PROMISE AND POTENTIAL OF AIR-TO-AIR ENERGY RECOVERY SYSTEMS

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ABSTRACT

This paper describes and discusses the principles, advantages, and disadvantages of several types of air-to-air energy recovery devices including the open and closed run-around systems, the heat pipe exchanger, the thermal wheel, and the plate exchanger. Emphasis is placed on the potential energy savings in heating and cooling equipment and fuel costs by recovering energy from exhaust air before it is thrown away. Results indicate annual energy savings up to 23% with even larger savings in the size of the heating and cooling equipment. As expected, greatest savings occur when large amounts of outside air are required for ventilation.

INTRODUCTION

Increased energy costs have brought about increased concern by building owners about the operating cost and energy budgets for buildings. This growing energy conservation consciousness has brought about many changes in the attention focused on the energy performance of buildings, particularly that of the heating, ventilating, and air-conditioning system--hereafter abbreviated HVAC system. The use of energy recovery equipment must now be considered in the design of all cooling and heating systems for commercial, industrial, and institutional buildings. Even residences are becoming candidates for ventilation system energy recovery (1).

Air-to-air heat recovery devices are a very important consideration for energy conservation since they can be used for retrofit projects as well as in new construction. This is not always the case with many of the other types of heat recovery concepts which involve changes in the major HVAC components as well as in the basic system design. In many cases, the addition of air-to-air heat recovery heat exchangers can be made with a minimal amount of building changes and/or system alterations. Payback is attractive now and doubly attractive over the life of the energy recovery system.

Air-to-air heat recovery exchangers find use in at least three different areas of application: process-to-process energy transfer, process-to-comfort energy transfer, and comfort-to-comfort energy exchange. Various processes which might be served by those types of heat exchangers include: food and grain dryers, foundry furnaces, laundry dryers, textile ovens, laboratory exhausts, paint spraying booths, etc. Various types of comfort heating-, ventilating-, and air-conditioning (HVAC) applications are: apartment buildings, banks, office buildings, hospitals, industrial plants, schools, restaurants, department stores, hotels, etc. Process-to-process and process-to-comfort conditions are quite varied and each application usually has unique features which preclude general quantitative conclusions on their energy savings potential. The study reported herein is concerned with comfort-to-comfort heat recovery.

Many types of heating, cooling, and ventilating equipment are available and in use for inclusion in unitary or centrally integrated air-conditioning systems. Such systems may provide full year-round environmental control or only seasonal functions such as heating or

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TYPES OF AIR-TO-AIR EXCHANGERS

There are at least five different types of air-to-air heat recovery exchangers commercially available for HVAC applications. These types are commonly identified as: rotary, coil loop run-around, open run-around, heat pipe, and plate type. There are many commercially available units of each type as well as hybrid modifications of some of the basic unit types. A good description of these devices, construction materials, controls, selection procedures, and operating cost analyses is given in the ASHRAE HANDBOOK, 1979 Equipment Volume (3) as well as in the SMACNA manual (2).

The basic types of units are listed with some of their characteristics in Fig. 5, and are briefly described in the following paragraphs.

Rotary. A rotary air-to-air regenerative heat exchanger (commonly called a heat wheel) is a mechanically revolving cylinder composed of an air permeable material having a large surface area exposed to the air. As the cylinder is rotated, it is alternately heated and cooled by the two air streams passing through the unit. If the transfer of latent heat is desired, the wheel media is treated to make it hygroscopic. Some cross contamination can exist between the supply and exhaust streams, but the purge section minimizes the mixing of the two streams. The unit does require a drive unit and the speed of the drive is used to control frosting conditions as well as supply air temperature. The supply and exhaust air streams have to be brought together in order to use the rotary type of heat recovery device.

Coil Loop Run-Around. The coil loop run-around type uses standard extended surface, finned-tube water coils with a circulation pump. Sensible heat only is transferred between the air streams by alternately heating and cooling the circulated fluid (usually an anti-freeze solution). There is no cross-contamination of the air streams and frost control and supply air temperature control is usually accomplished with a three way control valve. The supply and exhaust air streams do not have to be brought together since the circulating fluid can be piped to each heat exchanger.

