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Heat Recovery Devices For Building HVAC Systems

Ronald H. Howell

Harry J. Sauer Jr.
Missouri University of Science and Technology

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Ronald H. Howell and Harry J. Sauer, Jr. Professors
Department of Mechanical and Aerospace Engineering
University of Missouri - Rolla
Rolla, Missouri

Abstract

The opportunities and advantages of air-to-air heat recovery are described. The five basic types (rotary regenerative, coil loop run around, open run-around, heat pipe, and plate type) are described and their typical performance is presented. The potential savings in operating costs as well as initial equipment costs for common applications are presented.

1. INTRODUCTION

There is no doubt that our nation faces an energy crisis. Whether contrived or not there is a fuel shortage. If nothing is done soon to reduce our shameful waste of energy, the affluence of every American who lives through the next decade will be affected substantially.

This recent need and concern for energy conservation has generated a great amount of interest in the energy efficiency of building heating, ventilating, and air conditioning (HVAC) systems. In the past, and still in many cases today, architectural features and construction cost considerations dominated building design. Consequently, from an energy conservation viewpoint, the majority of existing buildings have been designed in such a manner as to require large quantities of energy in their operation. Rising energy costs have resulted in increased concern by owners about energy costs and may result in legislated energy budgets for buildings. This concern has motivated HVAC system designers and equipment manufacturers to consider expanded utilization and more rapid development of air-to-air heat recovery devices.

Heat recovery considerations applicable to building design are quite numerous and, in some cases, extremely complex. In addition innovative concepts are generated quite frequently. Examples of heat recovery concepts include: air-to-air heat recovery exchangers, double bundle condensers, simultaneous heat pumps, air cooled condenser heat recovery, and condenser heat storage systems. This paper deals only with the air-to-air heat recovery exchanger concept.

Air-to-air heat recovery devices are a very important consideration for energy conservation since they can be used for new construction as well as in retrofit projects. 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.

2. OPPORTUNITIES FOR HEAT RECOVERY

At this point, it is necessary to say a few words about the interaction of these air-to-air energy recovery systems with conventional types of HVAC systems. A few examples of several HVAC systems are shown in Figures 1, 2, and 3.

Although these systems can be seen to differ substantially from one another in the method of meeting the needs for the spaces to be conditioned, they all have at least one feature in common. Exhaust air is

