

Best Practices Guide Energy Recovery in Laboratory Facilities

December 2023

The International Institute for Sustainable Laboratories (I2SL) developed this best practices guide for lab owners, operators, builders, architects, and engineers to consider various types of energy recovery systems to improve efficiency in heating and cooling laboratories. The types of systems that will work best depend on a wide variety of factors in a particular lab building; for example, an energy recovery device will operate more efficiently with a variable air volume system than a constant air volume one.

Introduction

Laboratories require single-pass air from central heating, ventilation, and air-conditioning (HVAC) systems to provide a level of containment. Energy recovery can be very cost-effective in these applications, given the following considerations:

- Laboratory systems may operate at up to 100% outside air and at higher airflow rates than other commercial buildings.
- The heating and cooling energy needed to condition this air can be five to 10 times greater than the amount of energy used in office buildings.
- In some laboratories, the required airflow rate exceeds the airflow needed for space conditioning, requiring additional heating energy to maintain space temperatures.
- Laboratories generally have tighter temperature and humidity controls, which may drive colder air for dehumidification along with supplemental heating to prevent overcooling.
- Most laboratories also operate with a negative airflow offset to maintain containment from non-laboratory zones, which may lead to additional heating in adjacent spaces such as corridors that provide the replacement air pulled into negative-pressure laboratories.

Energy recovery devices and systems can substantially reduce heating and cooling energy



Energy Systems Integration Facility (ESIF) at NREL South Table Mountain campus in Golden, Colorado. Photo by Joshua Bauer, NREL 59215.

required for conditioning spaces in laboratories. These systems take many forms, including heat pumps that capture heat generated in high-load spaces and transfer it to spaces requiring heat. Energy recovery systems also reduce peak heating and cooling requirements, allowing for downsized heating and cooling systems that can save energy.

This guide includes descriptions of several air-to-air energy recovery devices and methods, such as using fixed plate heat exchangers, enthalpy/sensible wheels (Figure 1 on page 2), heat pipes, and run-around loops. These devices recover energy from lab exhaust to precondition outside air during both cooling and heating modes of operation. While fixed plate heat

International Institute for Sustainable Laboratories





exchangers, enthalpy/sensible wheels, and heat pipes require proximity of outside air to lab exhaust, run-around loops can be remotely located. A key aspect of all these systems is protection against the cross-contamination of the outside air being conditioned.

This guide also includes water-to-water heat recovery systems that collect heat from high-load spaces and transfer that energy to spaces that need heat. While air-to-air recovery devices provide significant energy reduction, the amount of energy available from the exhaust air may exceed the energy needed to maintain supply air conditions, especially in more temperate times of the year. During these periods of time, controls reduce the energy recovery capacity to match the demand. If energy recovered from the exhaust is not needed, then the system is shut off. By using a water-to-water recovery system, it is possible to significantly lower building energy use by first reusing heating or cooling energy generated in the building before directing it outdoors.

Laboratory managers are encouraged to perform a life-cycle cost analysis (LCCA) of an energy recovery

system to determine the feasibility of its application in their laboratory. Usually, the shortest payback periods occur when the application of an energy recovery system allows the facility to downsize the associated heating (e.g., hot water or steam) and cooling (e.g., chilled water) systems based on the energy reduction.

Technology Description

To understand and assess energy recovery devices, it is critical to determine the laboratory ventilation air flow rates, as well as containment requirements. Minimum ventilation is provided to laboratories at air change per hour (ACH) rates in accordance with codes and adopted design standards. For example, the U.S. Occupational Safety and Health Administration (OSHA) states this minimum ventilation rate "should not be relied on for protection from toxic substances released into the laboratory;" it specifically indicates that it is intended to "provide a source of air for breathing and for input to local ventilation devices (e.g., chemical fume hoods or exhausted bio-safety cabinets), to ensure that laboratory air is continually replaced, preventing



Figure 1. Enthalpy/Sensible Wheel System Cross Sections

Key Terms

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

Latent energy: The energy contained in moisture of the air.

Latent effectiveness: Proportional to the ratio of the difference between the moisture content (humidity ratio) of the outside air and the supply air, and the difference between the humidity ratio of the exhaust and the outside air.

Recovery efficiency ratio (RER): The ratio of actual energy recovered to the fan motor energy consumed. Can be expressed as total, sensible, and latent.

