WATER AND SPACE HEATING HEAT PUMPS

Alan F. Kessler, PE
The Trane Company
Tyler, Texas

ABSTRACT

This paper discusses the design and operation of the Trane Weathertron III Heat Pump Water Heating System and includes a comparison of features and performance to other domestic water heating systems.

Domestic water is generally provided through fossil fired heating units or electric resistance water heaters. When electric resistance water heaters are utilized there are three alternative electric heating concepts available to reduce home energy consumption. They are desuperheaters, dedicated heat pump water heaters and the Trane system Weathertron III.

Desuperheaters offer low cost with good payback and low investment requirements. Dedicated heat pump water heaters do not require integration with an air conditioning system. The Weathertron III system is an integrated air conditioning, heating and domestic hot water heating system. This system provides demand hot water heating. It has the best savings and good payback with high recovery capacity. Also, the free cooling provided during water heating can provide additional dehumidification in warm humid climates typical of Texas coastal areas.

The basic components of the Trane Weathertron III system are the outdoor unit, indoor air handler, water heating unit and computerized control center. Unique aspects of the Weathertron III system design and operation are described in United States Patent No. 4,299,098, 4,399,644 and others pending. A significant feature of the invention lies in the fact that during operation in any particular mode, the inactive heat exchanger of the circuit is vented to the suction side of the compressor, so as to afford proper refrigerant control within the system.

Annual operating cost savings vary from 27% to 36% for the three systems with the Weathertron III having the most. When compared to a conventional all resistance heating system and a conventional heat pump system, the Weathertron III can save 24% to 49% of the space conditioning and water heating energy used in a home.

INTRODUCTION

This paper discusses the design and operation of the Trane Weathertron III Heat Pump Water Heating System and includes a comparison of features and performance to other domestic water heating systems.

Water heating typically makes up approximately 20% of the total energy usage in a home, while space heating and cooling are 60% and 10%, respectively depending on location. Therefore, reducing water heating costs by heating with a heat pump at a COP of 2.5 would reduce total home energy usage by 10% to 12%.

Domestic hot water is generally provided through fossil fired heating units or electric resistance water heaters. When electric resistance water heaters are utilized there are three alternative electric heating concepts available to reduce home energy consumption. They are desuperheaters, dedicated heat pump water heaters and this system, which is an integrated home air conditioning, heating and hot water heat pump.

Desuperheaters -

Desuperheaters are installed in the discharge line of the air conditioning system and extract a portion of the refrigerant heat for water heating when the system is operating. Desuperheaters offer a low cost option with good payback and low investment requirements. Their disadvantage is the non-demand feature, i.e., hot water is provided only when there is a call for air heating or cooling. They also have low relative savings and are typically regional in their application due to installation requirements.

Dedicated Heat Pump Water Heaters -

Dedicated heat pump water heaters use a conventional vapor compressor cycle to extract heat from their surrounding environment and transfer port water heating. They are generally 115V plug-in devices

Proceedings of the Second Symposium on Improving Building Systems in Hot and Humid Climates, College Station, TX, September 24-26, 1985

so limited to approximately the same output capacity as a typical electric water heater but at a much higher efficiency. Dedicated heat pump water heaters do not require integration with an air conditioning system. They are moderate in cost with installation ease and have good savings. They provide hot water on demand and free localized cooling in the summer. The disadvantage of dedicated heat pump water heaters are poor payback and localized winter cooling.

Weathertron III -

The Weathertron III, is an integrated air conditioning, heating and domestic hot water heating system. The basic components of this integrated system are the outdoor unit, indoor air handler, water heating unit and computerized control center. It provides hot water heating on demand. It has high recovery capacity; depending on system size and weather conditions, it can be better than domestic gas water heaters. It can utilize the outdoor air as a source or distribute free cooling within the conditioned space. Free cooling is the cooling provided to the conditioned space as a by-product of a water heating requirement when the conditioned space can utilize it. It has the best savings and good payback. It fits well with existing air conditioning dealer distribution systems. The relative disadvantages of this system are the higher cost and investment and the increased complexity.