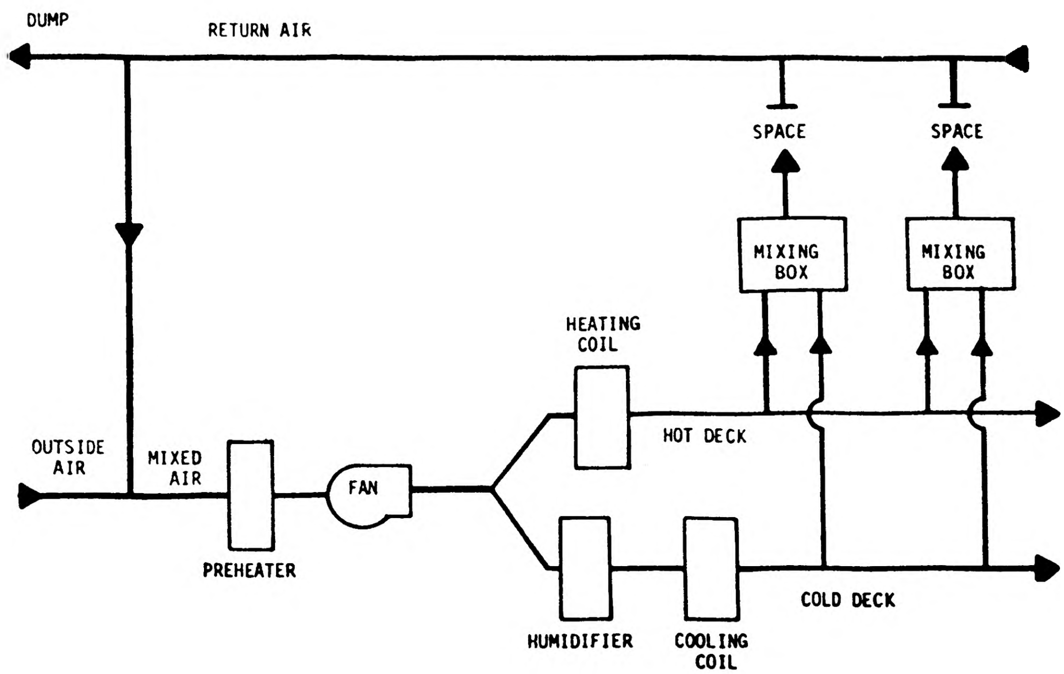


Figure 1 Double Duct or Multi-Zone System

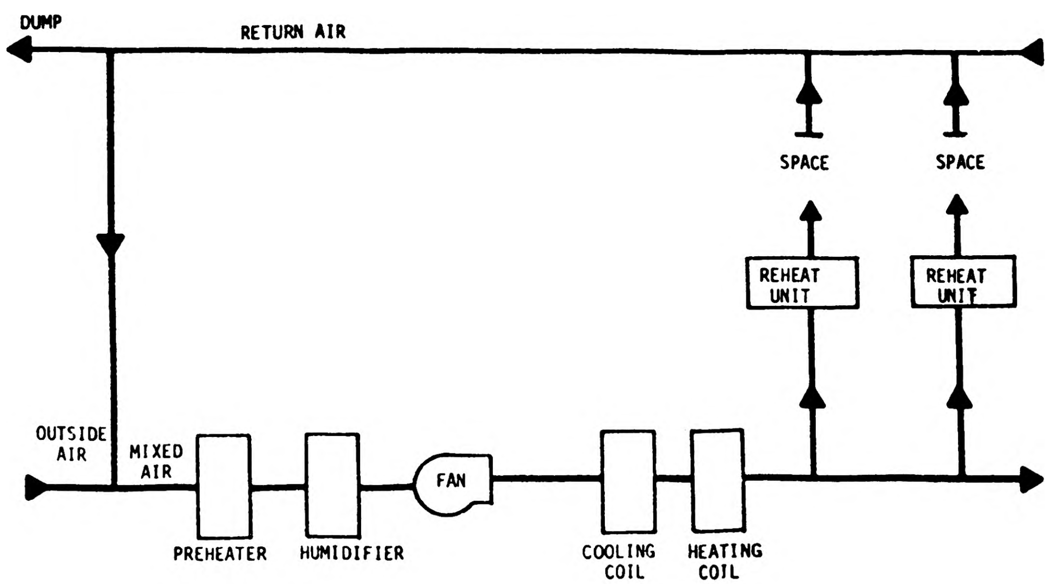


Figure 2 Single Zone Reheat System

dumped to the outside in order to make room for outside ventilation air. The exhaust air is close to the desired comfort conditions, whereas the incoming outside air maybe far from the desired conditions of humidity and temperature. During the summer the ventilation air can be hot and humid while the winter months it can be cold and dry. Treatment of this outside air is a must if comfort conditions are to be maintained. As shown in Figure 4, an air-to-air heat exchanger can be inserted in the system for pretreatment of the ventilation air using the discharged exhaust air.

3. AIR-TO-AIR HEAT RECOVERY DEVICES

There are at least five different types of air-to-air heat recovery exchangers com-

