AIR CONDITIONING AND REFRIGERATION
Journal
The magazine of the Indian Society of Heating, Refrigerating and Air Conditioning Engineers

Issue : January-March 2001

Heat Pump for Domestic & Commercial Markets

Conditions Air, Heats Tap Water and Cools Potable Water

By Milind V. Rane and

Avijit Das Gupta

Heat Pump Laboratory

Mechanical Engineering Department

IIT, Mumbai 400 076

Milind Rane is an Associate Professor in Mechanical Engineering at Indian Institute of Technology Bombay. He holds a Ph.D. from University of Maryland, College Park in Mechanical Engineering.

Avijit Das Gupta is a research engineer working on a project in the Heat Pump Laboratory at IIT and also studying part time for an M.Tech in the Mechanical Engineering Dept.

Improving living standard and globalization is throwing up a new challenge in coping with the increased demand for electricity. The demand for air conditioning, water heating and potable water cooling, in domestic and light commercial markets is increasing rapidly. Concern for the environment and increasing price of energy is forcing us to review conventional practices and develop novel alternatives. It is a challenge to develop new systems which use environment friendly refrigerants, while, ensuring low initial and operating costs. This article presents a novel heat pump for domestic and light commercial markets which demonstrates several advantages. Performance of a 1.5 TR split heat pump capable of catering to air conditioning, heating tap water to 45°C and cooling potable water to 15°C is indicated and shows that initial and operating cost can be reduced substantially and simultaneously.