Sensible energy: The energy associated with the change in dry bulb temperature.

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 and the outside air.

Total effectiveness: Proportional to the ratio of the difference between the total energy (enthalpy) of outside air and the supply air, and the difference between the enthalpy of the exhaust and the outside air.

the increase of air concentrations of toxic substances during the working day, direct air flow into the laboratory from non-laboratory areas and out to the exterior of the building."

Air-to-Air Recovery Devices

Air-to-air energy recovery devices exchange energy from one stream of air to another. The air being exhausted contains sensible (heat) and latent (water vapor) energy. Both types of energy can be recovered; however, not all air-to-air recovery devices exchange both types of energy. The effectiveness of an energy recovery device reflects the efficiency of the device in recovering available energy. While most devices rate sensible effectiveness, some also have a rating for latent effectiveness and total effectiveness. Note that in humidified buildings in cold climates, the performance of the energy recovery device may need to be limited in winter months (reduced effectiveness) to prevent freezing or moisture condensation on the recovery device in the exhaust air, which will drastically reduce the energy recovery available.

These air-to-air energy recovery devices restrict airflow (i.e., increase the pressure drop) that must be offset by the supply and exhaust fans. The pressure drop across energy recovery devices varies with the type of device, although actual values depend on the design and sizing. A pressure drop of no more than 1-inch water gauge in the supply and exhaust air streams is a reasonable design goal and will minimize the increase in fan energy associated with these devices. For example, an increase in pressure drop of 1-inch water gauge on a 76% efficient fan and a 95% efficient motor assembly results in an increase in fan energy of 0.16 watt per cubic foot of air per minute (W/cfm). The total increase for supply and exhaust fans together in this example would be around 0.32 W/cfm.

For laboratory applications, the standard design face velocity of recovery devices in HVAC systems should never exceed 500 feet per minute (fpm). However, lower face velocities will result in lower pressure drops, higher effectiveness, and lower operating costs. Pressure drop varies by the square of the velocity such that a 30% reduction in velocity will reduce the pressure drop by 49%. The tradeoff is larger HVAC equipment, larger mechanical space requirements and, possibly, higher first cost. It is important to note that an energy recovery device will operate more efficiently with a variable air volume (VAV) system than with a constant air volume system,

	Heat Wheels	Plate HX	Heat Pipes	Run-Around Coils
Exhaust vs. supply airflow rates	Y	Y	Y	Y
Heat transfer surface area	Y	Y	Y	Y
Heat transfer material and thickness	Y	Y	Y	Y
Air pressure drop	Y	Y	Y	Y
Fan efficiency	Y	Y	Y	Y
Temperature control in moderate temperatures	Y	Y	Y	Y
Control sequences	Y	Y	Y	Y
Frost control sequence in cold climates	Y	Y	Y	Y
Working fluid used			Y	Y
System fluid flow rate				Y
Avoiding laminar flow conditions				Y
Typical heating RER values at -11 outside air temperature (OAT) and 75/56 return air temperature (RAT, humidified space), balanced airflow (Btu/hour/ watt [h/W])	340.7	145.8	163	124.8
Typical heating COP values at -11 OAT and 75/56 RAT (humidified space), balanced airflow	99.9	42.7	47.8	36.6
Typical cooling RER values at 97/57 OAT and 75/56 RAT, balanced airflow (Btu/h)/W	69.2	55.9	71.0	54.4
Typical cooling COP values at 97/57 OAT and 75/56 RAT, balanced airflow	20.3	16.4	20.8	15.9

Table 1	. Energy	Recovery	Impacts	and	Efficiencies
		-			

Y= yes

because VAV systems operate at lower velocities most of the time. If redundant HVAC equipment is included, lower operating pressure drops can be accomplished simply by operating the redundant unit with the primary units. For example, an HVAC system with two primary units and a redundant unit operating together achieves a 33% velocity reduction with no changes to unit sizes. While fans are sized for the units operating at their design condition, operating energy is greatly reduced.