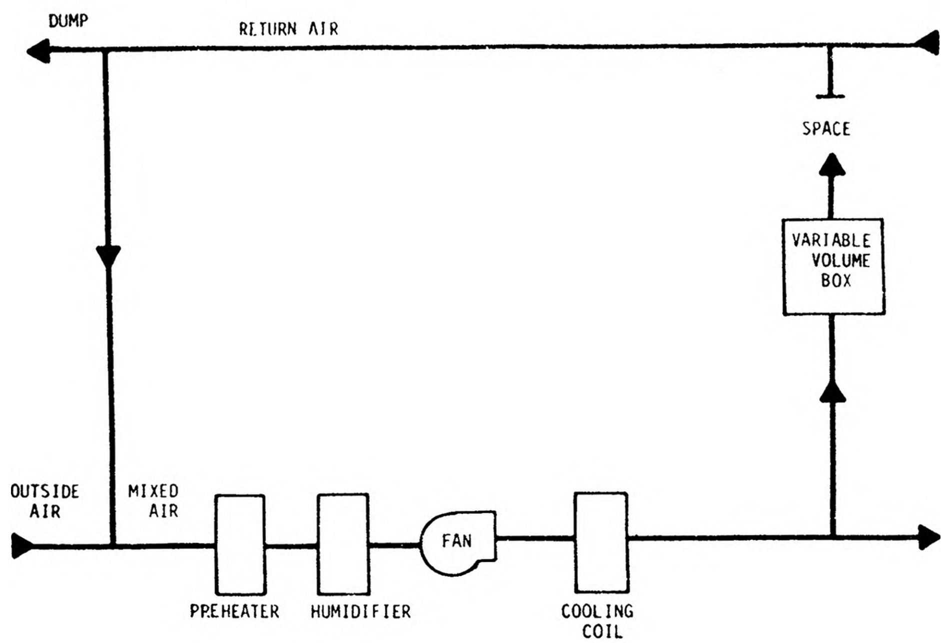


Figure 3 Variable Volume System

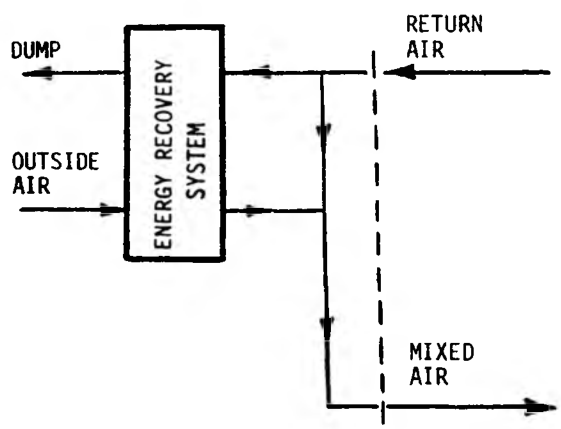


Figure 4 Addition of Energy Recovery System to an HVAC System

mercially 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.

The five basic types of units and their individual features are shown in Figure 5 and briefly described in the following paragraphs.

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 can use the speed of the drive 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.

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.

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 hy-

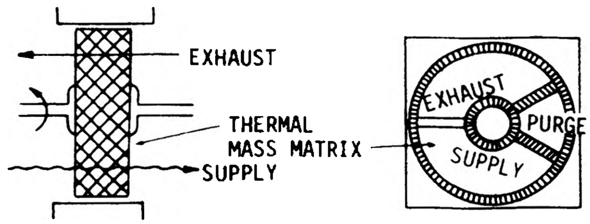
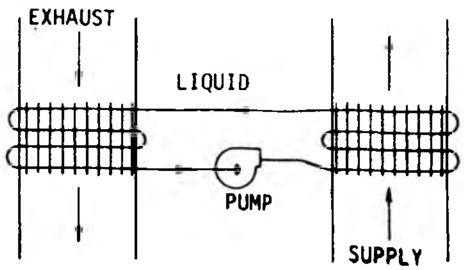
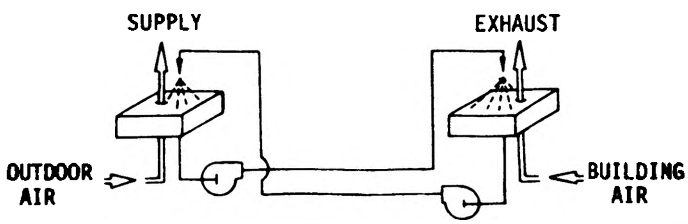
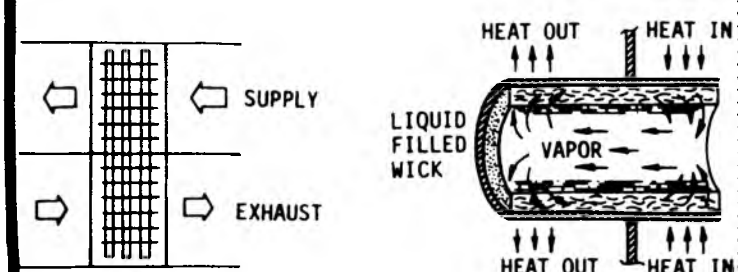
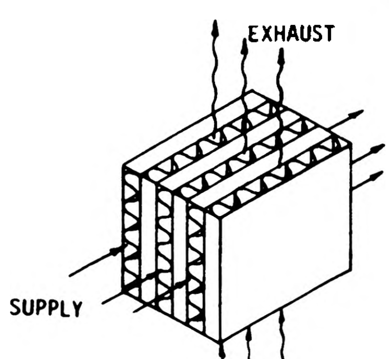
SCHEMATICS	FEATURES
	**Rotary** SENSIBLE AND LATENT HEAT RECOVERY MINIMAL CROSS CONTAMINATION PURGE SECTION REQUIRED MECHANICAL DRIVER REQUIRED FROSTING LIMITATIONS CLOSE PROXIMITY OF SUPPLY AND EXHAUST
	**Coil Loop Runaround** SENSIBLE HEAT RECOVERY NO CROSS CONTAMINATION PUMP REQUIRED FROST CONTROL 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

