



Ventilation Heat Recovery For Laboratories

By Otto VanGeet, P.E., and Sue Reilly, P.E.

Laboratories typically require 100% outside air at high ventilation rates—between 6 and 12 air changes per hour—primarily for safety reasons. The heating and cooling energy needed to condition this air, as well as the fan energy needed to move it, often is five times greater than the amount of energy used in most offices for these same purposes. Energy recovery can substantially reduce the mechanical heating and cooling requirements associated with conditioning ventilation air in most laboratories. As a result of the lower peak heating and cooling requirements with energy recovery, heating and cooling systems can be downsized.

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Many opportunities exist for energy recovery in laboratories. Energy recovery can occur between any two media or processes that differ in energy content. The focus of this article is on air-to-air energy recovery—using enthalpy wheels (*Figure 1*), heat pipes, or runaround loops in new construction.

Technology Overview

Air-to-air energy recovery devices exchange energy from one stream of air to another. Most commonly, energy is recovered from exhaust air and used to precondition supply air. National Fire Protection Association's NFPA 45: *Standard on Fire Protection for Laboratories Using Chemicals*, 2004 edition, states that, if there is a chance of cross contamination between airstreams, air-to-air energy recovery only can be used on general exhaust. The air contains sensible (heat) and latent (water vapor) energy. Both types of energy can be recovered.

However, not all recovery devices exchange both types of energy. The effectiveness of an energy recovery device is the ratio of actual energy recovered to theoretical energy that could be recovered. Most devices have a rating for sensible effectiveness. Some also have a rating for latent effectiveness and total effectiveness.

Energy recovery devices increase the pressure drop across the supply and exhaust fans. Enthalpy wheels generally have a lower pressure drop than heat pipes and runaround loops, although the pressure drop depends on the design. If exhaust filtration is required to protect the energy recovery device, filter pressure drop also must be considered. An additional pressure drop of no more than 1 in. w.g. (249 Pa) in the supply and exhaust airstreams is a reasonable design goal, and will minimize the increase in fan energy.

For laboratory applications, the design face velocity of devices in air-handling units is typically 500 fpm (2.54 m/s) or less. Lower face velocities result in lower pressure drops, higher effectiveness, and lower operating costs. The trade-off is larger air-handling equipment and higher first costs. An energy recovery device operates more efficiently with a variable air volume (VAV) system than with a constant volume system

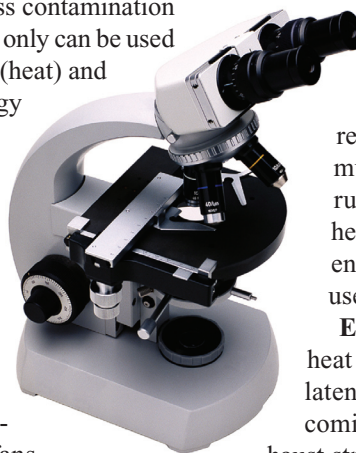
because VAV systems typically operate at face velocities lower than those of design conditions.

Frost can occur when the exhaust air contains sufficient moisture and the exhaust heat transfer surface temperature drops below freezing. Frost control must be considered in cold climates to keep the exhaust heat transfer surface temperature above freezing. Frost control can be accomplished by controls that limit energy recovery such as bypass dampers, flow controls on runaround loops, or tilt controls on heat pipes. Heat also can be added to runaround loops or preheat of outside air.

Before deciding on an energy recovery technology, laboratory managers are encouraged to perform life-cycle cost (LCC) analyses to determine the feasibility of the application in their laboratories. All energy recovery devices require maintenance, the cost of the maintenance must be considered in the LCC analysis. As a rule, the shortest payback periods occur when the heating and cooling load reduction provided by an energy recovery system allows the laboratory to use smaller hot water and chilled water systems.

Enthalpy Wheels. Enthalpy wheels, or rotary heat exchangers, transfer sensible or sensible and latent energy between the exhaust air and the incoming outside air (*Figure 1*). The supply and exhaust streams must be located next to each other. Both sensible-only wheels and total energy wheels, sometimes referred to as desiccant wheels, are available. A total energy wheel can have a sensible and latent effectiveness as high as 75%, which results in a total effectiveness of 75%. Control of the wheel at part loads is accomplished by varying the speed of the wheel, or using a bypass duct, or both.