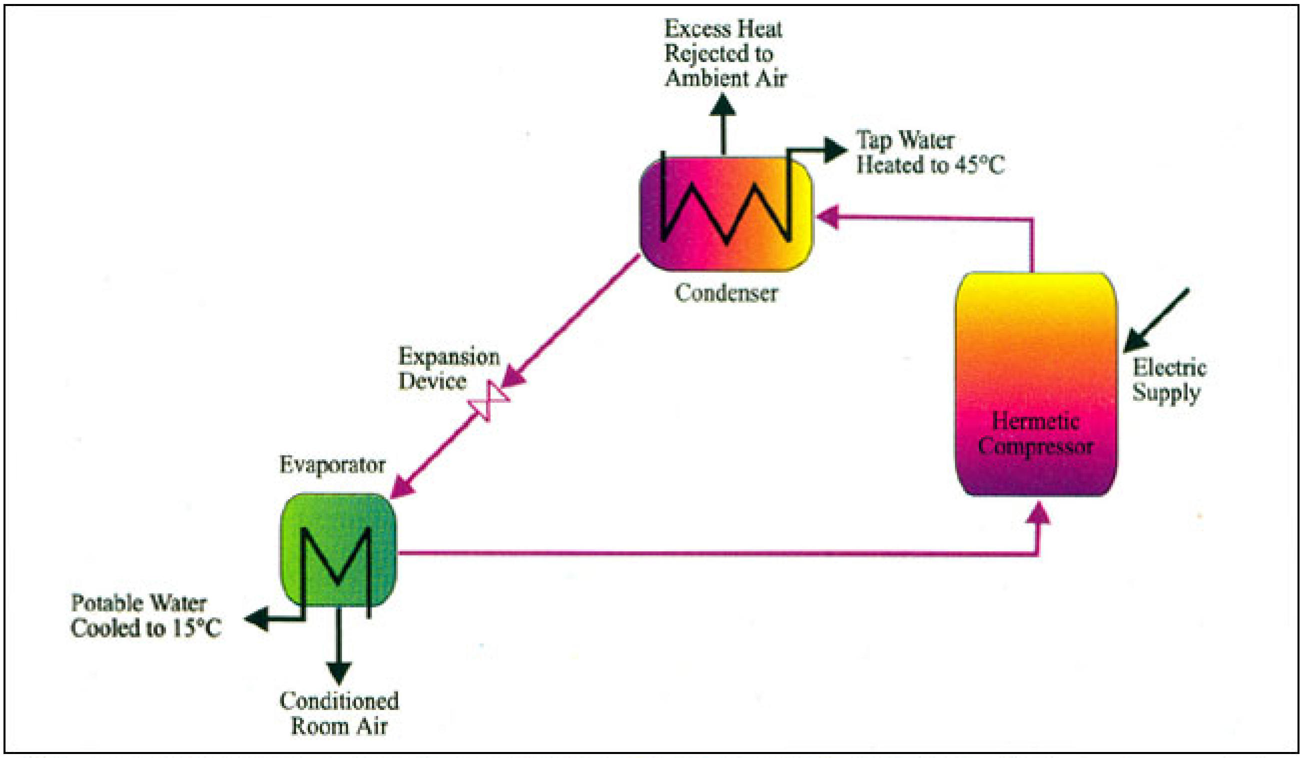

Figure 1 : Heat Pump for domestic and light commercial markets that can be used for simultaneous Air Conditioning, Water Heating and Water Cooling

Introduction

Increasing use of energy and its effect on the environment is a matter of concern. Inefficient usage of energy can be controlled by using the latest techniques in design and manufacture of equipment. Proper application engineering is the key to reduce energy usage and associated fuel cost.

Cost reduction has become essential in order to survive in the global market. One way to achieve significant energy cost reduction, in HVAC & R applications, is by recovering and recycling waste heat. Co-generating cold and hot utilities can reduce energy consumption and a heat pump is one such device which can be used to deliver cold and hot utility simultaneously.

A heat pump is a device which pumps heat from a low temperature source to a high temperature sink, with the help of an external source of energy. Heat pumps can be of various types, viz. vapour compression, absorption, adsorption and ejection type. Vapour compression heat pump (VCHP) is driven using electrical energy or shaft power as input energy, while the energy input to the absorption, adsorption and ejection type heat pumps is in the form of heat. This heat can be obtained by direct burning of fuel or by recovering heat from various waste heat sources.

A VCHP cycle is the same as that of the refrigeration cycle, **Figure 1**. The HP shown in **Figure 1**, can be used to simultaneously cater to Air Conditioning (AC) requirement, along with Water Heating (WH) and Water Cooling (WC) needs. Tap water can be heated to 45°C. This hot utility can be used for bathing, cooking, dish washing, drying, laundry, etc. Potable water can be cooled to 15°C and be used for drinking. This article presents the benefits of Novel Window and Split Heat Pumps, developed at the Heat Pump Laboratory of IIT Bombay, which can simultaneously cater to AC, WH and WC needs in domestic and light commercial applications in the range of 1 to 2 TR range.

Applications

Heat pumps can be used to reduce energy costs in residential and commercial applications where air conditioning is required along with water heating, and potable cold water for drinking. Hotels, restaurants, canteens, hospitals, laboratories, guest houses and offices can also benefit from these heat pumps.

Heat pumps can also be used in industrial process plants such as textile, pharmaceuticals, chemical, dairy, etc. The chilled utility can be used for air conditioning, process cooling or maintaining cold stores, while the hot utility can be in the form of hot water for process heating or drying, preheated boiler feed water, etc.

Matching of cooling and heating loads, with respect to capacity and time of use, is a critical issue which influences selection of the type and size of a heat pump for an application. While storage of one of the utilities is an obvious answer to take care of time of use mismatch, this may not be the most economical solution when the increased cost of insulated storage tanks, pumps for circulation, controls, etc. are taken into account.

Additional power consumed by the auxiliary circulation pumps associated with storage tanks and excess heat rejection fans can eat into the anticipated savings in operating costs of the heat pumps. Additional initial investment for storage tanks, pumps, and controls may increase payback periods significantly. Space consideration adds another dimension to the selection of the heat pump system. Proper application engineering is essential to maximize the benefits of the heat pump technology.

The Novel Heat Pump

A novel heat pump (HP) was developed at the Heat Pump Laboratory, IIT Bombay, which is capable of catering to air conditioning, heating tap water to 45°C and cooling potable water to 15°C. Hot water at 45°C can be used for bathing, washing clothes, cooking, dish washing, drying, etc., and cooled potable water at 15°C can be used for drinking purposes.