In summary then, we have the hot water desuperheater system that heats water only when the air conditioning system is cooling or heating. It is low in cost and has best payback. The dedicated heat pump water heater heats water on demand, has moderate cost and payback. It provides year round localized cooling which is a disadvantage in the winter, and it requires only plumbing skills for installation. The integrated Weathertron III system heats water on demand, has a good payback, excellent recovery capability, utilizes either indoor or outdoor air as a source, provides free cooling in the Summer and utilizes conventional available HVAC dealer skills.

TRANE WEATHERTRON-III OPERATING MODES

A unique aspect of system design and operation lies in the fact that during operation in any particular mode, the inactive heat exchanger is vented to the suction side of the compressor, so as to afford proper refrigerant control within the system. This will be seen as we view the various operating modes - space cooling, space heating, water heating outdoor source and water heating/space cooling.

Space Cooling -

In space cooling, heat is transferred from the indoor air handler to the outdoor unit. Figure 1 shows the system operation with dark arrows being high side discharge refrigerant progressing from the compressor to the water reversing valve (WRV) to the refrigerant reversing valve (RV) to the outdoor coil. In the outdoor coil, it is condensed to a liquid and passes through the liquid line through the water heating unit to the indoor coil, where it is expanded and absorbs heat. The low pressure suction gas returns through the reversing valve and the accumulator to the compressor. The unused water heating coil is vented to suction pressure through the water reversing valve back to the compressor suction line as shown by the round designation on the refrigerant schematic.

Space Heating -

In space heating, heat is transferred from the outdoor unit to the indoor unit. The circuiting shown in Figure 2 is reversed from that shown in Figure 1 by switching the reversing valve (RV) and one of the solenoids in the water heating module. There again, the water heating module remains vented.

Water Heating Outdoor Source -

When heating water during the spring, fall and winter using the outdoor source, heat is transferred directly from the outdoor unit to the indoor water heating unit. In this case, the water reversing valve (WRV) is shifted as shown in Figure 3 and discharge gas is directed to the water heating coil to heat water. It is returned through an open solenoid valve as a liquid to the outdoor coil where it is expanded and absorbs heat. It passes through the normal reversing valve and accumulator back to the compressor. When the water reversing valve was switched, it also vented through the refrigerant reversing valve, the indoor coil as shown.

Water Heating/Space Cooling -

In the summer water heating and space cooling mode, heat is transferred from the indoor conditioned space to the hot water, utilizing the outdoor unit only for the compressor function. Figure 4 shows the refrigerant circuit to accomplish this. The refrigerant reversing valve is used to switch between indoor and outdoor coils as a source along with appropriate solenoid valve changes in the water heating module. Again, you will note that the unused outdoor coil is vented to suction pressure to manage refrigerant and maintain proper system charge and operation.