Table 1 on page 4 lists the key variables to consider in determining the efficiency of an energy recovery system. The effectiveness of a system is the ratio of actual energy recovered to the theoretically available energy that could be recovered. While key to determining the overall efficiency of a system, there are other energy losses and energy consuming parts that need to be assessed. Recovery efficiency ratio (RER, as defined in the 2020 American Society of Heating Refrigeration, and Air-conditioning Engineers [ASHRAE] HVAC Systems and Equipment Handbook, Chapter 26 Air-to-Air Energy Recovery, and 2011 Air-Conditioning, Heating and Refrigeration Institute [AHRI] Guideline V) is a good method to compare energy recovery products as it accounts for pressure drop, fan and motor efficiency, and other energy sources. RER units are the same as energy efficiency ratio (EER) and can be converted to coefficient of performance (COP), providing simple comparison to other forms of energy production on a design day.

Note that RER only addresses the addition of the heat recovery device and does not include systemlevel energy such as heating and cooling energy. Typical values of RER for heating and cooling conditions for a humidified building in Colorado are shown, assuming 5,000 cfm balanced flow and supply fan efficiency of 71% with a 93% efficient motor. The heat exchanger pressure drop was 0.62" water gauge for the heat wheel, 0.74 for the plate heat exchanger (HX), 0.69 for heat pipe and 0.69" water gauge for run-around coils. The heat wheel had a 0.25 horsepower motor and the run around coil used a 0.5 horsepower pump.

ASHRAE 62.1 2022 designates classes of exhaust air from 1 to 4 based on: contaminant concentration; sensory-irritation intensity and offensive odors; highly objectionable fumes or gases; dangerous particles; and bio-aerosols or gases at concentrations high enough to be considered as harmful. It also details how much of a class of air can be recirculated or transferred. The 2020 ASHRAE *HVAC Systems and Equipment Handbook* Chapter 26, Table 3 details the typical leakage values from the exhaust to the supply, exhaust air transfer ratio (EATR) values, which are quoted below.

Bypass and Control Considerations for Fixed Plate Heat Exchangers

Fixed plate heat exchangers for laboratory applications are typically sensible only and consist of alternating airflow paths for exhaust and outside air with a fixed plate in between like a heat exchanger. EATR is 0% to 2% for fixed plates; therefore, up to Class 3 air can be exhausted per ASHRAE 62.1 2022. The supply and exhaust streams must be located directly adjacent to each other. When free-cooling economizer operation is advantageous, bypasses will reduce pressure drop (and fan energy) along with minimizing undesired energy recovery by allowing the air to go around the energy recovery devices.

The 2021 International Energy Conservation Code (IECC) requires systems with energy recovery and an air-side economizer to have a bypass or controls that permit economizer operation. With no bypass in moderate conditions when the outside air temperature is near to or slightly below the required supply air temperature, too much heat will transfer from the warmer exhaust air and will require mechanical cooling, even though the system should be in the equivalent of an economizer mode. For example, ratings with a 57% effective fixed plate heat recovery system show an increase in supply air temperature of 8.6°F with no energy recovery bypass and an outdoor air temperature of 55°F and an exhaust temperature of 70°F. Mechanical cooling had to be used to achieve the design supply air temperature, highlighting the importance of the bypass. However, a supply bypass alone does not prevent the supply airstream from being overheated, and ratings show that a temperature rise of 3°F to 4°F will occur when the bypass is opened. The addition of an exhaust bypass will reduce the temperature rise approximately another 1°F in addition to the fan energy saved.

Energy modelers should take into account the additional cooling load required. Face and bypass dampers will prevent the supply air from being overheated; however, access to the heat exchanger through the face damper is limited, and the increase in cost and unit length needs to be taken into consideration.

To further emphasize why a bypass is required, consider the following examples using a fixed plate heat exchanger that is 57.4% effective, when the outside air is 55°F and the return air is 70°F (note the effectiveness increases as airflow drops and surface area increases):

- Unit with no bypass in economizer mode: The temperature leaving the fixed plate will be 55+(70-55) * 57.4% = 63.6°F with no bypass.
- Unit with a single bypass in economizer mode: With a bypass on the supply side, a 0.6" air pressure drop on the fixed plate and a 0.1" air pressure drop on the bypass damper, both devices will equalize at 0.05" air pressure drop. This results in 71% of the air flowing through the bypass, and 29% going through the heat exchanger with an effectiveness of 89.4% for the 29% of the air going through the

heat exchanger. The temperature leaving the fixed plate will be 55+(70-55) * 89.4% = 68.4°F, which is then mixed with 71% bypass air at 55°F for a mixed air temperature of 58.9°F.

