9.3	25.9	0.359	1.89	15.0	10.2	0.18
21	43.5	9.7	25.8	0.375	1.95	0.0	0.0	0.18
22	42.7	10.0	25.7	0.390	2.00	0.0	0.0	0.18
23	41.9	10.4	25.6	0.406	2.06	0.0	0.0	0.18
				9.2	46.28	62.4	42.6	4.2

TABLE 2A

WATER STORAGE CALCULATIONS ALLOWING FOR BENEFIT OF INTEGRATION
(EACH HOUR CALCULATED WITH 3 TON,7 BTU/W-HR SYSTEM USING DOE RULES)
8.8 BTU/W-HR IS AVERAGE HEATING PERFORMANCE FACTOR IN 27F TO 62F RANGE

DALLAS/FORT WORTH, JANUARY

	47F	35F	17F
HEATING CAPACITIES :	36000	26500	20600
HEAT DESIGN TEMP	5 F		
DESIGN HEAT REQUIREMEN	35000		

		H20	
MAXIMUM DAILY TEMPERATU	48.3 F	ENTERIN	58 F
DAILY TEMPERATURE RANG	12 F	LEAVING	140 F
ENERGY FACTOR	91%	CHARGE	50 GALLONS

HR OF DAY	50 GAL TANK INIT.	50 GAL TANK FINAL	DES USED KBTU
0	140.0	140.0	0.18
1	140.0	140.0	0.18
2	140.0	140.0	0.18
3	140.0	140.0	0.18
4	140.0	140.0	0.18
5	140.0	140.0	0.18
6	140.0	120.7	2.38
7	120.7	101.2	2.31
8	101.2	96.3	2.24
9	96.3	101.1	2.16
10	101.1	105.6	2.07
11	105.6	110.0	1.99
12	110.0	114.1	1.89
13	114.1	117.3	1.49
14	117.3	120.2	1.40
15	120.2	122.9	1.31
16	122.9	125.8	1.36
17	125.8	128.8	1.42
18	128.8	123.0	1.47
19	123.0	116.4	1.53
20	116.4	96.0	1.89
21	96.0	100.2	1.95
22	100.2	104.6	2.00
23	104.6	109.1	2.06
MINIMUM	96.0	96.0	
MAXIMUM	140.0	140.0	
AVERAGE	120.2	118.9	
DES DHW			34.0
USE EFF.:			73.4%
NEED EFF:			72.5%
DHW SVGS			
KBTU:			34.0
KWH:			3.9

Proceedings of the Eighth Symposium on Improving Building Systems in Hot and Humid Climates, Dallas, TX, May 13-14, 1992

TABLE 3.

WATER STORAGE CALCULATIONS ALLOWING FOR BENEFIT OF INTEGRATIO
(EACH HOUR CALCULATED WITH 3 TON,10 BTU/W-HR SYSTEM USING DOE RU
DHW BY DESUPERHEATING

DALLAS\FORT WORTH, JULY

	82F	95F
COOLING CAPACITIES :	39500	36200

OD DESIGN TEMPERATURE	95 F	H20	
MAXIMUM DAILY TEMPERATU	98.3 F	ENTERIN	58 F
DAILY TEMPERATURE RANG	22.7 F	LEAVING	140 F
ENERGY FACTOR	91%	CHARG	50 GALLONS