Open Run-Around. The open run-around type is a sensible and latent heat transfer system in which the energy transfer between air streams is accomplished by alternately contacting the supply and exhaust air streams with a hygroscopic liquid. The solution is usually a salt solution such as lithium chloride and water. The solution is continuously transported between the supply and exhaust air towers and transports both heat and moisture from one air stream to another. Frosting is not a problem and the control of the supply air temperature is usually accomplished by solution heaters and three-way control valves. Make-up water must be piped to the unit in order to control the solution concentration. The supply and exhaust air streams do not have to be brought together.

Heat Pipe. The heat pipe type of recovery unit is in appearance like a dehumidification coil with a partition separating the face into two equal sections. The supply air flows through one side of the heat exchanger while the exhaust air flows counterflow through the other side of the heat exchanger. The unit is composed of a set of finned tubes which are sealed at each end. Those tubes are the heat pipes. Each heat pipe consists of the outer tube, a wick material and a working fluid (R-12 is common). When heat is applied at one end, evaporation of the working fluid occurs and the vapor flows to the cold end where it is condensed. The condensed working fluid is then transported by capillary action to the warm end where the cycle is completed. The heat pipe type of unit recovers sensible heat only and it has no cross contamination. No auxiliary pumps or drives are necessary and frost and temperature control can be accomplished with tilting at the unit or by-passing air around a portion of the unit. Heat pipe devices require that the supply and exhaust air streams be brought together.

Plate. The plate type air-to-air heat recovery devices contain fixed surfaces for sensible heat transfer and may be made of metal, plastic, composition fiber, and even papter materials. Normally, the supply and exhaust air streams are cross-flow or counterflow and there is no contamination of the two air streams. No auxiliary pumps or drives are necessary and frost and temperature control can be accomplished with bypass of the air streams. Plate-type devices require that the supply and exhaust air streams be brought together.

Research is currently underway on a sixth types of device, the *thermosiphon* exchanger, (Fig. 6), under ASHRAE RP-188-Multiple Tube Evaporator and Condenser Thermosiphon Loops at the University of Windsor. The difference between heat pipe and thermosiphon is that in the heat pipe, capillary force ensures liquid return to the evaporator end of the tube; with the thermosiphon, gravity is relied upon to return liquid to the evaporator end, so orientation is more critical.

The energy recovery device effectiveness numerical value, when computed with sensible heat transferred/total heat potential, will be smaller than when both values are sensible heat (sensible heat transferred/sensible heat potential).

Care must be taken when working with effectiveness values. High sensible heat effectiveness for a device does not mean it has high total heat effectiveness and vice versa.

TYPICAL PERFORMANCE OF ENERGY RECOVERY DEVICES

The basic types of air-to-air heat recovery devices will exhibit similar performance trends; however, their quantitative results can be quite different. Fig. 9 depicts typical variations in effectiveness for unequal flow rates between the exhaust and supply sides for an air-to-air heat exchanger. Also shown in Fig. 9 is how a reduction in flow rate can increase the effectiveness. In Fig. 10, the typical variation of effectiveness with face velocity is shown. The benefits of low air velocities are very evident in the quantitative value for the heat recovery effectiveness. Also shown in Fig. 10 is the pressure drop which would occur for the heat recovery device. This additional pressure loss in the system due to the heat recovery device is an additional expense which must be borne by the heat recovery system.

ENERGY SAVING SIMULATIONS

The potential energy savings brought about by the utilization of air-to-air heat recovery devices in HVAC systems depends on many factors. Some of the most obvious factors are: efficiency of the device, local weather conditions, type of HVAC system being used, quantity of outdoor air required for ventilation, type of control process for the heat recovery device, etc.

An attempt has been made to find the effect of heat recovery on the first cost and operative costs by simulation of conditions for an existing building by using different heat recovery devices for the following types of air-conditioning systems:

- Reheat
- Induction
- Variable Volume.

The AXCESS (5) Energy Analysis Computer Program used in the study evaluates building energy requirements on an hour-by-hour basis for a full year, using local weather data (dry-bulb temperature, relative humidity, cloud cover), building operating profiles, and base load usage profiles. Although the HVAC energy is the one of concern here, the cost of energy is very much predicated on the combination of all energy using devices in the structure. AXCESS determines total energy consumption of HVAC systems and other energy consuming devices.