Bypass dampers and fans need to be carefully arranged with multiple supply fans, as the bypass air may overload one fan, starving the other fan, causing performance issues and sound anomalies. Due to the pressure difference from the heat exchanger to the bypass damper, when the bypass damper is cracked open, a high percentage of air may be bypassed immediately, causing damper whistling and temperature control issues. The use of multiple staged bypass dampers can smooth out this transition and minimize the control issues associated with the larger dampers, but that increases cost.

Additionally, there is a concern in cold climates where the return air dewpoint is above the exhaust temperature, creating condensation and frost on the exhaust side of the heat exchanger. Fixed plate heat exchangers provide cross flow heat recovery, and therefore are susceptible to cold corners, which may freeze. When the exhaust air dry bulb is below 32°F and below the return air dewpoint, condensation and frosting will occur. The cold corner freezes more quickly than the rest of the fixed plate, reducing the heat exchange surface, damaging the heat exchanger seal between the airstreams and increasing leakage. Typically, a supply bypass damper is used to raise exhaust temperature above freezing. This limits the device effectiveness at design temperatures.

Energy Recovery Wheels

There are two main types of energy recovery wheels: sensible wheels that recover sensible energy, and enthalpy wheels (also called total energy wheels, molecular sieves, or rotary heat exchangers) that transfer sensible and/or latent energy between the exhaust air and the incoming outside air (see Figure 1 on page 2). Enthalpy recovery devices provide the highest effectiveness for sensible and total energy recovery and reductions in energy use. The supply and exhaust streams must be located directly adjacent to each other. Enthalpy wheels can have sensible and latent effectiveness as high as 80% (total effectiveness of up to 80%). Control of the wheel at part loads is accomplished by varying the speed of the wheel, using bypass dampers, or both.

Energy recovery wheels have an inherent control advantage, as they can be slowed down or turned off to minimize energy recovery. Ratings show that slowing the wheel speed from 100% down to 20% does not produce much temperature change. Selecting systems that allow for operating the wheel from 20% to 5%, then off is recommended to minimize heat recovery during economizer conditions.

Enthalpy recovery wheels have a desiccant media to absorb and release moisture. The desiccant wheel must be designed to transfer only moisture and not airborne contaminants. Desiccant wheels are discouraged in the application of vivariums or programs with strong odors. Studies have found that in the absence of moisture, desiccant wheels have the potential to transfer exhaust odors to the supply air. Where odors are a problem, specialized applications of this technology may be considered for general lab exhaust using a molecular sieve with a 3-angstrom wheel. Instead of the typical energy recovery media, a specialized engineered media has 3-angstrom diameter holes. As water vapor is about 2.75 angstroms, it fits in the hole while more complex compounds do not and are exhausted. ASHRAE Research Project Report 1780-RP provides insight into applying enthalpy and molecular sieve products at very low velocities (but does not address sensible recovery wheels).

To reduce potential contamination of the supply air stream, the recovery wheels are flushed with outside

air that is deflected by a baffle in the purging section of the rotor. The baffle redirects conditioned outside air, leaving the wheel to the inlet side of the wheel exhaust. The purge section utilizes the pressure difference between the supply air and exhaust air streams (see Figure 1 on page 2). Purge volumes for laboratory applications are typically between 5% and 10%, so additional fan energy is required to move this air. For example, the Whitehead Biomedical Research Building at Emory University in Atlanta uses enthalpy wheels for energy recovery between the supply and exhaust air streams. The installation cost for the wheels was reported at \$425,000, and anticipated energy savings are \$125,000 per year. The simple payback is less than four years.

Fan arrangement and pressure relationships can be critical in these types of systems. Review all operating conditions (heating, cooling, moderate temperatures, and unoccupied modes) to ensure that the exhaust path is always at a lower pressure than the supply to prevent exhaust entrainment into the supply air. If these pressures cannot be ensured in all conditions, then consider moving the supply air fan ahead of the recovery wheel while leaving the exhaust fan after the wheel to ensure that the pressurization will always be from clean to dirty.