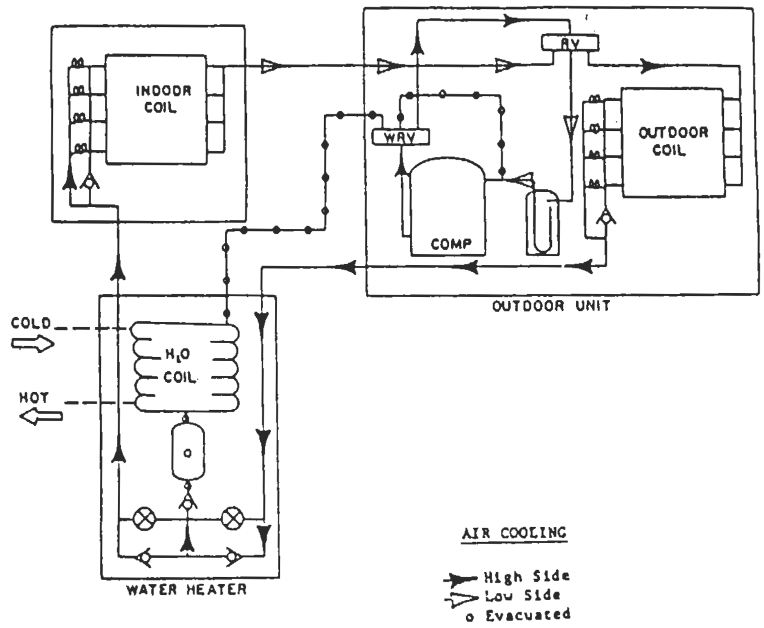


Figure 1

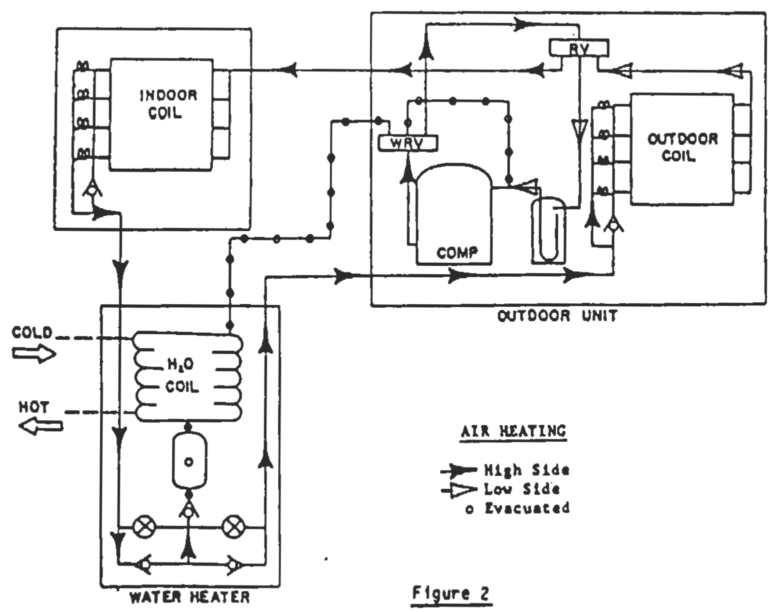
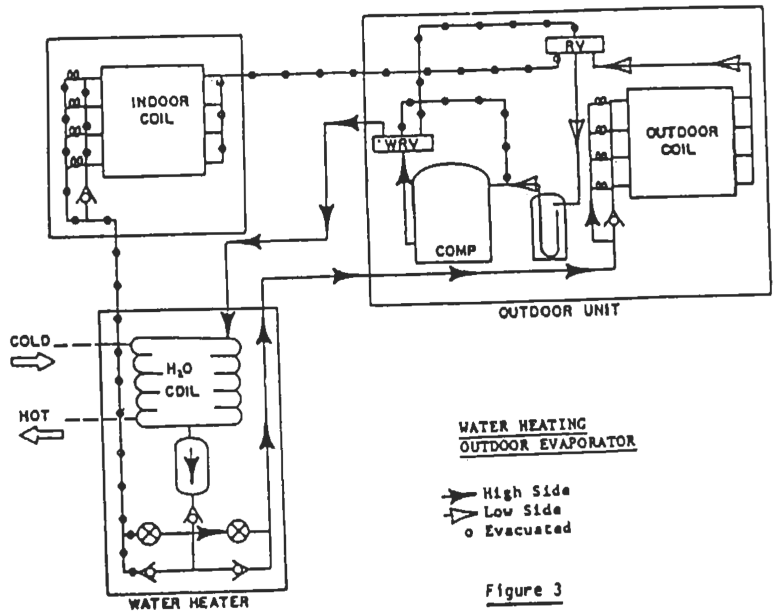