HPs have been designed to cater to the domestic and the light commercial market with nominal airconditioning capacity of 1, 1.5 and 2 TR in window and split models. Energy efficiency of these HPs is higher than conventional window and split ACs, while suppling hot and/ or cold water. Care is taken to keep the increase in cost and size to a nominal level, while incorporating features like instantaneous-ondemand supply of hot water and cooled potable water. This is achieved without complicated controls and storage of any utility. The dimensions of HPs and conventional ACs are listed in **Table 1**.

Table 1 : Typical Dimensions of the Novel Heat Pump and Conventional Air Conditioner

Systems	Length (mm)	Height (mm)	Width (mm)
Split Heat Pump (SHP)*	690	546	395
Split Air Conditioner (SAC)*	690	470	395
Window Heat Pump (WHP)	750	496	650
Window Air Conditioner (WAC)	750	420	650

These HPs have the same footprint as the conventional ACs with a marginal increase in height.

Testing of Split Heat Pump (SHP)

1.5 TR Split and Window HPs were carefully tested at the laboratory. The water side temperatures were measured using RTD sensors with an accuracy of ±1°C. Flow rate was measured manually by collecting water for 2 minutes in a container and weighing it using a precision balance (PAG Oerlikon AG CHDietikon Precisa Balances, model no 87113 type 300-9535/H6200D) with an accuracy of ±0.1 g and maximum capacity of 6200 g. Single phase two wire electronic Wattmeter (manufactured by L&T model no EM101+, with Class I accuracy as per ISI 3779 1993, that is ±0.5% of the full scale reading having maximum current rating of 40 amp) was used to measure the power input to the HPs.

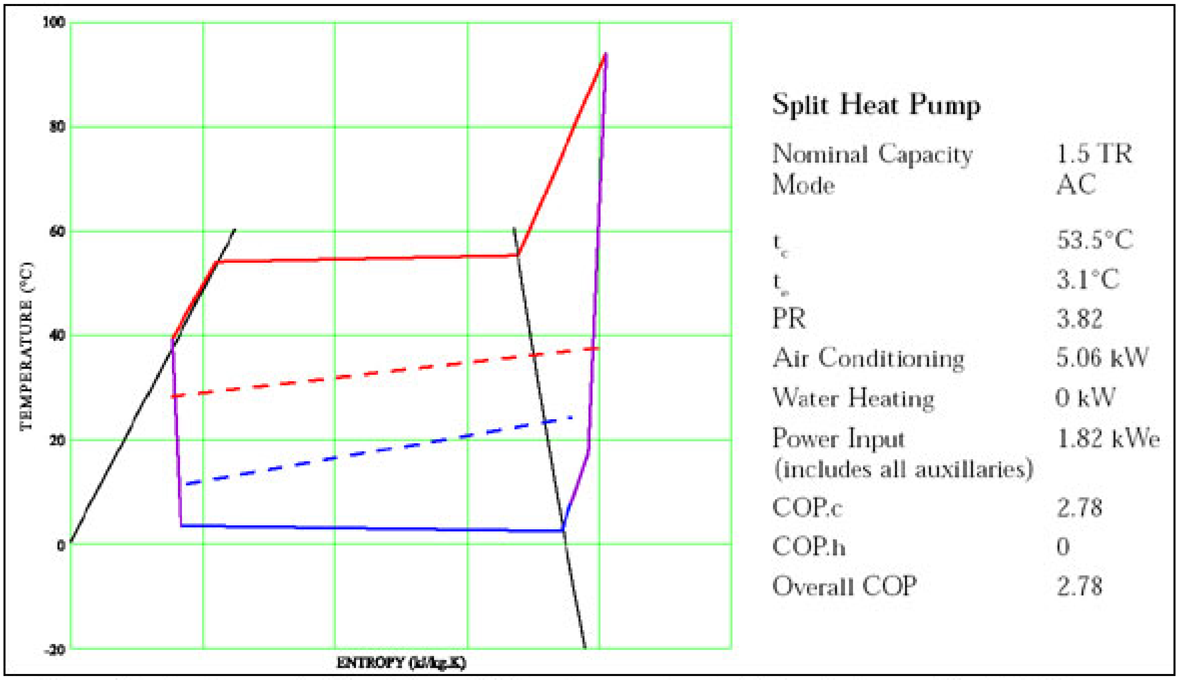

Figure 2 : t–s diagram for Heat Pump (HP) cycle operating in AC mode along with dotted lines indicating temperature of heat transferred media

A few important parameters, needed to evaluate the performance of the SHP, are tabulated in **Table 2**. Performance of the SHP operating in different modes is compared with the air conditioning (AC) mode that is when no hot and cold water is tapped out of the SHP.