Figure 5 Types of Air-to-Air Heat Recovery Devices

groscopic 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.

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 (see Figure 5). 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. This arrangement is depicted in Figure 5. 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.

The plate type air-to-air heat recovery devices contain fixed surfaces for sensible heat transfer and may be made of metal, plastic, or composition fiber 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 by-pass of the air streams. Plate type devices require that the supply and exhaust air streams be brought together.

4. EFFECTIVENESS OF AIR-TO-AIR HEAT RECOVERY DEVICES

For a number of years air-to-air heat exchangers have been rated by using a term called efficiency. In applications where the exhaust air mass flow is less than the supply air mass flow the efficiency expression leads to an erroneous criteria of performance.

The effectiveness is defined as the ratio of the actual heat transfer to the thermodynamically limited maximum heat transfer in a counter-flow heat exchanger with infinite transfer area. A schematic diagram of an air-to-air heat recovery exchanger is shown in Figure 6.

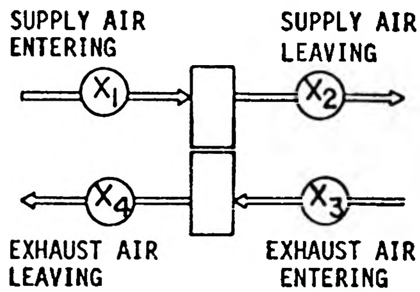


Figure 6 Schematic diagram of air-to-air heat recovery exchanger

Effectiveness is defined by

$$\eta \equiv \frac{W_s(X_1 - X_2)}{W_{min}(X_1 - X_3)} \qquad (1)$$

where

η = sensible, latent, or total heat effectiveness

X = dry-bulb temperature, humidity ratio, or enthalpy respectively

W_s = mass flow rate of supply air

W_e = mass flow rate of exhaust air

W_{min} = minimum value of W_s or W_e

Efficiency would be evaluated as

$$e = \frac{X_1 - X_2}{X_1 - X_3} \qquad (2)$$

where

e = sensible, latent or total efficiency

The use of effectiveness can accomodate sensible as well as total heat transfer devices. In addition, it properly accounts for unequal mass flow rates through the two sides of the heat exchanger device. For the case of equal air flows, the terms effectiveness and efficiency are identical.

5. TYPICAL PERFORMANCE RESULTS

The five basic types of air-to-air heat recovery devices will exhibit similar performance trends; however, their quantitative results can be quite different. Figure 7 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 Figure 7 is how a reduction in flow rate can increase the effectiveness.