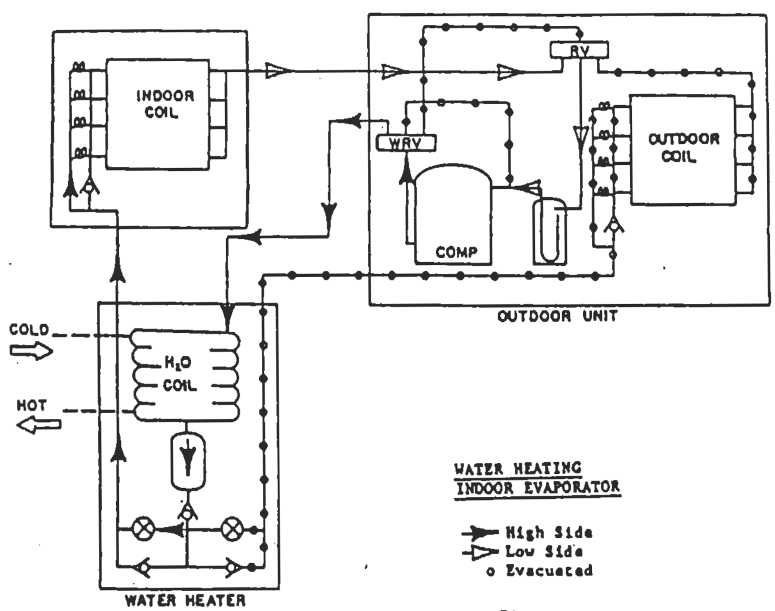
Figure 2



WATER HEATING
OUTDOOR EVAPORATOR

High Side
Low Side
o Evacuated

Figure 3



WATER HEATING
INDOOR EVAPORATOR

High Side
Low Side
o Evacuated

Figure 4

MICROCOMPUTER CONTROL SYSTEM

As noted earlier, this system is more complex than desuperheaters dedicated heat pump water heaters or standard space conditioning heat pumps. As a result, microcomputer controls are utilized to integrate the operation and decision making requirements of the system. Utilizing microcomputer controls allows additional features and benefits to be added at minimal incremental cost for software development. The benefits provided by the system control center are water temperature set point changes, water heating mode decisions, intelligent night and day setback or setup programming over a true seven day week cycle, automatic heating cooling changeover and trip programming, all of which are easily entered by the user. In addition, service diagnostics are available.

Control Center Operation

The control center interface includes a "banker's display" format, which alternately flashes time, *indoor* temperature, and outdoor temperature. The display can be turned off or on. An annunciator in the middle of the display indicates AM or PM time, while top and bottom annunciators indicate various other features. These annunciators are "WARMER" and "COOLER", which indicate a temporary set point adjustment has been made by depressing the WARMER or COOLER keys. When a temporary change in the heating or cooling setpoint is desired until the next economy or comfort period is entered, the user can depress the key once and raise or lower the set point 2°F appropriately and the annunciator will light. A second depression will move the set point an additional 2°F, and the annunciator will flash. Third and subsequent depressions have no effect. When operating in an economy or set-back mode, the ECON annunciator is lighted. Economy can be initiated or terminated early by depressing the appropriate START or END ECON keys. A FAIL light indicates a failure mode has been encountered and the system is operating on backup electric resistance heat in either air heating or water heating. The BAT annunciator indicates a weak battery which would cause customer programming to be lost in the event of a power interruption of several minutes duration. The UNIT ON annunciator indicates normal system operation is programmed. UNIT OFF results in shifting of the set points to 50°F for heating and 90°F for cooling. The DISHWASHER annunciator indicates that the DISHWASHER key has been depressed and the water heating set point temporarily raised to 140°F for one hour. This feature is available to provide extra hot water for dishwashing and other applications only when required and utilize lower temperature water (typically 120°F) for other domestic applications, and thus achieve a sizeable energy savings. The FAN ON annunciator indicates whether the continuous fan or automatic fan mode of operation has been selected.

Customer Programming

Customer programming is entered through programming cards which change the key function with a switch on the face of the control center. This also changes the annunciator functions, which also provide guidance in directing the customer through the programming steps. In addition to setting the clock time with the programming card, there are the COMFORT, SLEEP, WORK and TRIP programs. The COMFORT program is for the normal temperatures, heating and cooling, desired during the occupied hours. The SLEEP program is for the setback/economy mode desired during the night time hours. The WORK program provides energy conservation during the unoccupied time. The TRIP program utilizes the WORK program settings and a 100°F water temperature whenever it is programmed to set back for a specific number of days and recover at a certain time on the last one. As noted, these programs can be overridden temporarily by use of the END ECON key or they may not be utilized at all simply by programming START and END times the same or temperatures the same.