HR OF DAY	AMB. TEMP.	LOAD KBTUH	CAP KBTUH	RUN HRS	AVAILABL BOOST KBTU	DHW DRAIN GALLONS	DHW DRAIN KBTU	STANDBY LOSSES KBTU
0	84.7	21.6	38.8	0.556	3.34	0.0	0.0	0.18
1	83.2	19.9	39.2	0.508	3.05	0.0	0.0	0.18
2	81.7	18.3	39.6	0.461	2.77	0.0	0.0	0.18
3	80.1	16.6	40.0	0.415	2.49	0.0	0.0	0.18
4	78.6	14.9	40.4	0.370	2.22	0.0	0.0	0.18
5	77.1	13.3	40.7	0.326	1.96	0.0	0.0	0.18
6	75.6	11.6	41.1	0.283	1.70	15.0	10.2	0.18
7	78.1	14.4	40.5	0.356	2.13	15.0	10.2	0.18
8	80.6	17.2	39.8	0.431	2.58	6.0	4.1	0.18
9	83.2	19.9	39.2	0.508	3.05	0.0	0.0	0.18
10	85.7	22.7	38.6	0.589	3.53	0.0	0.0	0.18
11	88.2	25.5	37.9	0.671	4.03	0.0	0.0	0.18
12	90.7	28.2	37.3	0.757	4.54	0.0	0.0	0.18
13	93.3	31.0	36.6	0.846	5.08	0.0	0.0	0.18
14	95.8	33.8	36.0	0.938	5.63	0.0	0.0	0.18
15	98.3	36.5	35.4	1.000	6.00	0.0	0.0	0.18
16	96.8	34.9	35.7	0.975	5.85	0.0	0.0	0.18
17	95.3	33.2	36.1	0.919	5.51	0.0	0.0	0.18
18	93.8	31.5	36.5	0.864	5.18	5.4	3.7	0.18
19	92.2	29.9	36.9	0.810	4.86	6.0	4.1	0.18
20	90.7	28.2	37.3	0.757	4.54	15.0	10.2	0.18
21	89.2	26.6	37.7	0.705	4.23	0.0	0.0	0.18
22	87.7	24.9	38.1	0.655	3.93	0.0	0.0	0.18
23	86.2	23.2	38.4	0.605	3.63	0.0	0.0	0.18
				15.3	91.84	62.4	42.6	4.2

TABLE 3A.

DHW BY DESUPERHEATING
DALLAS\FORT WORTH, JULY

	82F	95F
COOLING CAPACITIES :	39500	36200

OD DESIGN TEMPERATURE .	95 F	H20	
MAXIMUM DAILY TEMPERATURE	98.3 F	ENTERING	58 F
DAILY TEMPERATURE RANGE :	22.7 F	LEAVING	140 F
ENERGY FACTOR	91%	CHARGE:	50 GALLONS

HR OF DAY	50 GAL TANK INIT.	FINAL	DES USED KBTU
0	140.0	140.0	0.18
1	140.0	140.0	0.18
2	140.0	140.0	0.18
3	140.0	140.0	0.18
4	140.0	140.0	0.18
5	140.0	140.0	0.18
6	140.0	119.1	1.70
7	119.1	99.2	2.13
8	99.2	95.1	2.58
9	95.1	102.0	3.05
10	102.0	110.1	3.53
11	110.1	119.3	4.03
12	119.3	129.8	4.54
13	129.8	140.0	4.43
14	140.0	140.0	0.18
15	140.0	140.0	0.18
16	140.0	140.0	0.18
17	140.0	140.0	0.18
18	140.0	140.0	3.86
19	140.0	140.0	4.27
20	140.0	125.9	4.54
21	125.9	135.6	4.23
22	135.6	140.0	2.00
23	140.0	140.0	0.18
MINIMUM :	95.1	95.1	
MAXIMUM	140.0	140.0	
AVERAGE	130.7	130.7	
DES DHW :			46.8
USE EFF.			51.0%
NEED EFF.			100.0%
DHW SVGS			
KBTU :			46.8
KWH .			13.7

INTEGRATION AND DEMAND

Table 4 is included with this study to set the stage for a discussion of the benefits of integration regarding power demand on a very warm day when residential cooling equipment is being used near its maximum capability. Peak temperature is assumed to be 101 F and the daily range is 12 F (minimum temperature 89 F). The hour by hour temperature profile was established with the methods previously described. Table 4 shows that, under these conditions, system running time is much more than is needed to keep the occupants supplied with hot water without electrical heat input to the water heater. Hot water is "free" but, more importantly, the intermittent use of a 4.5 KW electric water heating element is avoided. Note that the need efficiency of heat supplied by desuperheating is 100% and that this amounts to the full daily need of 14.4 KW-HR.

Table 5 (right column) shows the hour by hour demand for a standard non-integrated heat pump used in conjunction with a water heater having efficiency of 87%. The draw schedule in Table 5 is the same heavy morning and evening usage schedule assumed in the energy analysis. Demand peaks occur during the hours of 6 a.m. (6.52 KW-HR/HR), 7 a.m. (6.01 KW-HR/HR), 6 p.m. (6.82 KW-HR/HR) and 8 p.m. (8.29 KW-HR/HR). The peak demand for the integrated system is 3.93 KW-HR/HR during the noon hour.