The type of desiccant used in a total energy wheel must be designed to transfer only moisture and not airborne contaminants. To further reduce potential contamination of the supply airstream, the wheel is flushed with outside air that is



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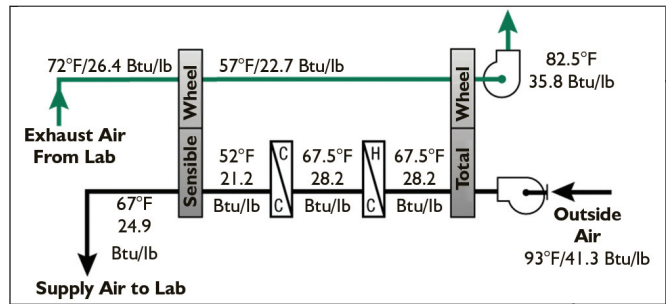
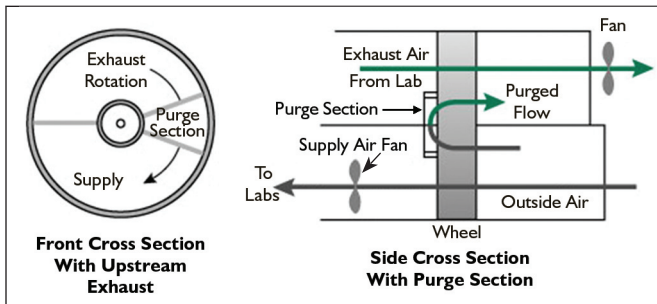


Figure 1 (left): Cross section (front and side) of enthalpy wheel with purge section. Figure 2 (right): Two energy recovery wheels at sea level with equal supply and exhaust airflows.

deflected by a damper in the purging section of the rotor. The damper redirects supply air leaving the wheel to the inlet side of the wheel exhaust. The purge section uses the pressure difference between the supply air and exhaust airstreams (Figure 1). Purge volumes for laboratory applications typically are between 5% and 10%, so additional fan energy is required to move this air.

The maximum relative humidity (RH) allowed in most labs is 50%. In many climates, removing moisture (latent energy) from the air is a significant energy use. An enthalpy wheel can remove a significant amount of latent energy as shown in Figure 2, but to achieve 50% RH at 72°F (22°C), the supply air must be cooled to 52°F (11°C). If the lab has significant latent heat gain, the supply air would need to be even dryer (colder)

Key Issues on Energy Recovery in Laboratories

Integration of energy recovery into a laboratory ventilation system requires careful consideration of some key issues. Design teams have taken different approaches to handling these issues, which demonstrates the importance of considering all options.

Contamination. If cross contamination from fume hood exhaust is an issue, consider heat pipes, runaround loops or plate-type energy recovery. Another approach is isolating the fume hood exhaust and recovering energy from the general exhaust only. Note that the chemicals in the fume hood exhaust may become too concentrated and require additional treatment. Purge sections on enthalpy wheels reduce cross contamination to below 0.1%, according to ASHRAE.³ No cross contamination issues occur with heat pipes or runaround loops.

Space Requirements and Duct Adjacencies. Enthalpy wheels and most types of heat pipes require the main supply and exhaust ducts to be adjacent. Runaround loops do not. Additional space is required for the energy recovery device, typically in the makeup air unit and main exhaust duct. Runaround loops also require space for a pump. Manifold exhaust systems are ideally suited to energy recovery because all the potentially available energy can be captured by one energy recovery system.

Hazardous Chemicals. If isolating the fume hood exhaust or condensate from a heat recovery device results in too high of a concentration of volatile organic compounds, disposal could become a problem. Potential hazardous waste issues need to be addressed early.

Humidity. If humidity is controlled, energy used for

space heating increases by an estimated 25%. The potential energy savings with energy recovery increases and so do the possible alternatives. Desiccant wheels can be used for dehumidification, wraparound coils can be used for reducing reheat energy, and evaporative cooling can be used for humidification. Avoid over-specifying control of humidity. The wider the control range, the less energy used.