Optimum advantage of these economy modes with a heat pump, is obtained with the intelligent or smart setback and recovery. Significant details of smart heat pump set-back are described in U. S. Patent No. 4,266,599. In addition to setback and recovery time, temperature set points, and actual indoor and outdoor temperatures, it is necessary to have EQUIPMENT CONSTANTS relative to the building structure. There are four EQUIPMENT CONSTANTS that must be addressed for good comfort control and energy conservation. These constants are set by the user along with the NORMAL WATER TEMPERATURE desired. The COOLING equipment constant is the outdoor temperature at which the cooling system capacity balances the cooling load requirements. Typically, this should be at or near the outdoor cooling design condition; in College Station, this would be 98°F. The HEAT PUMP equipment constant is the balance point temperature where the heat pump capacity equals the structure load. This is dependent on how the heat pump is sized to the structure. Typically, this might be 25°F. The HEATING equipment constant is the temperature where the total heating system (heat pump plus auxiliary heat) balances against the structure load. Since the system must be sized to have recovery capacity at low temperatures, this will be substantially lower than the heating design balance point. Typically, with a 24°F winter design condition, the total HEATING equipment constant might be 0°F. A $ LOCK equipment constant is provided for dual fuel systems, i.e. heat pumps mounted on natural gas or more typically oil furnaces where economics dictate switching to all alternate fuel below a certain temperature as the electric heat pump efficiency declines. Typically, this might be 10°F or 15°F. There is a RECOVERY FACTOR which is a customer input variable to account for the building design, structure mass, infiltration, etc. It is factory set at an average value and adjusted experimentally based on actual recovery time vs. scheduled recovery time by the customer and need not be changed once determined for a particular installation.

Service Tool

The service tool has the capability to monitor temperatures, customer temperature set points, failure mode detection and override the system control to force it into different operating modes and monitor which devices have been activated.

The temperatures monitored are compressor discharge, outdoor coil, heating suction line, water at the bottom of the conventional water storage tank, the hot water supply leaving the unit to the conventional storage tank, the outdoor ambient, the liquid line and indoor conditioned space temperature.

The failure mode detection is to determine which failure mode occurred, if a sensor has failed or if an intermittent failure has occurred but not caused the system to lock out and go to backup heating modes.

To assure the proper system operation in all modes at startup or diagnose abnormal conditions during or after occurrence of a failure, a drive override/monitor mode is available. In this mode, the system may be operated in any of the normal operating modes, regardless of settings, external temperatures and demand requirements. This allows typical system operating pressures and temperatures to be checked while operating. The various enunciators on the display identify which system components have been energized by the control.

OPERATING MODE LOGIC SUMMARY

Figure 5 is a graphic presentation summarizing the logic and operating modes of the heat pump water heating decisions. Depending on the outdoor ambient and the water temperature setting, either the heat pump water heater system is enabled or backup electric heat utilized. Below 10°F outdoors backup electric heat is used at all conditions. This is done because of the low heat pump water heating capacity and the need for space heating capacity. Between 10°F and 25°F, backup electric heat is utilized at water temperature settings above 130°F and in all cases above 140°F water temperature setting, backup electric heat is used due to code/control requirements and system design/reliability considerations. Above the heat pump system balance point, water heating has priority over air heating. This priority continues below the heat pump balance point until a second stage air heating call is initiated. Then air heating has priority until the load is satisfied. Under normal comfort conditions, a false 35°F heat pump balance point is set to prevent conditioned space droop during water heating. This is done to prevent situations in the morning above the balance point when all family members rise and shower coincidentally which can produce large demands for hot water. This demand, while met with the heat pump water heater, could allow the condition space to drop unacceptably. Under these conditions when there is a second stage call for heat, the system switches to air heating with backup electric water heating. The free cooling switchover from outdoor to indoor source is based on a 70°F outdoor ambient and the indoor condition space temperature.