TABLE 4.

WATER STORAGE CALCULATIONS TO GET MAXIMUM BENEFIT OF INTEGRATION
(EACH HOUR CALCULATED WITH 3 TON,10 BTU/W-HR SYSTEM USING DOE RULES)
DHW BY DESUPERHEATING

	82F	95F		
COOLING CAPACITIES :	39500	36200		
OD DESIGN TEMPERATURE :	95 F		H20	
MAXIMUM DAILY TEMPERATURE	101 F		ENTERING	58 F
DAILY TEMPERATURE RANGE :	12 F		LEAVING:	140 F
ENERGY FACTOR :	87%		CHARGE:	50 GALLONS

HR OF DAY	50 GAL TANK INIT.	FINAL	DES USED KBTU
0	140.0	140.0	0.27
1	140.0	140.0	0.27
2	140 0	140 0	0 27
3	140.0	140.0	0.27
4	140.0	140.0	0.27
5	140.0	140.0	0.27
6	140.0	124 8	4.19
7	124.8	110.3	4.46
8	110.3	111 2	4.74
9	111 2	122.6	5.02
10	122.6	134 7	5.31
11	134.7	140.0	2.47
12	140.0	140.0	0.27
13	140 0	140.0	0 27
14	140 0	140.0	0.27
15	140.0	140.0	0.27
16	140 0	140.0	0 27
17	140 0	140.0	0.27
18	140.0	140.0	3.95
19	140.0	140.0	4.36
20	140 0	128.9	5.90
21	128.9	140.0	4.88
22	140.0	140.0	0.27
23	140.0	140.0	0.27
MINIMUM :	110.3	110.3	
MAXIMUM	140.0	140.0	
AVERAGE	135 5	135 5	
DES DHW :			49.0
USE EFF :			38.2%
NEED EFF.			100 0%
DHW SVGS			
KBTU .			49.0
KWH :			14.4

TABLE 5

COOLING AND WATER HEATING DEMAND FOR HOT DAY
EQUIPMENT RATING 10.20 BTU/W-HR

HEAVY MORNING & EVENING DRAW SCHEDULES

	82F	95F
BTUH COOLING CAPACITIES	39500	36200
WATT INPUT	3562	3660
DEGRADATION COEFFICIENT	0.16	
PART LOAD WATT PENALTY	1.00	
OD DESIGN TEMPERATURE	95 F	
MAXIMUM DAILY TEMPERATURE	101 F	
DAILY TEMPERATURE RANGE	12 F	

WATER HEATER INPUT	4500 WATTS
INITIAL CHARGE	34.15 KBTU
ACTIVATE TEMP	115 F
ACTIVATE CHARGE	25.76 KBTU
E.F.	87%
STORAGE	50 GALLONS
TEMP IN	58 F
TEMP OUT	140 F