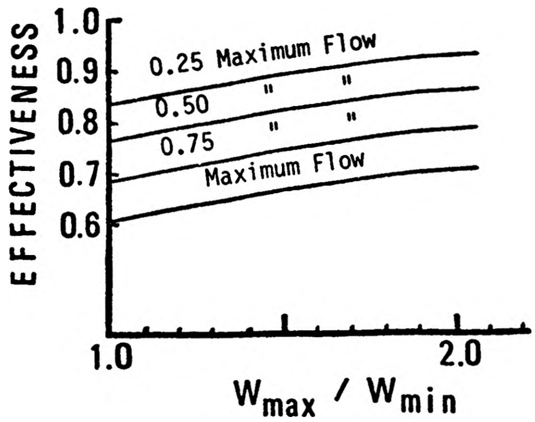


Figure 7 Typical Effectiveness Variation for Unequal Flows

In Figure 8 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 Figure 8 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.

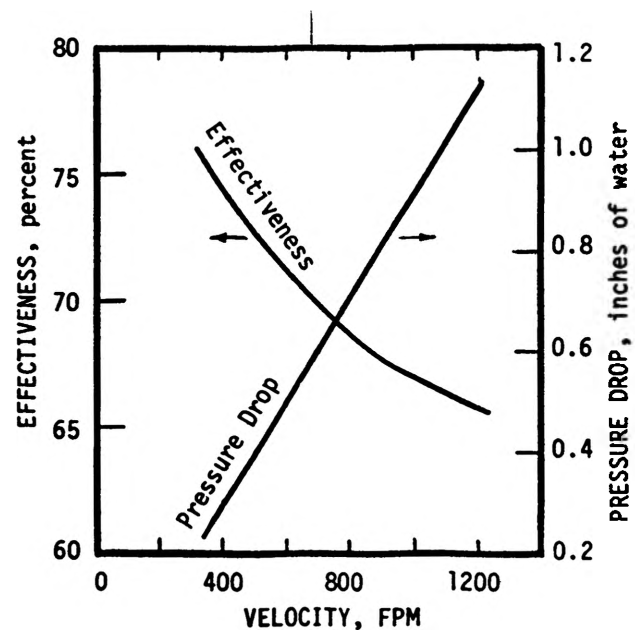


Figure 8 Pressure Drop and Effectiveness for a Heat Recovery Device

6. POTENTIAL SAVINGS

With the recent developments in air-to-air heat recovery exchangers, an energy recovery system should be considered not only in the design of new buildings but also for retrofit in existing buildings. However, fuel savings would be augmented by equipment savings if the heat recovery unit is installed when the building is built or when a new air-conditioning system is installed.

As a preheater of supply air, these energy recovery devices can typically recover 60% of the energy in the exhaust air. Exhaust air at a temperature of 70°F could preheat supply air from 0°F to 42°F. As a precooler in the air conditioning system, the exchanger could reduce the temperature of supply air from 95°F to 80°F given the same efficiency and an exhaust air temperature of 70°F.

In a recent publication [1] the authors presented the energy savings potential of HVAC air-to-air heat recovery exchangers. These savings were evaluated using the AXCESS-UMR Energy Analysis Program for a typical two-story office building located in St. Louis, Missouri. The building had a reheat type of HVAC system. The exterior zones of this test building were analyzed separately in order to illustrate the greater potential for heat recovery for heating only situations. During the winter months cooling is not usually needed in the exterior zones of this building and therefore a significant quantity of reheat is needed for the exterior zones. In addition, with the reheat type terminal HVAC system, very seldom can the heat recovery system operate at maximum efficiency without over-recovery. The exterior zones were analyzed using the simulation for a heating and ventilating system. This system itself has no cooling provisions and would be inoperative during the summer season.

The percent of annual energy savings for the complete building as a function of the heat recovery device efficiency is shown in Figure 9. For 50% outside ventilation air up to 6% annual savings can be realized.

For the exterior zones only the potential for energy savings is much greater. These results are summarized in Figure 10. For 50% ventilation air up to 85% annual savings can be realized.