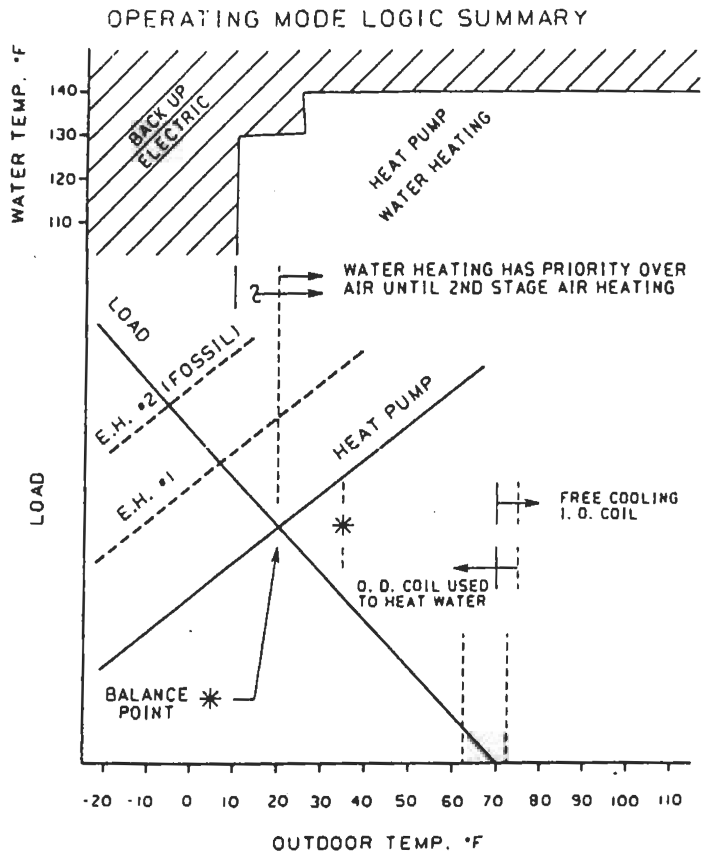
SYSTEM COMPARISONS

With this understanding of the Weathertron III system, we can now more easily review a product comparison between it, desuperheaters and dedicated heat pump water heaters. In the water heating comfort area, we see that the system described here has excellent demand activated recovery capability compared to none with the desuperheater and limited capacity with the dedicated heat pump type water heater. From an operating standpoint, all major operating components generating noise are outside of the home and no adverse cooling effects occur during the winter time as with the dedicated heat pump water heater system.

From an installation/application standpoint, this system is slightly more complex due to the control requirements. However, this is offset by unlimited geographic application compared to a desuperheater and space requirements relative to a dedicated heat pump system. This system is integrated into a total comfort system whereas the desuperheater is ancillary to the heat pump or air conditioner unit and the dedicated heat pump water is available only for stand alone applications.

From a product economy comparison, the Trane energy conservation system described here has the highest first cost but the best total savings. It has intelligent, distributed free cooling compared to the dedicated heat pump water heater with localized cooling which fights the normal heating system during the winter. This unique system can be programmed to provide substantial energy savings through reduced water temperature settings and conditioned space heating setback/cooling setup.

Figure 6 shows a typical operating cost comparison of just the comfort conditioning and water heating costs used in an average home. The annual operating cost savings for the three systems vary from 27% to 36% with the Weathertron III system having the lowest operating cost.



* FALSE 35°F. BALANCE POINT SET DURING COMFORT TO PREVENT DROOP DURING WATER HEATING

Figure 5

TYPICAL OPERATING COST COMPARISON

BASE SYSTEM HEAT PUMP WITH ELECTRIC RESISTANCE WATER HEATER	WITH DESUPERHEATER	WITH DEDICATED WATER HEATER	WEATHERTRON III
$1200	$876	$816	$756
	-27%	-32%	-37%
ANNUAL SAVINGS	$324	$384	$444

Figure 6

A detailed system energy comparison is shown in Figure 7 for College Station for a gas/electric, all electric heat pump, all electric resistance and the integrated Weathertron III system. The base system has a 9.2 SEER in cooling. In the heat pump mode the HSPF is 7.0 with a COP of 2.7 at 47°F. The gas heat has a 75% annualized efficiency.