Maintenance. Maintenance differs according to the type of energy recovery and the application. Heat pipes appear to have the lowest maintenance requirements, followed by runaround loops and plate-type energy recovery. Periodic cleaning needs depend on the fouling and corrosion potential of the exhaust air, but cleaning is critical to maintaining equipment performance. Prefiltration often is required to reduce fouling, which adds maintenance for filter changing.

Part-Load Operation. Outside air bypass dampers can be used for part-load operation to minimize overheating, overcooling, and fan energy use. They also can serve to prevent condensation and frosting. Alternatively, you can vary the wheel speed on enthalpy wheels, change the tilt on heat pipes, or vary the flow on runaround loops.

Redundancy. Laboratories usually have redundant chillers and boilers to ensure control over a room's climate conditions at all times. If the capacity provided by energy recovery is not accounted for in sizing the chilled water and hot water systems, then the systems should at least be optimized to operate with the lower loads resulting from the use of energy recovery. Otherwise, the chillers and boilers may operate inefficiently at low loads.

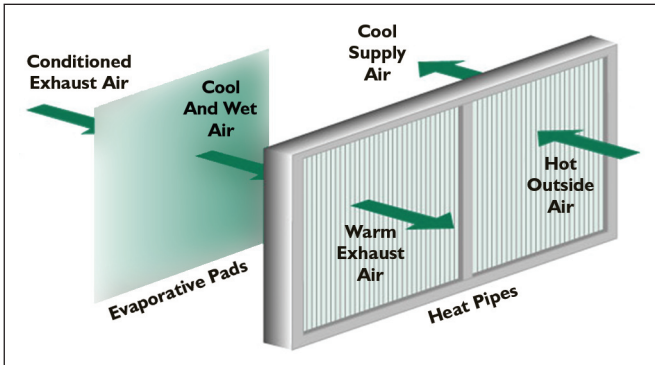


Figure 3: Heat pipe system with indirect evaporative cooling.

to maintain the lab at 50% RH at 72°F (22°C). Fifty-two degrees Fahrenheit (11°C) supply air is too cold for most labs because of the high ventilation rate, so a significant amount of reheat energy must be added to avoid overcooling the lab. Adding a sensible-only wheel provides “free” reheat energy as shown in Figure 2. The Marian E. Koshland Integrated Natural Sciences Center in Haverford, Pa.,¹ is an excellent example of the use of two energy recovery wheels.

Heat Pipes. Heat pipes transfer only sensible energy. If air is cooled to below its dew point, however, condensation oc-

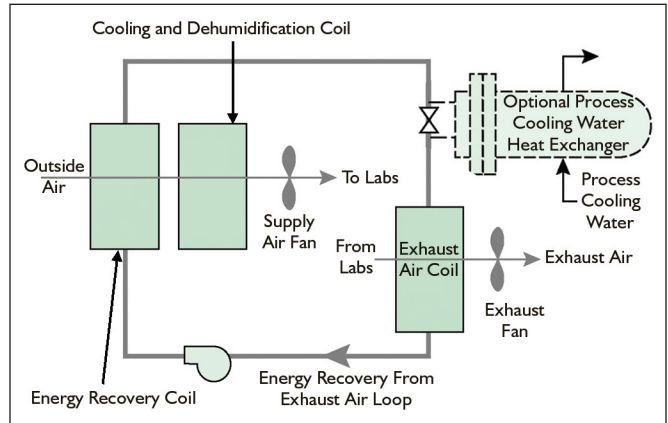


Figure 4: Runaround energy recovery loop.

cur on the heat pipe and results in some latent heat transfer. In heat pipe applications, the supply and exhaust airstreams are next to one another although some modified or split heat pipes allow the airstreams to be separated.

The sensible effectiveness of heat pipes is between 45% and 65%. Cross contamination is not an issue. Heat pipes have no moving parts, and failure of the entire unit is rare. A tube may malfunction, but other tubes continue to transfer energy. Heat

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pipes can be controlled for part-load operation with a bypass duct or by tilting the unit.