Figure 2 shows the HP cycle represented on the t-s diagram while the SHP was run in the AC mode. In the AC mode the condenser is air cooled. Large temperature difference between the condensing refrigerant and outdoor air, represented by the upper dotted line, indicates that the LMTD is high for the air-cooled condenser. Since, the overall heat transfer coefficient in the air-cooled condenser is low the design LMTD is usually high. This is done to keep the size and cost of the air-cooled condenser within commercially viable limits. This leads to a condensing temperature of 53.5°C and a pressure ratio of 3.82. Cooling capacity of 5.06 kWc was obtained as compared to the rated nominal capacity of 5.27 kW or 1.5 TR. Power consumption recorded was 1.82 kWe.. This results in cooling COP of 2.78 when operated in the AC mode.

Table 2 Experimental Results of 1.5 TR Split Heat Pump (SHP)

Mode of Operation		**AC**	**AC+WH+WC**	**AC+WH**	**AC+WC**
DBT e.a.i	C	23.9	24.6	25.8	25.1
WBT e.a.i	C	15.7	17.6	18.7	17.8
DBT e.a.o	C	11.0	13.2	12.2	12.8
WBT e.a.o	C	8.2	10.6	10.9	11.0

Nomenclature

Symbol	**Description**
AC	air condition
COP	coefficient of performance
DBT	

t w.i	C		25.9	23.7	25.9
t hw.o	C		45	45	15
t cw.o	C		15	2.1	0.55
volf hw	lpm		2.7		
volf cw	lpm		0.64		
Q.ac	kW (TR)	5.06 (1.44)	4.79 (1.36)	5.68 (1.61)	4.91 (1.40)
Q.h	kW		3.59	3.11	
Q.cw	kW (TR)	5.06 (1.44)	0.49 (0.14)		0.42 (0.11)
Q.tot.c	kW (TR)		5.27 (1.50)	5.68	5.32 (1.51)
Power Input (includes all auxiliaries)	kW	1.82	1.58	1.60	1.68
COP.c		2.78	3.34	3.55	3.17
COP.h			2.27	1.95	
Total COP of the System		2.78	5.61	5.49	3.17
Reduction in Power Input, P.sys	%		13.43	12.28	7.89
Increase in Cooling Effect, Q.tot.c	%		4.16	12.19	5.19
Increase in COP.c	%		20.33	27.90	14.21

Q	dry bulb temperature, °C
RTD	heat duty, kW and TR
SAC	resistence temperature detector
SHP	split air conditioner
SS	split heat pump
t	stainless steel
volf	temperature, °C
WAC	volume flow rate, lpm
WBT	window air conditioner
WC	wet bulb temperature, °C
WH	water cooling
WHP	water heating
	window heat pump

Suffix	**Description**
ac	air condition
c	cooling
cw	cooled water
cw.o	cooled water outlet
e.a.i	evaporator air inlet
e.a.o	evaporator air outlet
h	heating
hw	hot water
hw.o	hot water outlet
tot.c	total cooling
w.i	water inlet

In AC + WH + WC mode most of the condenser heat is delivered to the water being heated. This helps lower the condensing temperature to 44°C. Lower condensing pressure leads to a lower pressure ratio of 3.07. This results in reduced flashing at the outlet of the expansion device and higher compressor volumetric efficiency. This leads to 4.16% increase in total cooling capacity, to 5.27 kWc, of which about 4.79 kW is in the form of AC and 0.49 kW in the form of cooled potable water cooled to 15°C. Lower pressure ratio leads to 13.43% lowering of power consumption, to 1.58 kWe, which results in 20.33% increase in cooling COP, to 3.34. Water heating duty works out to be 3.59 kW and the corresponding heating COP is 2.27. Overall COP of the HP is 5.61.