ENERGY CONSUMPTION COMPARISON
(COLLEGE STATION)

ELECTRIC RESISTANCE WATER HEATER

	GAS HEAT	HEAT PUMP	ALL ELECTRIC	WEATHERTRON III
COOLING	7180 KWH	7180 KWH	7180 KWH	6510 KWH
HEATING	33630 KBTU	2930 KWH	7390 KWH	2930 KWH
WATER HEATING	26750 KBTU	5880 KWH	5880 KWH	2660 KWH
FREE COOLING				(670 KWH)
DEHUMIDIFICATION				(465 KWH)

Figure 7

The portion of free cooling is broken out for information. This is the cooling provided coincidentally with a demand for water heating thus fully utilizing all energy input to this integrated system. The extra dehumidification or overcooling is also shown. This extra dehumidification is provided when the outdoor temperature is above 70°F and the load relative to the system setpoint has been satisfied. This is of particular importance in humid climates where a drier indoor space condition can be maintained without the expense of overcooling. In this example there is 7% more latent capacity provided due to the integrated system than with a conventional air conditioner.

Figure 8 is an operating cost comparison for this application.

OPERATING COST COMPARISON
(COLLEGE STATION)

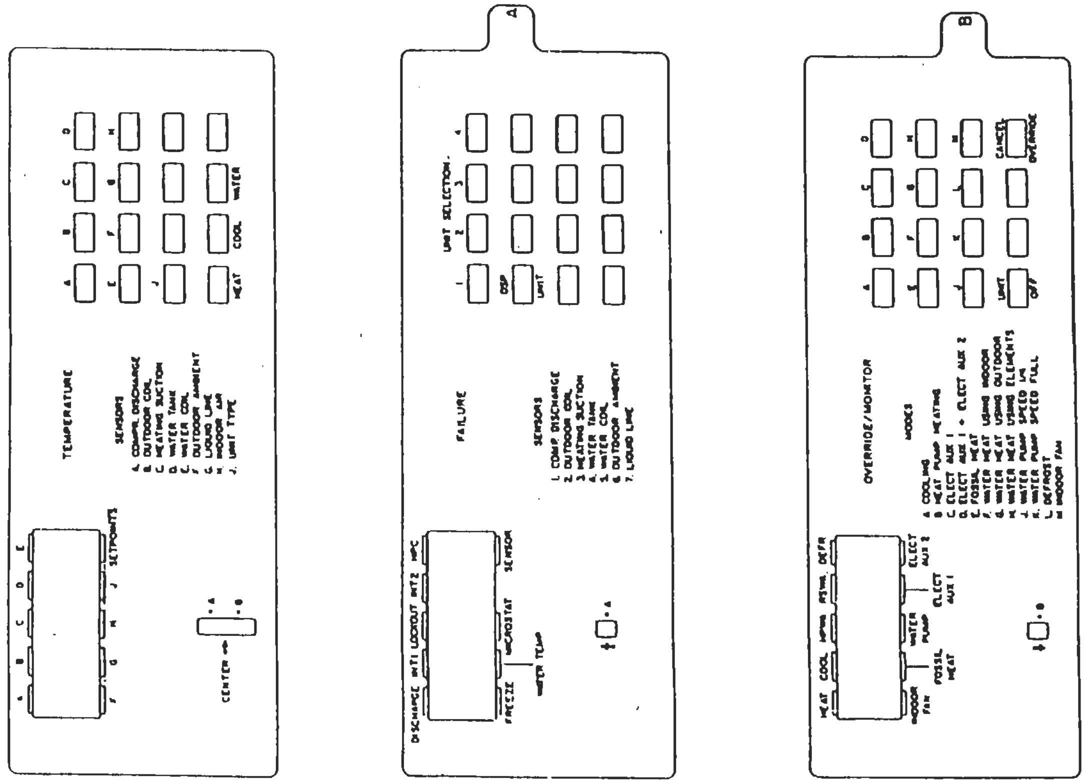
	GAS HEAT	HEAT PUMP	ALL ELECTRIC	WEATHERTRON III
COOLING	$503	$503	$503	$456
HEATING	$235	$205	$517	$205
WATER HEATING	$187	$412	$412	$186
TOTAL	$925	$1120	$1432	$847
	+9%	+32%	+69%	BASE
SIMPLE PAYBACK (YRS)	19	5.5	2.6	