Heat pipes can be used as indirect evaporative coolers (*Figure 3*). Water is added on the exhaust side of the pipe to cool the exhaust air, which, in turn, is used to precool the supply air.

Runaround Loops. Runaround loops circulate a fluid between two airstreams. Most designers are familiar with this technology because it usually just involves additional coils and pumps. The airstreams do not need to be next to one another, and no cross contamination issues exist. Runaround loops have a sensible effectiveness between 55% and 65%.

In the U.S. Department of Agriculture's new laboratory in Ames, Iowa, the preheat coil and runaround loop coil are combined, so the added pressure drop in the supply system is lower than a system with separate energy recovery and preheat coils.

Runaround loops are well-suited for transferring energy between process loads and ventilation air as shown in *Figure 4*. Fred Hutchinson Cancer Research Center in Seattle uses a runaround loop to take heat rejected from the process cooling water system to preheat outside air, thus providing free cooling of the process cooling water.

Runaround loops and heat pipes also can be used to reduce cooling and reheat energy in warm, humid climates. The energy recovery device precools the outside air before the air enters the main dehumidification cooling coil. Heat recovered from the exhaust air or the outside air is used to reheat the air leaving the main cooling coil. This design is similar to *Figure 4* with the energy recovery wheels replaced by runaround loops or heat pipes.

The Viral Immunology Center at Georgia State University in Atlanta uses a packaged rooftop ventilation unit with two

Key Terms

Effectiveness: The ratio of actual energy recovered to theoretical energy that could be recovered.

Latent Effectiveness: Proportional to the ratio of the difference between the humidity ratio of the outside air and the supply air, and the difference between the humidity ratio of the exhaust air and the outside air.

Sensible Effectiveness: Proportional to the ratio of the difference between the dry-bulb temperature of the outside air and supply air, and the difference between the dry-bulb temperature of the exhaust air and the outside air.

Total Effectiveness: Proportional to the ratio of the difference between the enthalpy of the outside air and the supply air, and the difference between the enthalpy of the exhaust air and the outside air.

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	Minneapolis	Denver	Seattle	Atlanta
Constant Volume With Enthalpy Wheel	57%	53%	34%	29%
Constant Volume With Heat Pipe Or Runaround Loop	31%	28%	24%	14%
VAV With Enthalpy Wheel	69%	60%	50%	56%
VAV With Heat Pipe Or Runaround Loop	48%	40%	43%	45%

	Minneapolis	Denver	Seattle	Atlanta
Constant Volume With Enthalpy Wheel	\$1.4	\$1.3	\$0.2	\$0.0
Constant Volume With Heat Pipe Or Runaround Loop	\$0.5	\$0.4	\$0.0	-\$0.4
VAV With Enthalpy Wheel	\$2.3	\$1.9	\$0.8	\$0.9
VAV With Heat Pipe Or Runaround Loop	\$1.5	\$1.3	\$0.7	\$0.6

Table 1 (left): Percent gas savings. Table 2 (right): Annual energy cost savings (\$/cfm/yr).

heat pipes. In the summer, one heat pipe pre-cools the outside air by transferring heat to the exhaust air, the mechanical system DX coil subcools the air, and the other heat pipe reheats the air with heat recovered from the exhaust air. In the winter, both heat pipes are used to heat the air.

Plate Heat Exchangers. Fixed-plate heat exchangers are constructed of plates arranged for cross flow or counter flow of supply and exhaust airstreams. The plates are normally constructed of aluminum and, therefore, conduct only sensible heat. Fixed-plate heat exchangers have a sensible effectiveness between 55% and 65%. Fixed-plate heat exchangers have not typically been used in lab buildings because of the large airflow in labs and because of the potential difficulty in cleaning large fixed-plate heat exchanger. Control of fixed-plate exchangers at part loads is accomplished by using a bypass duct.

Water-vapor-permeable microporous polymeric membranes may be used to provide total (enthalpy) energy recovery in plate heat exchangers. Membrane flat-plate heat exchangers may become more common in lab applications because of their high recovery effectiveness and little or no leakage between airstreams.