The building simulated was modeled after an existing two-story all-electric office building located in St. Louis, MO. The building had a roof area of 22,810 ft^2 (2119 m^2), total wall area of 9,460 ft^2 (879 m^2), total glass area of 7,536 ft^2 (700 m^2), gross floor area of 45,620 ft^2 (4238 m^2), and a ceiling height of 9 ft (2.74 m). The design loads are given in Table 1. First, the building was simulated as it was designed and built in order to illustrate the effect of heat recovery for both heating and cooling using the existing type of HVAC terminal system, all electric reheat.

TABLE 1

Test Building Design Loads (Btuh)	
SUMMER	WINTER
Glass Solar = 139,852 (41 kW)	
Glass - Solar and Transmission = 246,353 (72 kW)	Glass - Transmission = 425,604 (125 kW)
Walls - Solar and Transmission = 44,522 (13 kW)	Walls - Transmission = 178,088 (52 kW)
Roof - Solar and Transmission = 257,644 (75.5 kW)	Roof - Transmission = 429.407 (126 kW)

REFERENCES

1. Shoukri, M., "The Use of a Regenerative Air-to-Air Rotary Heat Exchanger for Heat Recovery in Residential Ventilation Systems," ASME Paper 79-WA/HT-32, ASME Winter Annual Meeting, December 2-7, 1979.

2. , ENERGY RECOVERY EQUIPMENT AND SYSTEMS, AIR-TO-AIR, Sheet Metal and Air Conditioning Contractors National Association, Inc., Vienna, Virginia, 1978.

3. ASHRAE HANDBOOK, 1979 Equipment Volume, Chap. 37, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, New York, 1979.

4. Bowlen, K. L., "Energy Recovery from Exhaust Air," ASHRAE Journal, April 1974.

5. Reeves, G., "Engineers Now Have Axcess to AXCESS," Actual Specifying Engineer, p. 99, December 1972.

TABLE 2

Annual HVAC Energy Consumption and Unit Sizes

A. SINGLE ZONE REHEAT SYSTEM

OUTSIDE PRIMARY AIR %	MAXIMUM RECOVERY EFFICIENCY %	HVAC ENERGY 10^6KWH	SAVINGS,%	BOILER SIZE 10^6BTUH	SAVINGS,%	CHILLER SIZE 10^6BTUH	SAVINGS,%
50	0	2.94	0	1.60	0	2.39	0
50	25	2.86	3	1.24	23	2.28	5
50	50	2.81	4	1.05	34	2.18	9
50	75	2.78	5	1.05	34	2.08	13
50	100	2.77	6	1.05	34	1.98	17
100	0	3.72	0	3.05	0	3.49	0
100	25	3.34	10	2.32	24	3.29	6
100	50	3.04	18	1.60	48	3.08	12
100	75	2.91	22	1.05	66	2.88	17
100	100	2.87	23	1.05	66	2.68	23

B. FOUR PIPE INDUCTION SYSTEM

OUTSIDE PRIMARY AIR %	MAXIMUM RECOVERY EFFICIENCY %	HVAC ENERGY 10^6KWH	SAVINGS,%	BOILER SIZE 10^6BTUH	SAVINGS,%	CHILLER SIZE 10^6BTUH	SAVINGS,%
50	0	2.33	0	0.68	0	1.78	0
50	25	2.32	0	0.64	6	1.73	3
50	50	2.31	1	0.64	6	1.68	6
50	75	2.31	1	0.64	6	1.63	8
50	100	2.31	1	0.64	6	1.48	17
100	0	2.55	0	1.39	0	2.33	0
100	25	2.42	5	1.03	26	2.23	4
100	50	2.36	7	0.68	51	2.13	9
100	75	2.35	8	0.64	54	2.03	13
100	100	2.34	8	0.64	54	1.93	17