Figure 8

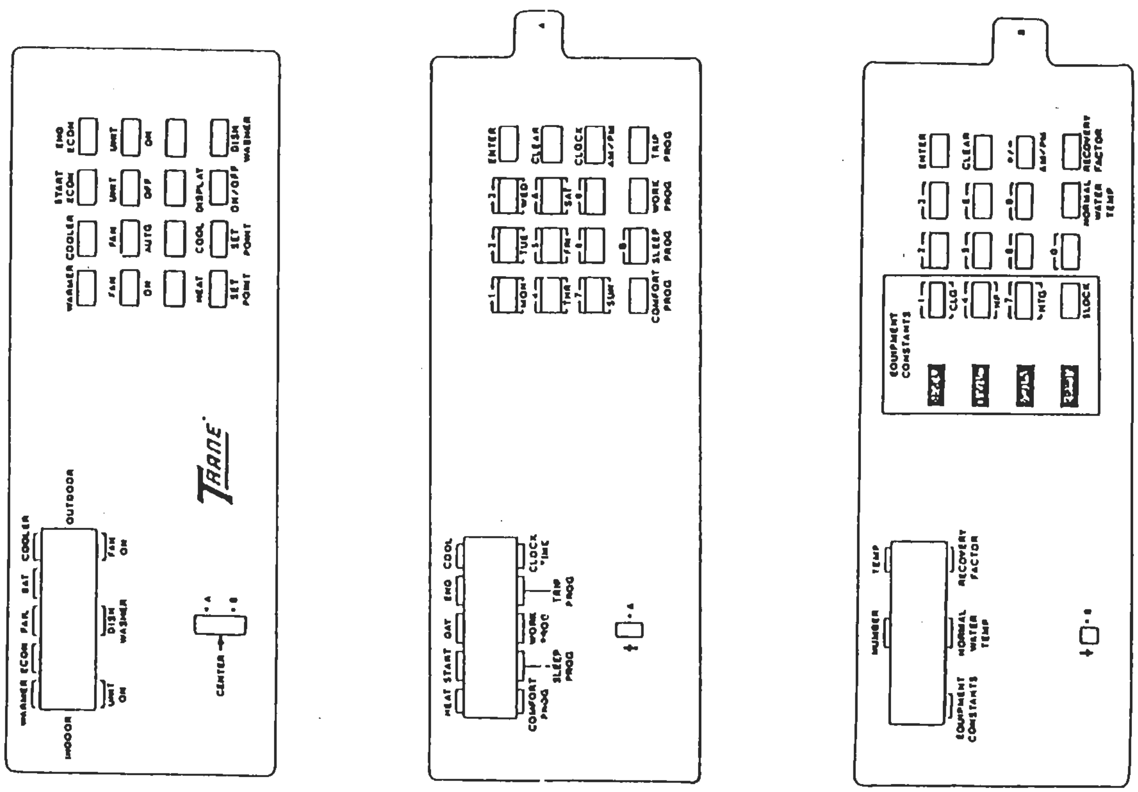
SUMMARY

This operating cost comparison shows a significant economic benefit for the integrated Weathertron III system relative to either a conventional heat pump or an all electric system. The simple payback is very good compared to an all electric system and acceptable relative to the standard heat pump system assuming a $1500 incremental cost. While lower in operating cost than a gas/electric comfort system, the long payback cannot justify using this system where gas is available.

In summary, a unique new integrated space and water heating system has been presented. This system yields substantial economic benefits compared to current water heating methods such as desuperheaters and self-contained dedicated heat pump water heaters. It also provides significant economic benefits relative to standard all electric resistance and heat pump air conditioning systems. In humid climates the free dehumidification profided during summer water heating can also improve the relative comfort in the conditioned space.



Control Center
service diagnostics



Weathertron III Control Center