Additionally, there is a concern in cold climates where the return air dewpoint is above the exhaust temperature, creating condensation and frost on the exhaust side The condensate will be absorbed into the wheel, and subsequently re-evaporated on the supply side. The potential for chemicals to be entrained in this process needs to be analyzed.

Heat Pipes

Heat pipes transfer only sensible energy between independent coils in the airflow streams by employing a phase change refrigerant that vaporizes when absorbing heat from a warm airstream and condenses by releasing heat to a cold airstream. The sensible effectiveness of heat pipes is between 40% and 60%. In heat pipe applications, the supply and exhaust air streams are typically next to one another, although some modified or "split" heat pipes allow the air streams to be separated by using independent coils and interconnection piping with some also requiring pumping units to function properly. EATR is 0% to 2% for heat pipes, therefore up to Class 3 air can be exhausted per ASHRAE 62.1 2022. When not provided with pumping units, the heat pipe coils in both units must have the same height and arrangement (width may vary); be installed at the same height; and will require multiple circuits connecting these coils that must stay level. Note, this may create a physical barrier at the pipe location, requiring space to walk around.

Most heat pipes have no moving parts (so minimal maintenance needed), and failure of a coil (e.g., loss of refrigerant charge) is rare. Even with a failure of a single refrigerant circuit, the other circuits will continue to transfer energy. Fixed-position heat pipes must be level to within 1/8" from end to end, so careful structural design and installation is required for proper operation. Similar to fixed plates, heat pipes should be controlled for economizer operation with bypass dampers (supply and exhaust are recommended); bypass ducts; solenoid (open/closed) valves on refrigerant circuits; or rarely by tilting the unit.

Heat pipes that have mechanisms that change tilt to control heat transfer have a higher potential for EATR between exhaust and supply, as they employ a flex connector to allow movement and may leak over time.

Split heat pipes rely on field charging of refrigerant piping, and therefore are subject to leakage, which can have a bigger global warming potential impact than the saved carbon with heat recovery. Recovering the refrigerant at end of life is a time-consuming process, as each tube needs to be evacuated to prevent release of refrigerant to the atmosphere. The amount of refrigerant used for heat pipes should also be evaluated in accordance with ASHRAE 15 Safety Standard for Refrigeration Systems. Depending on refrigerant type, quantity, and room size, the application of heat pipes may trigger the requirements for a machinery room with refrigerant monitoring and alarm, purge exhaust, etc. The transition to A2L refrigerants will need special analysis.

Additionally, there is a concern in cold climates that condensation and frosting will occur with heat pipes that are counter flow heat recovery when the exhaust air dry bulb temperature is below 32°F and the return air dewpoint is higher than the exhaust air drybulb temperature. To prevent this, typically a supply bypass damper is opened, which limits energy recovery efficiency to maintain the exhaust temperature above freezing.

Run-Around Loops

Run-around loops circulate a fluid between two air streams and provide only sensible energy recovery. Run-around loops have a theoretical sensible effectiveness of between 45% and 65%. This technology may seem familiar to most designers because it involves additional coils and pumps. The air streams do not need to be next to one another and can have different supply and exhaust air handling unit quantities; there are no cross-contamination issues, so they can handle Class 1 through Class 4 air.

In cold climates, the actual performance may be limited by controlling the fluid temperatures to prevent freezing of the loop to avoid moisture condensation on the tubes in the exhaust air stream. For a humidified laboratory with the outdoor air temperature at 0°F and a return air dewpoint temperature greater than the fluid temperature in the exhaust of 28°F, the run-around loop may have an effectiveness of around 30%. Note that this limitation



Figure 2. Run-Around Energy Recovery Loop With Dehumidification

for humidified buildings occurs only when conditions are below roughly 20°F outside air temperatures. This limitation also depends on system effectiveness—the higher the effectiveness, the more condensation and frosting will occur. Above 20°F outside air temperature, run-around loops can provide most or all pre-heat needed without supplemental sources of energy, depending on coil heat transfer effectiveness and discharge air setpoint.

Run-around loops are also well-suited for transferring energy between process loads and ventilation air.

The Fred Hutchinson Cancer Research Center in Seattle, Washington, uses a run-around loop to take heat rejected from the process cooling water system to preheat outside air, thus providing free cooling of the process cooling water. This same approach could be applied for liquid-cooled data centers or other applications with a consistent hot water source. If these approaches are then compared to using evaporative heat rejection systems (cooling towers with plate-and-frame heat exchangers), this will result in considerable water and cooling tower fan energy savings as well.