HR OF DAY	AMB TEMP	LOAD KBTUH	CAP KBTUH	RUN HRS	UNIT WATTS	KBTU COOLING	COOLING KW-HR	WATER DRAW GALLONS	DRAW LOSSES KBTU	STANDBY LOSSES	MAKEUP KW-HR	INITIAL CHARGE KBTU	FINAL CHARGE KBTU	TOTAL DEMAND KW-HR
0	93.8	31.6	36.5	0.865	3651	31.6	3.43	0.0	0.0	0.27	0.00	33.36	[illegible]	3.41
1	93.0	30.7	36.7	0.837	3645	30.7	3.32	0.0	0.0	0.27	0.00	33.09	32.81	3.32
2	92.2	29.8	36.9	0.808	3639	29.8	3.20	0.0	0.0	0.27	0.00	32.83	32.56	3.20
3	91.4	29.0	37.1	0.780	3633	29.0	3.08	0.0	0.0	0.27	0.00	32.56	32.30	3.08
4	90.6	28.1	37.3	0.753	3627	28.1	2.97	0.0	0.0	0.27	0.00	32.30	32.03	2.97
5	89.8	27.2	37.5	0.725	3621	27.2	2.85	0.0	0.0	0.27	0.00	32.03	[illegible]	2.85
6	89.0	26.3	37.7	0.698	3615	26.3	2.74	15.0	[illegible]	0.27	3.78	31.77	34.15	6.52
7	90.3	27.8	37.4	0.743	3625	27.8	2.80	15.0	10.2	0.27	3.88	34.15	34.15	6.68
8	91.7	29.3	37.0	0.790	3635	29.3	3.12	6.0	4.1	0.27	0.00	34.15	29.79	3.12
9	93.0	30.7	36.7	0.837	3645	30.7	3.32	0.0	0.0	0.27	0.00	29.79	29.52	3.32
10	94.3	32.2	36.4	0.885	3655	32.2	3.51	0.0	0.0	0.27	0.00	29.52	29.26	3.51
11	95.7	33.6	36.0	0.934	3665	33.6	3.72	0.0	0.0	0.27	0.00	29.26	28.99	3.72
12	97.0	35.1	35.7	0.983	3675	35.1	3.93	0.0	0.0	0.27	0.00	28.99	28.73	3.93
13	98.3	36.6	35.4	1.000	3685	35.4	4.06	0.0	0.0	0.27	0.00	28.73	28.46	4.06
14	99.7	38.0	35.0	1.000	3695	35.0	3.70	0.0	0.0	0.27	0.00	28.46	28.20	3.70
15	101.0	39.5	34.7	1.000	3705	34.7	3.71	0.0	0.0	0.27	0.00	28.20	27.93	3.71
16	100.2	38.6	34.9	1.000	3699	34.9	3.70	0.0	0.0	0.27	0.00	27.93	27.67	3.70
17	98.4	37.7	35.1	1.000	3693	35.1	3.69	0.0	0.0	0.27	0.00	27.67	27.40	3.69
18	98.5	36.9	35.3	1.000	3687	35.3	3.69	5.4	1.7	0.27	3.14	27.40	34.15	6.82
19	97.8	36.0	35.5	1.000	3681	35.5	3.68	6.0	4.1	0.27	0.00	34.15	29.79	3.68
20	97.0	35.1	35.7	0.983	3675	35.1	3.61	15.0	10.2	0.27	4.36	29.79	34.15	8.36
21	96.2	34.2	35.9	0.951	3669	34.2	3.60	0.0	0.0	0.27	0.00	34.15	33.89	3.60
22	95.4	33.3	36.1	0.924	3663	33.3	3.48	0.0	0.0	0.27	0.00	33.89	33.62	3.48
23	94.6	32.5	36.3	0.894	3657	32.5	3.56	0.0	0.0	0.27	0.00	33.62	33.36	3.56
TOTALS				[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	6.5	[illegible]			[illegible]

Table 6 is similar to Table 5. The only difference is the draw schedule. For Table 6, a draw schedule presented in chapter 44 of the ASHRAE GUIDE & DATA BOOK (8) as 'typical residential' was used. This changed both magnitude and times for demand peaks with the standard heat pump and water heater. Peaks occur at 8 a.m. (7.15 KW-HR/HR), 11 a.m. (6.98 KW-HR/HR), 4 p.m. (6.93 KW-HR/HR) and 9 p.m. (7.7 KW-HR/HR). The draw schedule has no effect on the integrated system.

TABLE 6

COOLING AND WATER HEATING DEMAND FOR HOT DAY
EQUIPMENT RATING 10.20 BTU/W-HR

TYPICAL FAMILY WATER USAGE
ASHRAE GUIDE [illegible] EDITION CH 44

	82F	95F
BTUH COOLING CAPACITIES	39500	36200
WATT INPUT	3562	3660
DEGRADATION COEFFICIENT	0.16	
PART LOAD WATT PENALTY	1.00	
OD DESIGN TEMPERATURE	95 F	
MAXIMUM DAILY TEMPERATURE	101 F	
DAILY TEMPERATURE RANGE	12 F	

WATER HEATER INPUT	4500 WATTS
INITIAL CHARGE	34.15 KBTU
ACTIVATE TEMP	115 F
ACTIVATE CHARGE	25.76 KBTU
E.F.	87%
STORAGE	50 GALLONS
TEMP IN	58 F
TEMP OUT	140 F