C. VARIABLE AIR VOLUME (WITH REHEAT)

OUTSIDE PRIMARY AIR %	MAXIMUM RECOVERY EFFICIENCY %	HVAC ENERGY 10^6KWH	SAVINGS,%	BOILER SIZE 10^6BTUH	SAVINGS,%	CHILLER SIZE 10^6BTUH	SAVINGS,%
50	0	1.55	0	0.93	0	2.09	0
50	25	1.52	2	0.79	15	2.00	4
50	50	1.50	3	0.71	24	1.91	9
50	75	1.49	4	0.64	31	1.83	12
50	100	1.49	4	0.64	31	1.74	17
100	0	1.86	0	1.58	0	3.03	0
100	25	1.71	8	1.24	22	2.86	6
100	50	1.60	14	.93	41	2.69	11
100	75	1.55	17	.71	55	2.51	17
100	100	1.54	17	.64	59	2.34	23

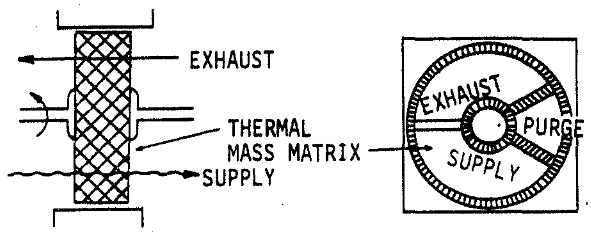
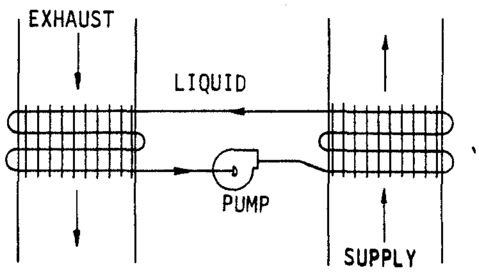
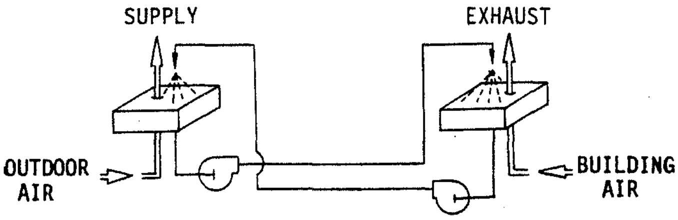
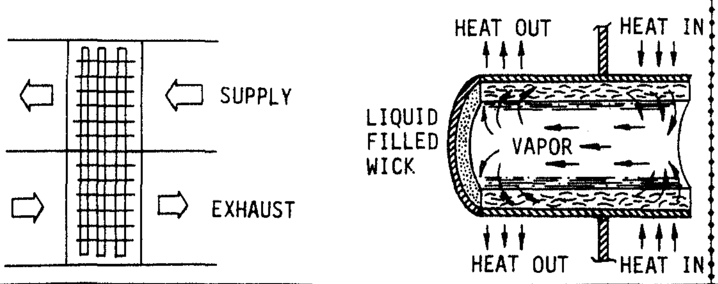
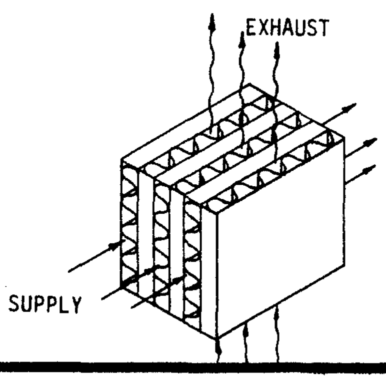
SCHEMATICS	FEATURES
	**Rotary** SENSIBLE AND LATENT HEAT RECOVERY MINIMAL CROSS CONTAMINATION PURGE SECTION REQUIRED MECHANICAL DRIVER REQUIRED FROST CONTROL AVAILABLE CLOSE PROXIMITY OF SUPPLY AND EXHAUST
	**Coil Loop Runaround** SENSIBLE HEAT RECOVERY NO CROSS CONTAMINATION PUMP REQUIRED FROST CONTROL AVAILABLE FLEXIBILITY OF EXHAUST AND SUPPLY
	**Open Runaround** SENSIBLE AND LATENT RECOVERY NO CROSS CONTAMINATION PUMP REQUIRED MAKE-UP WATER REQUIRED FLEXIBILITY OF EXHAUST AND SUPPLY
	**Heat Pipe** SENSIBLE HEAT RECOVERY NO CROSS CONTAMINATION NO PUMPS OR DRIVES REQUIRED FROST CONTROL AVAILABLE CLOSE PROXIMITY OF SUPPLY AND EXHAUST
	**Plate** SENSIBLE HEAT RECOVERY NO CROSS CONTAMINATION NO PUMPS OR DRIVES REQUIRED FROST CONTROL AVAILABLE CLOSE PROXIMITY OF SUPPLY AND EXHAUST