Since the use of an air-to-air heat recovery exchanger will save some energy which might be discarded, it will allow the installation of smaller heating and cooling equipment. As an example, the percent

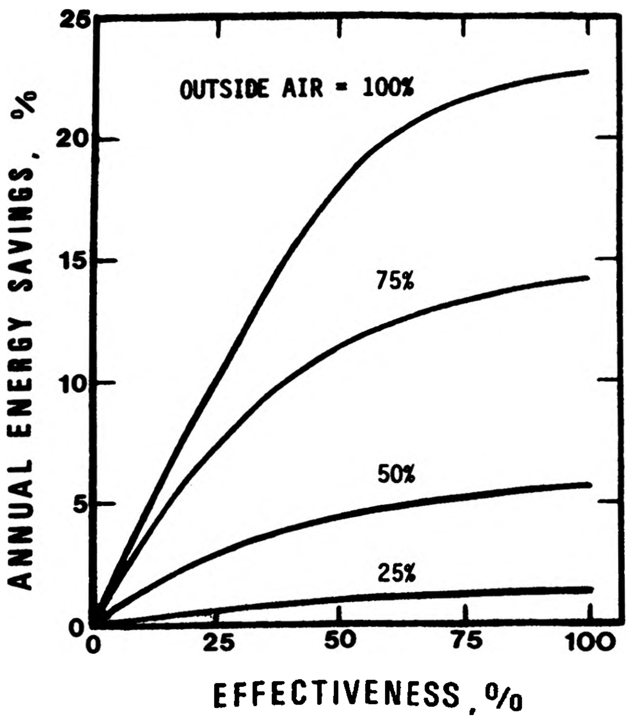


Figure 9 Annual Energy Savings for Complete Building

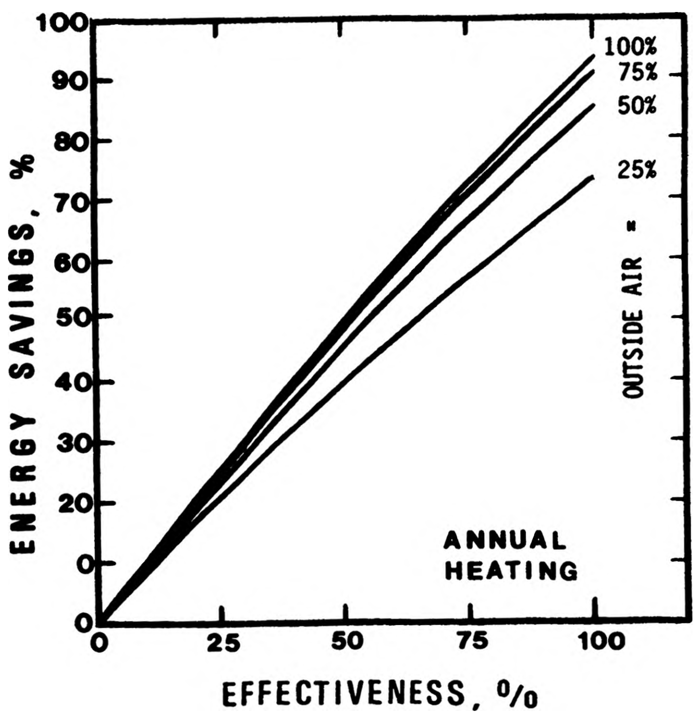


Figure 10 Annual heating energy savings for exterior zones

savings in boiler size for the complete building used in the previous calculation, are plotted in Figure 11.