Figure 3 shows the HP cycle represented on the t-s diagram while the SHP was run in the AC + WH mode. In this mode also most of the condenser heat is delivered to the water being heated. This helps lower the condensing temperature to 44°C as compared to 53.5°C in the AC mode. Lower condensing pressure leads to a lower pressure ratio of 3.28. This results in reduced flashing at the outlet of the expansion device and higher compressor volumetric efficiency. This leads to 12.2% increase in cooling capacity, to 5.68 kWc. Lower pressure ratio leads to 12.3% lowering of power consumption, to 1.60 kWe, which results in 27.9% increase in cooling COP, to 3.55. Water heating duty works out to be 3.11 kW and the corresponding heating COP is 1.95. Overall COP of the HP is 5.49.

In AC + WC mode the condenser is air cooled, which leads to a higher condensing temperature of 52°C. Evaporating pressure increased because of cold water extraction and higher indoor air temperature. The total cooling capacity increased by 5.2% because of cold water extraction which leads to a higher inlet air temperature to the indoor unit. Power consumption of the HP is reduced by 7.9%. Since, the cooling capacity increased and the power consumption reduced, the cooling COP of the system is enhanced by 14.2%, which takes up the overall COP of the HP to 3.17.

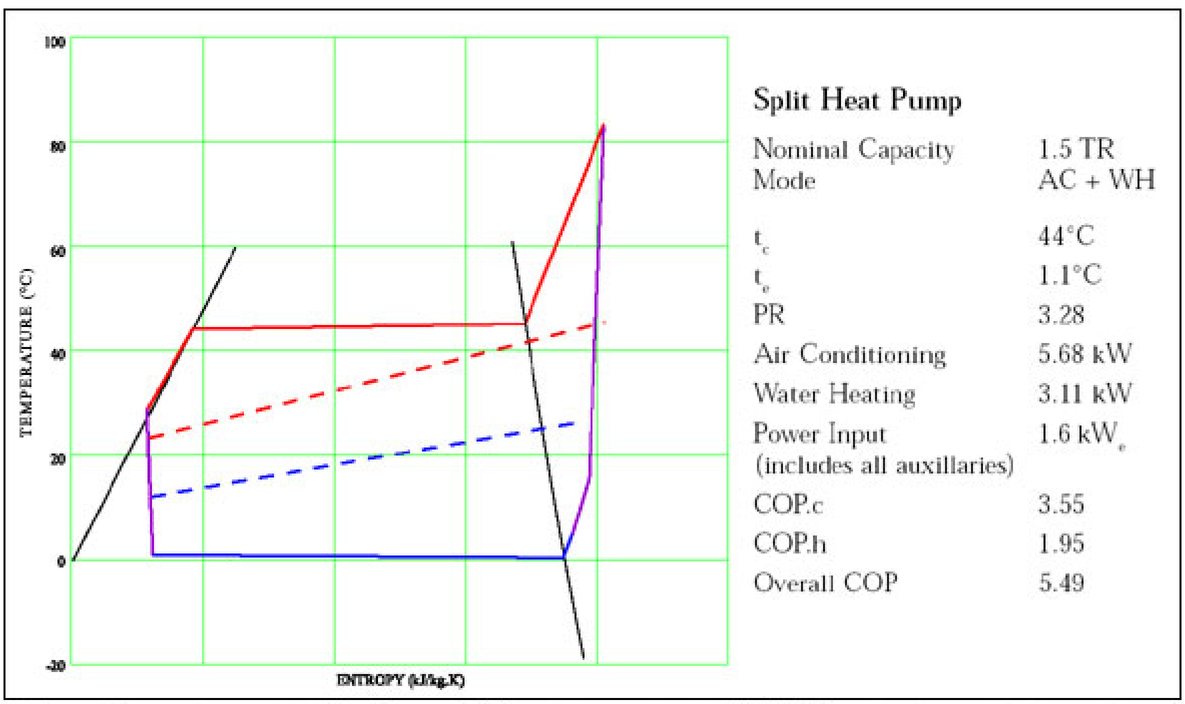

Figure 3 : t–s diagram for Heat Pump (HP) cycle operating in AC+WH mode along with dotted lines indicating temperature of heat transferred media