Fig. 5 Types of energy recovery devices

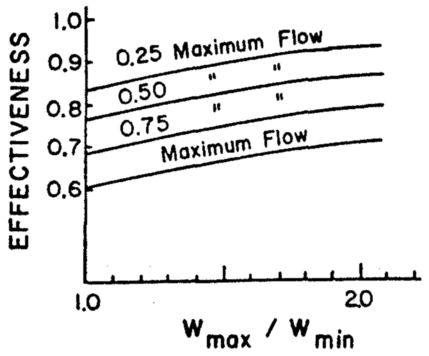


Fig. 9 Typical effectiveness variation for unequal flows

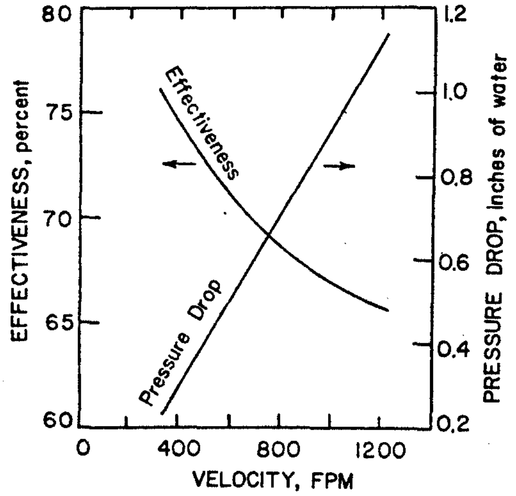