HR OF DAY	AMB TEMP	LOAD KBTUH	CAP KBTUH	RUN HRS	UNIT WATTS	KBTU COOLING	COOLING KW-HR	WATER DRAW GALLONS	DRAW LOSSES KBTU	STANDBY LOSSES	MAKEUP KW-HR	INITIAL CHARGE KBTU	FINAL CHARGE KBTU	TOTAL DEMAND KW-HR
0	93.8	31.6	36.5	0.865	3651	31.6	3.43	2.7	1.8	0.27	0.00	29.47	[illegible]	[illegible]
1	93.0	30.7	36.7	0.837	3645	30.7	3.32	0.8	0.5	0.27	0.00	[illegible]	26.54	[illegible]
2	92.2	29.8	36.9	0.808	3639	29.8	3.20	0.3	0.2	0.27	0.00	26.54	26.07	[illegible]
3	91.4	29.0	37.1	0.780	3633	29.0	3.08	[illegible]	0.1	[illegible]	0.00	26.07	[illegible]	[illegible]
4	90.6	28.1	37.3	0.753	3627	28.1	2.97	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	[illegible]
5	89.8	27.2	37.5	0.725	3621	27.2	2.85	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	[illegible]
6	89.0	26.3	37.7	0.698	3615	26.3	2.74	0.5	[illegible]	0.27	0.00	25.11	[illegible]	[illegible]
7	90.3	27.8	37.4	0.743	3625	27.8	2.80	1.0	0.7	0.27	0.00	[illegible]	[illegible]	[illegible]
8	91.7	29.3	37.0	0.790	3635	29.3	3.12	4.5	3.1	0.27	4.03	[illegible]	[illegible]	7.15
9	93.0	30.7	36.7	0.837	3645	30.7	3.32	4.8	3.1	0.27	0.00	[illegible]	[illegible]	[illegible]
10	94.3	32.2	36.4	0.885	3655	32.2	3.51	5.8	4.0	0.27	0.00	[illegible]	[illegible]	3.51
11	95.7	33.6	36.0	0.934	3665	33.6	3.72	4.5	3.1	0.27	[illegible]	[illegible]	[illegible]	6.98
12	97.0	35.1	35.7	0.983	3675	35.1	3.93	3.8	[illegible]	0.27	0.00	[illegible]	[illegible]	3.93
13	98.3	36.6	35.4	1.000	3685	35.4	4.06	[illegible]	[illegible]	0.27	0.00	[illegible]	[illegible]	4.06
14	99.7	38.0	35.0	1.000	3695	35.0	3.70	[illegible]	[illegible]	0.27	0.00	[illegible]	[illegible]	3.70
15	101.0	39.5	34.7	1.000	3705	34.7	3.71	[illegible]	1.0	0.27	0.00	[illegible]	[illegible]	3.71
16	100.2	38.6	34.9	1.000	3699	34.9	3.70	[illegible]	[illegible]	0.27	[illegible]	[illegible]	[illegible]	6.93
17	98.4	37.7	35.1	1.000	3693	35.1	3.69	[illegible]	1.6	[illegible]	0.00	[illegible]	[illegible]	3.69
18	98.5	36.9	35.3	1.000	3687	35.3	3.69	[illegible]	1.8	0.27	0.00	[illegible]	[illegible]	3.69
19	97.8	36.0	35.5	1.000	3681	35.5	3.68	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	3.68
20	97.0	35.1	35.7	0.983	3675	35.1	3.61	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	3.61
21	96.2	34.2	35.9	0.951	3669	34.2	3.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.7
22	95.4	33.3	36.1	0.924	3663	33.3	3.48	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	3.48
23	94.6	32.5	36.3	0.894	3657	32.5	3.56	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	3.56
TOTALS				[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	6.5	[illegible]			[illegible]

Other variables are introduced in Table 7. The ASHRAE 'typical' draw schedule was used, but the water heater size was changed from 50 gallons to 80 gallons. In addition, the heater element capacity was increased from 4.5 KW to 8.5 KW. The result was a pronounced change in the demand profile for a standard system and water heater. Peaks occurred at 9 a.m. (8.2 KW-HR/HR), 3 p.m. (8.64 KW-HR/HR) and 10 p.m. (8.87 KW-HR/HR).