Codes and Standards

As with all building components, various codes and standards apply to energy recovery. There are standards for testing the performance of the equipment and standards that specify when energy recovery must or must not be applied. American Industrial Hygiene Association codes and standards affecting laboratories can be found at www2.umdnj.edu/eohssweb/

aiha/technical/codes.htm#Energy. Here is a brief overview of codes and standards pertaining to energy recovery:

- Air-Conditioning and Refrigeration Institute (ARI) Standard 1060-2005, *Performance Rating of Air-to-Air Heat Exchangers for Energy Recovery Ventilation Heat Equipment*, rates the sensible, latent, and total effectiveness of equipment, excluding runaround loops. The ratings are performed by an independent laboratory per ASHRAE Standard 84-1991, *Method of Testing Air-to-Air Heat Exchangers*, except as amended by ARI 1060. The ARI Directory of Certified Product Performance (www.aridirectory.org) is useful for identifying manufacturers, products and for comparing effectiveness ratings.
- In the 2003 International Mechanical Code (IMC), Section 514 has been added to cover the installation of energy recovery ventilation. This section prohibits the use of all types of energy recovery ventilation, including heat pipes and runaround loops, with hazardous exhaust systems, as defined in Section 510. This is a significant change to the 2000 version of the code. The code committee approved exceptions for laboratory exhaust systems to Section 510, so that most research laboratory exhaust systems will not be defined as hazardous exhaust systems. The exception for laboratories will appear in the 2006 IMC.
- NFPA 45 states that, if a chance exists of cross-contamination between airstreams, air-to-air energy recovery only can be used on general exhaust.

The standard has not been adopted by all states, although it raises liability concerns for design teams. At the Whitehead Biomedical Research Building at Emory University in Atlanta, the National Institutes of Health (NIH) Louis Stokes Laboratory in Bethesda, Md., and the Nidus Center in St. Louis, the general exhaust system is separate from the fume hood exhaust, and there is an enthalpy wheel on the general exhaust. NIH had to use stainless steel ductwork for the fume hood exhaust because the exhaust was no longer being diluted enough to allow for galvanized ducts.

- ANSI/ASHRAE/IESNA Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings, requires energy recovery on fans of 15,000 cfm (7080 L/s) or greater in buildings with fume hoods. Laboratories with VAV fume-hood exhaust or direct makeup air for the hoods are exempt. The standard states the recovery method must have a minimum total effectiveness of 0.5. The fan power limitations often are difficult to meet in laboratories. Although, the calculation of fan power limitations in the standard does include an adjustment for energy recovery.

To demonstrate compliance with Standard 90.1, or show energy cost savings for certification under the Leadership in Energy and Environmental Design® (LEED) rating system, hourly simulations of energy use in a building are required. The annual energy costs for the proposed design are compared to those of a budget, or base case design that meets the mini-

num requirements in the standard. The budget building corresponding to more common laboratory buildings will have a variable air volume system. If the ventilation air cannot be modulated, then the budget building is modeled as a constant air volume system with energy recovery.

The energy recovery device in the budget building is modeled with a total effectiveness of 0.5. More guidance is provided in the “Laboratory Modeling Guidelines Using ASHRAE 90.1-1999” developed by Labs for the 21st Century (www.labs21century.gov/pdf/ashrae_v1_508.pdf).

Performance Examples

Air-to-air energy recovery reduces energy use and can significantly reduce heating and cooling system sizes. A large installation of enthalpy wheels done in 1991 at the Johns Hopkins Ross Research Building, Baltimore, has resulted in millions of dollars in energy savings. All exhaust, including fume-hood and biological safety cabinet exhaust, is passed through the enthalpy wheels. The equipment paid for itself in first-cost savings because the hot water and chilled water systems could be downsized.² The enthalpy wheels have performed so well that Johns Hopkins is installing enthalpy wheels in its new lab buildings, including the Cancer Research Building and the Broadway Research Building.