Fig. 10 Typical pressure drop and effectiveness for heat recovery devices

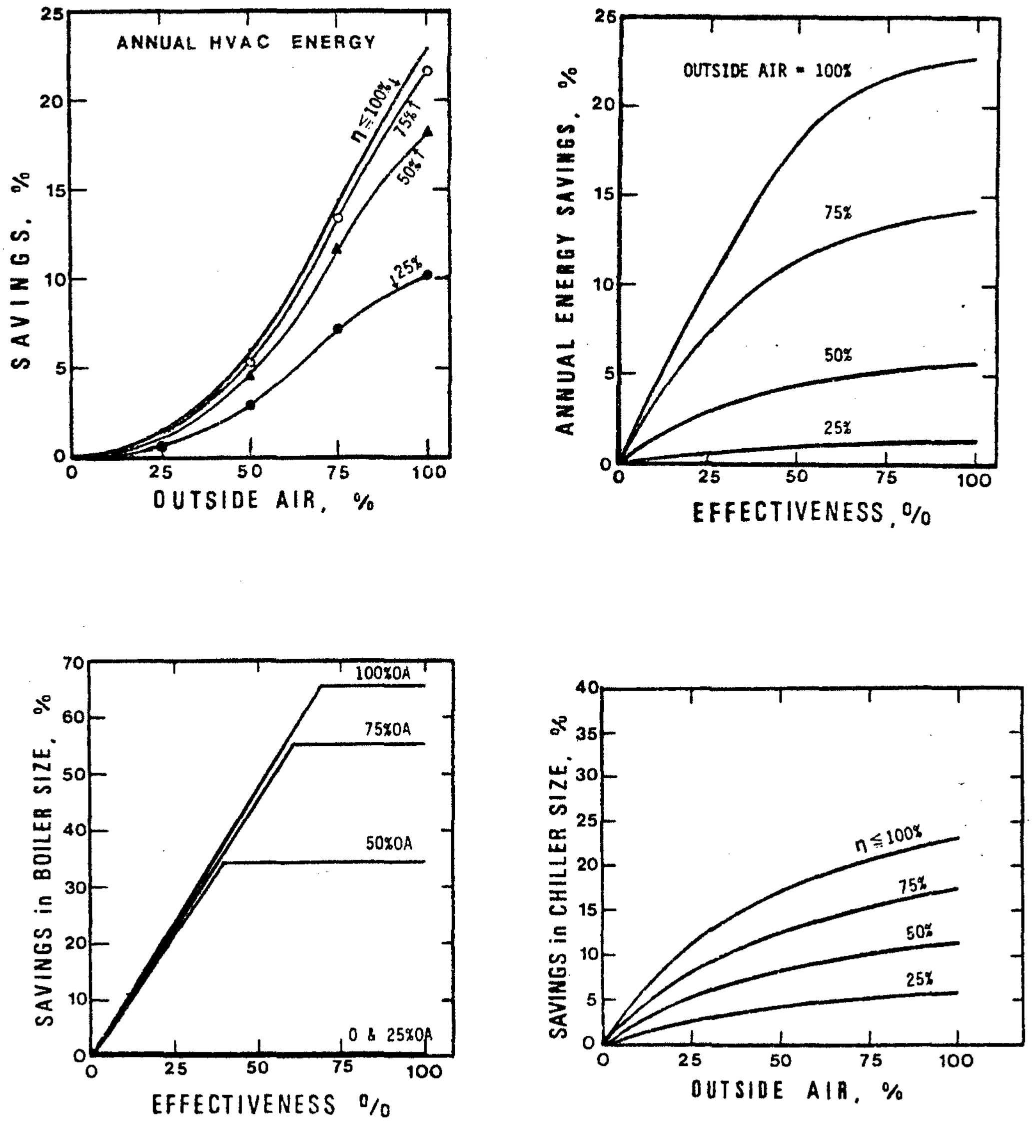


Fig. 11 Potential savings with reheat system

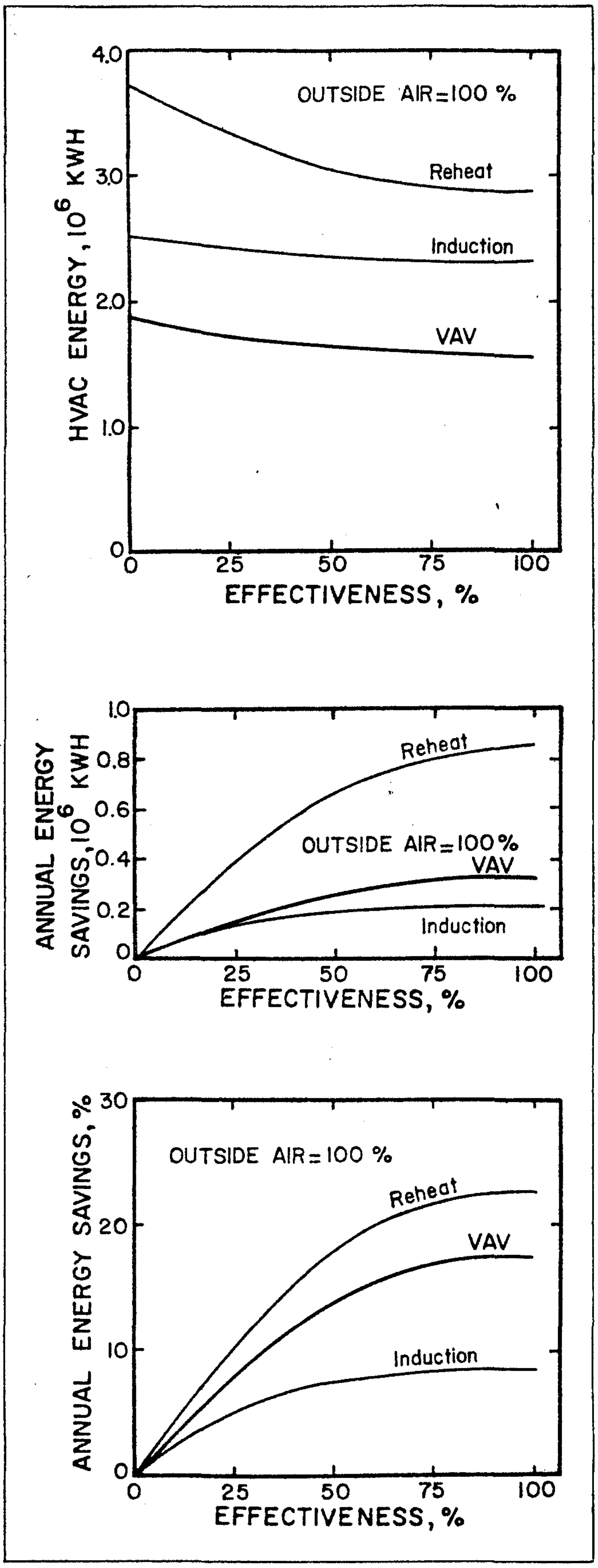