TABLE 7

COOLING AND WATER HEATING DEMAND FOR HOT DAY
EQUIPMENT RATING 10.20 BTU/W-HR

TYPICAL FAMILY WATER USAGE
ASHRAE GUIDE [illegible] EDITION CH 44

	82F	95F
BTUH COOLING CAPACITIES	39500	36200
WATT INPUT	3562	3660
DEGRADATION COEFFICIENT	0.16	
PART LOAD WATT PENALTY	1.00	
OD DESIGN TEMPERATURE	95 F	
MAXIMUM DAILY TEMPERATURE	101 F	
DAILY TEMPERATURE RANGE	12 F	

WATER HEATER INPUT	8500 WATTS
INITIAL CHARGE	54.64 KBTU
ACTIVATE TEMP	115 F
ACTIVATE CHARGE	41.98 KBTU
E.F.	87%
STORAGE	80 GALLONS
TEMP IN	58 F
TEMP OUT	140 F

HR OF DAY	AMB TEMP	LOAD KBTUH	CAP KBTUH	RUN HRS	UNIT WATTS	KBTU COOLING	COOLING KW-HR	WATER DRAW GALLONS	DRAW LOSSES KBTU	STANDBY LOSSES	MAKEUP KW-HR	INITIAL CHARGE KBTU	FINAL CHARGE KBTU	TOTAL DEMAND KW-HR
0	93.8	31.6	36.5	0.865	3651	31.6	3.43	2.7	1.8	0.27	0.00	50.64	[illegible]	[illegible]
1	93.0	30.7	36.7	0.837	3645	30.7	3.32	0.8	0.5	0.27	0.00	[illegible]	[illegible]	3.32
2	92.2	29.8	36.9	0.808	3639	29.8	3.20	0.3	0.2	0.27	0.00	[illegible]	[illegible]	[illegible]
3	91.4	29.0	37.1	0.780	3633	29.0	3.08	[illegible]	0.1	[illegible]	0.00	[illegible]	[illegible]	3.08
4	90.6	28.1	37.3	0.753	3627	28.1	2.97	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	[illegible]
5	89.8	27.2	37.5	0.725	3621	27.2	2.85	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	2.85
6	89.0	26.3	37.7	0.698	3615	26.3	2.74	0.1	0.2	[illegible]	0.00	[illegible]	[illegible]	[illegible]
7	90.3	27.8	37.4	0.743	3625	27.8	2.80	1.0	0.7	0.27	0.00	[illegible]	[illegible]	[illegible]
8	91.7	29.3	37.0	0.790	3635	29.3	3.12	4.5	[illegible]	0.27	0.00	[illegible]	[illegible]	3.12
9	93.0	30.7	36.7	0.837	3645	30.7	3.32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.20
10	94.3	32.2	36.4	0.885	3655	32.2	3.51	5.8	4.0	[illegible]	0.00	[illegible]	[illegible]	3.51
11	95.7	33.6	36.0	0.934	3665	33.6	3.72	4.5	3.1	[illegible]	0.00	[illegible]	[illegible]	3.72
12	97.0	35.1	35.7	0.983	3675	35.1	3.93	3.8	[illegible]	0.27	0.00	[illegible]	[illegible]	3.93
13	98.3	36.6	35.4	1.000	3685	35.4	4.06	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	4.06
14	99.7	38.0	35.0	1.000	3695	35.0	3.70	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	3.70
15	101.0	39.5	34.7	1.000	3705	34.7	3.71	[illegible]	1.0	[illegible]	4.93	[illegible]	[illegible]	8.64
16	100.2	38.6	34.9	1.000	3699	34.9	3.70	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	3.70
17	98.4	37.7	35.1	1.000	3693	35.1	3.69	2.1	1.6	[illegible]	0.00	[illegible]	[illegible]	3.69
18	98.5	36.9	35.3	1.000	3687	35.3	3.69	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]	3.69
19	97.8	36.0	35.5	1.000	3681	35.5	3.68	1.7	[illegible]	[illegible]	0.00	[illegible]	[illegible]	3.68
20	97.0	35.1	35.7	0.983	3675	35.1	3.61	[illegible]	1.3	[illegible]	0.00	[illegible]	[illegible]	3.61
21	96.2	34.2	35.9	0.951	3669	34.2	3.60	[illegible]	2.7	[illegible]	[illegible]	[illegible]	[illegible]	3.60
22	95.4	33.3	36.1	0.924	3663	33.3	3.48	[illegible]	[illegible]	[illegible]	5.[illegible]	[illegible]	[illegible]	8.87
23	94.6	32.5	36.3	0.894	3657	32.5	3.56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.56
TOTALS				[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