Features and Advantages of the Novel Heat Pumps

Some features and advantages of the novel heat pump over the conventional air conditioners are listed hereunder:

1. co-generation of air conditioning, cold and/or hot water simultaneously using a single unit – offers better COP compared to WAC/SAC when hot and/or cold water is tapped.
2. Instant–on–demand supply of hot and cold water – no storage required, no auxiliary pumps and controls required, hence lower initial and operating costs
3. Cooling capacity increases by 3.9 to 12.2% when hot and/or cold water is drawn.
4. Power required for air conditioning is reduced – 7.44 to 13.43 % decrease in power consumption when hot and/or cold water is drawn.
5. Higher cooling COP of the HP – enhanced by 10.98 to 27.9 % when hot and/or cold water is drawn, and reverts back to normal level when these utilities are not tapped.
6. Overall COP is very high – in the range of 4.5 to 5.5 as compared to 2.5 to 2.8 for WAC/ SAC, which means 65 to 70% saving in primary energy when co-generating.
7. Clean–in–place heat exchangers – novel heat exchanger allows water passages to be cleaned without opening the HP casing.

Economic Analysis

Economics of using a 1.5 TR Split or Window HP for a c o m m e r c i a l application, of s i m u l t a n e o u s l y conditioning air and heating water, is presented in **Table 3**. Costs and benefits are compared with the conventional system consisting of a SAC or WAC for air conditioning and Electric Water Heater (EWH) for water heating. Initial costs of SAC and WAC are Rs 36,000/- and Rs 25,000/- respectively and are based on the cost of the conventional ACs in the market. Initial costs of SHP and WHP are estimated to be Rs 44,000/- and Rs 33,000/- respectively. Initial costs do not include taxes and duties. Cost of EWH is taken as Rs 2,700/- for a 3 kWe heater.

The analysis is based on the assumption that 1.5 TR air conditioning is required for 6 h/day for 280 day/yr, a cooling requirement of 8870 kWh/yr, and the 3 kW water heater is required for 2 h/day for 365 day/yr, a water heating requirement of 2190 kWh/yr.

While the electric heater needs to be operated for 730 h/yr, the SHP in the AC + WH mode needs to be operated for only 704 h/yr. This is because the capacity of the SHP WH is 3.11 kW against 3 kW for the EWH. The SHP operates for an additional 963 h/yr, in the normal AC mode, to cater to the total cooling requirement of 8870 kWh/yr.

Total hours of operation of SHP reduced to 1667 h/yr as compared to 1750 h/yr for the SAC because the cooling capacity of the SHP is 5.67 kW as compared to 5.06 kW for the WAC when water is being heated in the SHP.

Due to higher cooling COP and cooling capacity of the SHP and WHP as compared to that of the SAC and WAC respectively, the total power consumed for cooling by the SHP and WHP is less than that for the SAC and WAC respectively. This leads to energy cost savings of Rs 1836/yr using SHP as compared to SAC. Similarly, use of WHP leads to energy cost savings of Rs 1348/yr as compared to WAC. While these savings may not seem to be significant, the saving in cost of electricity used for heating water is significant, Rs 13,140/yr. Thus, the total saving in electricity cost is Rs 14,976/yr and Rs 14,488/yr for SHP and WHP respectively.

Expected payback period for the SHP works out to be 4.2 months and that for WHP works out to be 4.4 months. Indeed very attractive!

The above payback periods are calculated without accounting for the benefit of availing 100% depreciation in the very first year towards the cost of the HPs. This when accounted for will lower the effective cost of the HP, by another 35% for a profit making organization. In such situations the cost of the HPs will actually work out to be lower than that of conventional WAC/ SAC + EWH option. Thus, the user can benefit from both, lower initial cost and lower operating cost.