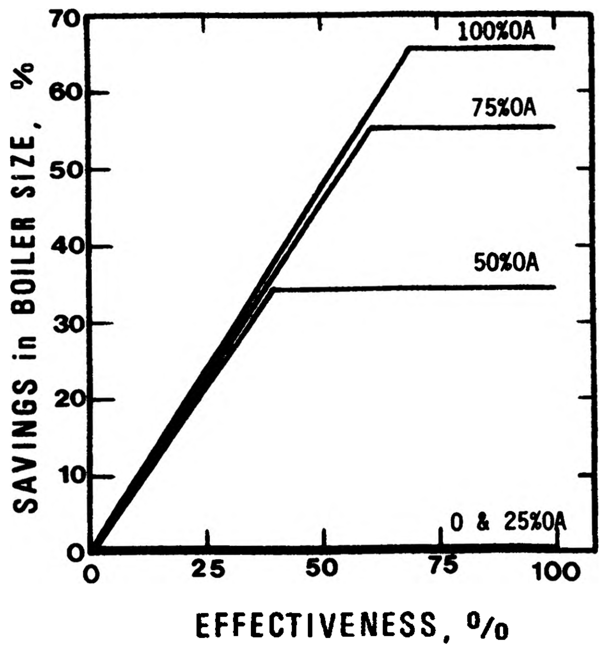


Figure 11 Savings in boiler size with energy recovery

Similar results are given in Figure 12 for the exterior zones only in the building. In all cases the base size was for the case without a heat recovery device.

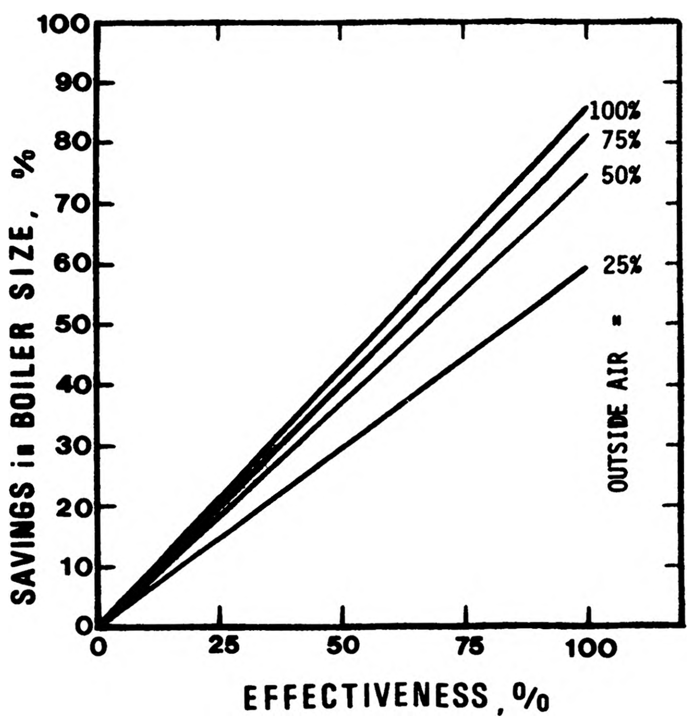


Figure 12 Savings in boiler size for exterior zones with heat recovery

These reductions in installed boiler size for high outdoor air flow rates are significant and substantially offset the cost of the air-to-air heat recovery exchanger.

HVAC applications of air-to-air heat recovery systems are demonstrating the significant energy savings possible with such systems. The thermal recovery system for a laboratory building reportedly saved 38 tons of cooling capacity and 900,000 Btuh of heating capacity. In another application, the combination of an air-to-air energy recovery system and sprayed on urethane foam wall insulation is calculated by the system designers to provide 54% of the heating and 45% of the cooling energy required at design conditions for the new University of North Carolina School of Medicine Building.

7. REFERENCE

1. Energy Savings Potential of HVAC Air-to-Air Heat Recovery Exchangers, H.J. Sauer, Jr. and R.H. Howell, presented at the 98th Winter Annual Meeting ASME, Nov. 27-Dec. 2, 1977, Atlanta, Georgia and included in Heat Transfer in Energy Conservation, Book No. H00106, ASME, New York, 1977.

8. BIOGRAPHIES

Ronald H. Howell is Professor of Mechanical Engineering at the University of Missouri-Rolla. He holds the B.S., M.S., and Ph.D. degrees from the University of Illinois. Dr. Howell has taught and conducted research in refrigeration, heating, and air-conditioning for over 17 years. He became a member of ASHRAE in 1969 and serves on several national committees of the society.

Harry J. Sauer, Jr. is Professor of Mechanical and Aerospace Engineering at the University of Missouri-Rolla. He holds the B.S. and M.S. degrees from the University of Missouri and the Ph.D. from Kansas State University. Dr. Sauer has been active in the environmental control field for over 19 years. He has been a member of ASHRAE since 1963 and serves on several national committees of the society.