An energy analysis of enthalpy wheels, heat pipes, and runaround loops was performed for a typical 100,000 ft² (9290 m²) laboratory in Minneapolis, Denver, Seattle, and Atlanta. The heating degree days, base 65, and cooling degree days, base 50, are given for each climate in *Table 1*. The analysis included constant volume systems with energy recovery and VAV systems with energy recovery.

The results assume a VAV system for the base case to which the other cases are compared. This is consistent with the Energy Cost Budget Method for demonstrating compliance with Standard 90.1-1999. Electricity rates have been updated to \$0.08/kWh and natural gas rates are \$1/therm (\$1/105.5 MJ).

The annual energy cost savings reflect

net savings. The increase in fan energy from the additional pressure drop introduced by the energy recovery device is included in the analysis. The potential energy savings may be less in applications that use general exhaust only for energy recovery. The energy recovered from general exhaust may be more than sufficient to heat outside air. Energy recovery from general exhaust has also been shown to be cost effective.

The most significant findings include:

- Air-to-air energy recovery reduces gas use for space heating and reheat for dehumidification by more than 10% in all climates (*Table 1*). The most significant savings are with the VAV systems with energy recovery, resulting in savings exceeding 40% in all climates.
- Only in the hot, humid climate of Atlanta did annual electricity savings occur with the enthalpy wheel. In other climates, the increase in annual fan energy offset the annual electricity savings.
- Savings in peak electricity demand is offset by the increase in fan energy.
- Annual energy cost savings are more than \$0.6/cfm (\$1.27 per L/s) of fan airflow (*Table 2*) for the VAV cases with energy recovery. The enthalpy wheel is the most cost effective of the three energy recovery devices as a result of its higher effectiveness and latent energy recovery.
- In Seattle and Atlanta, the results show that a VAV system, the base case, is more efficient than the constant air volume cases with energy recovery. However, using these devices as wraparound loops for dehumidification may be cost effective.

Another real-life example of the potential savings with energy recovery ventilation is the installation of heat pipes with bypass sections in two 30,000 cfm (14 160 L/s) air-handling units at the 120,000 ft² (11 148 m²) Fox Chase Cancer Center in Philadelphia. The incremental cost for heat pipes with the indirect evaporative cooling option on the exhaust was \$300,000. Anticipated energy cost savings were \$72,510, resulting in a simple payback of four years. A complete cost

analysis would include maintenance and replacements costs.

Conclusion

Energy recovery can prove cost effective in laboratory applications. The life-cycle cost analysis should include operation and maintenance costs, as well as replacement costs. In addition, significant first cost savings can be associated with downsizing equipment. Selecting an appropriate energy recovery technology, properly designing the system, meeting the applicable codes, and commissioning the system are all important.

Acknowledgments

This article is largely based on the Labs21 *Best Practices: Energy Recovery for Ventilation Air in Laboratories* (www.labs21century.gov/pdf/bp_recovery_508.pdf). It is one in a series of guides on best practices for labs produced by Labs for the 21st Century, a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy. See www.labs21century.gov/toolkit/bp_guide.htm for more information.

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For More Information

The different types of air-to-air energy recovery devices are discussed in many sources. For example, the *ASHRAE Handbook—HVAC Systems and Equipment* covers a range of devices, compares their performance, and identifies appropriate applications. The *ASHRAE Laboratory Design Guide* by McIntosh et al., includes a chapter on energy recovery and discusses laboratory-specific concerns. Also, *A Design Guide for Energy-Efficient Research Laboratories* is available in electronic format from Labs21 www.labs21century.gov/toolkit/design_guide.

htm. This searchable document includes a discussion of different types of energy recovery as well as case studies.

Labs21 has prepared laboratory building case studies available at www.labs21century.gov/toolkit/case_studies.htm. Several case studies feature energy recovery. For an example of enthalpy wheels, see the studies on the Integrated Natural Science Center at Haverford College, Whitehead Biomedical Research Building at Emory University, the Nidus Center, and Building 50 at the National Institutes of Health. For an example of heat pipes, see the study on the PETL at Sandia National Laboratories, Albuquerque, for an example of runaround loops see Pharmacia Building Q. More sources of information are:

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