Economic analysis for a domestic application, where the unit cost is about Rs 3/kWh as compared to Rs 6/kWh, will offer payback periods in the range of 8.4 to 8.8 months.

Industrial applications will be more attractive because of larger demand for hot utility, which will further increase the saving in energy used to produce the hot utility. Since, hot utility in industry may be generated using fuels instead of electricity the savings in fuel cost may be only slightly higher than the saving in electricity cost in the case of commercial applications.

Thus, these HPs can be used for reducing initial and operating cost not only in domestic and commercial markets, but also for industrial applications when properly engineered.

Table 3 Economics of Heat Pump Used for Commercial Application

Type of System		**SAC**	**SHP**	**WAC**	**WHP**
Mode of Operation		**AC**	**AC + WH**	**AC**	**AC + WH**
Initial Cost of the AC/HP	Rs	36000	44000	25000	33000

Initial Cost of the Electric Water Heater (EHW)	Rs	2700		2700	
Initial Cost of the (AC + EWH)/HP	Rs	38700	44000	27700	33000
EWH Capacity	kW	3.00		3.00	
HP Heating Capacity	kW		3.11		3.13
Cooling Capacity	kW	5.06	5.67	5.07	5.47
Hours of Operation of EWH	h/yr	730		730	
Hours of Operation of HP in AC + WH Mode	h/yr	704		700	
Hours of Operation of AC/HP in AC Mode	h/yr	1750	963	1746	995
Power Consumption of the AC/HP	kW	1.82	1.60	2.06	1.89
Cooling COP of the AC/HP		2.78	3.55	2.46	2.85
Heating COP of the EWH/HP		1.00	1.95	1.00	1.65
Total Utility Produced (Heating + Cooling)	kW	8.06	8.79	8.07	8.60
Total Power Consumption by (AC + EWH)/HP	kW	4.82	1.60	5.06	1.89
Overall COP of the (AC + EWH)/HP		1.67	5.49	1.59	4.55
Air Conditioning Requirement 8870	kWh/yr				
Required Hours of Operation	h/yr	1750	1667	1746	1695
Total Power Consumption for Cooling	kWh/yr	3185	2879	3597	3372
Cost of Electricity @ Rs 6 per kWh	Rs/yr	19110	17274	21582	20234
Saving in Cost of Electricity	Rs/yr		1836		1348
Water Heating Requirement 2190 kWh/	kWh/yr				
Required Hours of Operation	h/yr	730	704	730	700
Total Power Consumption for Water Heating	kWh/yr	2190	0		
Cost of Electricity @ Rs 6 per kWh	Rs/yr	13140	0	2190	0
Saving in Cost of Electricity	Rs/yr		13140		13140
Total Saving (Cooling + Heating)	**Rs/yr**		**14976**		**14488**
Extra Investment for Heat Pump	**Rs**		**5300**		**5300**
Expected Payback	**months**		**4.2**		**4.4**

Conclusions

A novel heat pump (HP) was developed at Heat Pump Laboratory, IIT Bombay, which is capable of catering to air conditioning, heating tap water to 45°C and cooling potable water to 15°C. HPs have been designed to cater to the domestic and the light commercial market with nominal airconditioning capacity of 1, 1.5 and 2 TR in window and split models.

The test results for both window and split HP in different modes shows that the cooling capacity is increased by 3.9 to 12.19 % and the cooling COP is enhanced by 10.98 to 27.9 % compared to conventional air conditioning systems. Performance of the HP reverts to that of conventional ACs when hot and cold water is not tapped.

Payback period for the SHP works out to be 4.2 months and that for WHP works out to be 4.4 months for the commercial application without accounting for 100% depreciation available for these energy saving devices. Cost of the HPs will actually work out to be lower than that of conventional WAC/SAC + EWH option. Thus, the user can benefit from both, lower initial cost and lower operating cost.

Economic analysis for a domestic application, where the unit cost is about Rs 3/kWh as compared to Rs 6/kWh, will offer payback periods in the range of 8.4 to 8.8 months.

Hence the novel Split and Window HPs can be used effectively for both residential and commercial purposes. These HPs can also prove to be very attractive for industrial applications when properly engineered.