It can be readily seen from studying Tables 5, 6 and 7 that times and magnitude of demand for conventional cooling and domestic water arrangements are very sensitive to water heater configuration and usage schedules. Because of the infinite variety of combinations that can and do exist in residences, peaks of considerable magnitude will always occur and are just as likely to occur at an undesirable time, such as 3 p.m., as a more desirable time, such as 12 a.m. The system that is integrated, which is more effective as cooling load increases, provides hot water evenly without relying on the water heater elements and presents a stable, essentially constant demand profile.

Should an attempt be made to control the demand profile by locking out the heater elements at certain times, the integrated system would still have a significant advantage. If a conventional water heater were locked out from, say, 10 a.m. until 10 p.m., the consumer would be inconvenienced during that time. In addition, a peak would occur at 10 p.m. (when the elements were allowed to energize) and the consumer would have to pay for the energy required to bring the tank back up to temperature after the long idle time.

An integrated system would have been providing hot water to the consumer during the period when electric heat was disallowed. There would be no peak at the end of that period and no energy penalty due to makeup requirements.

CONCLUSIONS

Integrating space cooling, space heating and water heating in heat pumps has been practiced for several years. The desuperheating, factory-assembled system used as an example in this study is but one of the configurations available. There are also several methods for calculating the effects of integration on total energy consumption - from quick rules of thumb to elaborate bin treatments linked to precise test methods. The approach used here is adaptable to specific applications, accounting for actual loads, operating times, water usage and months of operation. An interesting point to make, though not covered in this paper, is that the energy calculations will not differ significantly with any of the methods if the water is heated by simply desuperheating the discharge gas; all will show good energy and operating cost savings. It was demonstrated in this example that integration is more effective than raising the SEER from 10 to 15 BTU/W-HR.

An argument has been presented for using integrated systems to control demand peaks. An infinite variety of combinations of water heater efficiencies, draw schedules, control temperatures and tank volumes are present in the field. Only a few have been demonstrated. Peaks can be lowered as much as 5 KW without inconvenience to the customer with properly controlled integrated systems.

REFERENCES

1. Cook, R.E., Davidson, M.J., D'Valentine, M. and Goldschmidt, V.W., "A Simple Method to Determine the Yearly Consumption of a Combined Space - and Water - Heating Appliance with a Heat Pump and Desuperheater", ASHRAE Transactions, V. 92, Pt. 2, 1986, pp. 399-414.

2. Dougherty, B.P., "A Proposed Methodology for Rating Air - Source Heat Pumps That Heat, Cool,and Provide Domestic Water Heating", U.S. Department of Commerce, National Institute of Standards and Technology, Report number NISTIR 89-4154, August, 1989.

3. American Society of Heating, Refrigerating, and Air - Conditioning Engineers, "Methods of Testing for Efficiency of Space-Conditioning/Water-Heating Appliances That Include a Desuperheater Water Heater", SPC 137P.

4. Air-Conditioning and Refrigeration Institute, "ARI Standard 290P for Air-Conditioning and Heat Pump Equipment Incorporating Potable Water Heating Devices".

5. Department of the Air Force, United States of America, "Facility Design and Planning Engineering Weather Data", Manual AFM 88-29, 1 July, 1978.

6. Department of Energy, "Test Procedures for Central Air Conditioners, Including Heat Pumps", FEDERAL REGISTER, Vol. 44, No. 249, pp. 76700-76723.

7. Cook, R.E., Davidson, M.J. and Rice, M.A., "Heating and Cooling System", United States Patent No. 4,747,273, May 31, 1988.

8. American Society of Heating, Refrigerating and Air - Conditioning Engineers, Guide and Data Book, Systems Volume, Chapter 44, 1991.

9. Air Conditioning and Refrigeration Institute, "ARI Standard 210/240-89 Standard for Unitary Air-Conditioners and Air-Source Heat Pump Equipment", 1989.

Proceedings of the Eighth Symposium on Improving Building Systems in Hot and Humid Climates, Dallas, TX, May 13-14, 1992