Fig. 13 Potential energy savings with various HVAC systems

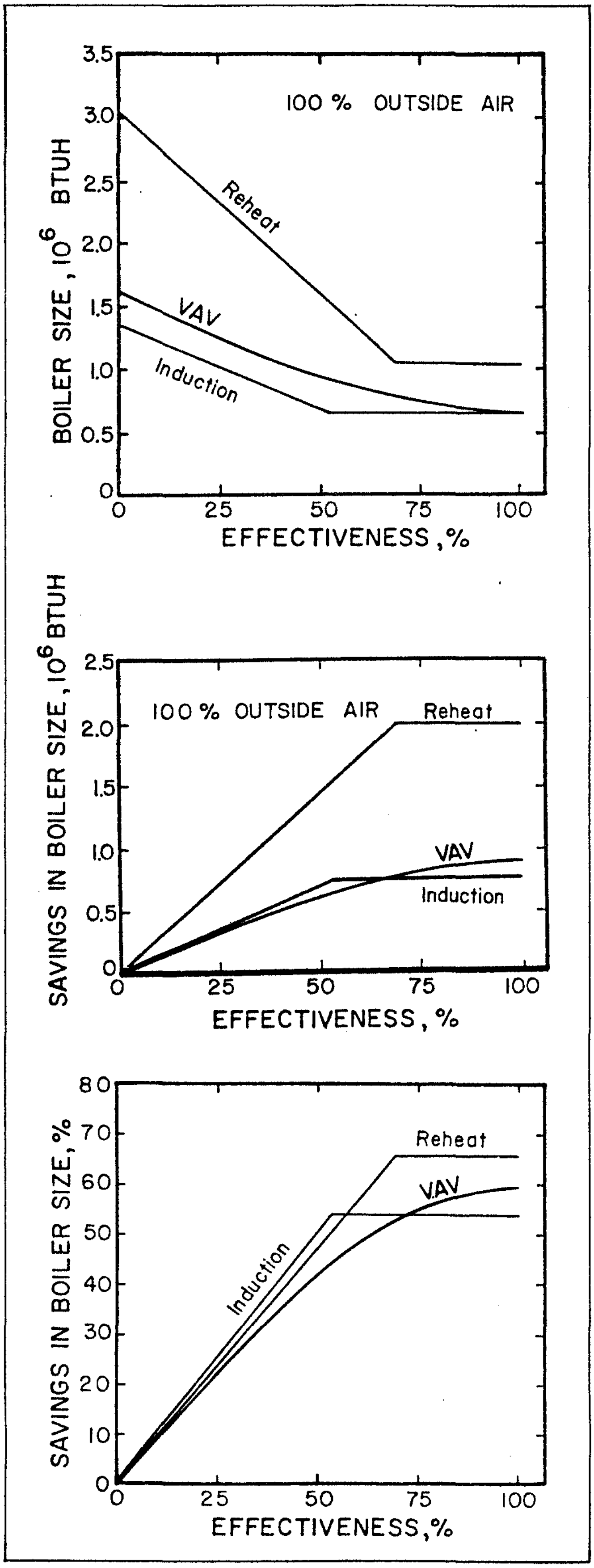


Fig. 14 Potential boiler size savings with various HVAC systems