Run-around loops and heat pipes can also be used to reduce cooling and heating energy by transferring heat from hot outside air to reheat coils located after dehumidification cooling coils for tempered air systems located in warm, humid climates. The run-around loop pre-cools the outside air before the air enters the dehumidification cooling coil and uses that energy to reheat the air leaving the cooling coil. When this application is applied locally at the HVAC equipment, these two coils wrap around the cooling coil; the assembly is often called a "wrap-around loop." This can also be done with a three-coil run-around loop with two flow paths (chilled and recovery loop). In winter, the loop uses exhaust air to pre-condition cold outside air with two coils in series. In humid summer months, the loop uses exhaust air to provides dehumidification reheat (see Figure 2 above).

Where dehumidification is required and the space has low internal loads, a reheat coil as shown in Figure 2 above should be considered to enhance the energy recovery and reduce reheat energy at the zone level. A detailed engineering analysis is required to identify a supply air temperature that can take advantage of this recovered reheat energy while balancing the fan energy penalty of the coil pressure drop.

Packaged run-around loops also have the ability to integrate a single high-effectiveness coil in lieu of three separate coils (recovery, heating, and cooling); plate-and-frame heat exchangers (cooling and heating); and pumps together with a control package. Packaged systems can include sophisticated frost/ defrost controls that improve energy recovery when the ambient temperature is below 20°F. The one coil design reduces the length of the HVAC equipment; reduces supply air pressure drop (one coil vs. three); requires less building space; reduces piping runs and size; and is a repeatable system from a control perspective. The package can include any of the devices shown in Figure 3 below and evaporative cooling, if specified.

For example, at the U.S. Department of Agriculture's laboratory in Ames, Iowa, the run-around loop and

pre-heat coil are combined into a single coil. After recovering heat from the exhaust, supplemental heat is added to the run-around loop via a plate-and-frame heat exchanger before being used to precondition outside air. This approach lowers the air pressure drop in the HVAC equipment when compared to a system with separate run-around recovery and preheat coils, saving fan energy. The approach also allows for freeze protection to be removed from the heating and chilled water system, as the fluids are no longer directly exposed to the cold outside air temperatures.

The packaged system can come with performance guarantees and remote monitoring of system performance. Packaged systems have many cost trade-offs that need to be considered. Based on a full scope and economic analysis, packaged run-around loops can be less expensive than a field-built systems with certified controls and better energy performance.



Figure 3. Exhaust Evaporative Cooling With Heat Pipe System

Exhaust Evaporative (Adiabatic) Cooling

Heat recovery may also be used as part of an indirect evaporative cooling process in which water is used to evaporatively cool exhaust ahead of the recovery coil to enhance the pre-cooling of outside air (see Figure 3 on page 10). Two examples of this approach are at the Fox Chase Cancer Center in Philadelphia, and in the Process and Environmental Technology Laboratory at Sandia National Laboratories in Albuquerque, New Mexico.

Consideration can also be given to recovering cold cooling coil condensate from HVAC equipment outside air cooling coils as a supplemental source of makeup water in the evaporative cooling process. If direct evaporative cooling is used in the exhaust airstream, connection of the drain to the laboratory waste system may be required due to the air washing effect of the evaporative cooler.

Variations on Air-to-Air System Energy Recovery

Concepts that combine the above systems may also be considered. These variations may include using various heat recovery types to support combination preheat and reheat systems. Vendors may also be able to provide series energy recovery devices in dehumidification units to optimize energy recovery. All energy recovery systems and variations should be optimized using energy modeling tools.

The Viral Immunology Center at Georgia State University in Atlanta uses a ventilationdehumidification unit with two heat pipes in lieu of run-around loops. In summer months, one heat pipe pre-cools outside air by transferring heat to the exhaust air, a refrigerant-based direct expansion (DX) mechanical system sub-cools the air for dehumidification, and the second heat pipe reheats the air with heat recovered from the exhaust air. In winter months, both heat pipes work together to provide an increased level of outside air heating.

Water-to-Water Recovery Devices

While air-to-air recovery devices provide significant energy reduction, additional energy recovery is possible in laboratories where common HVAC systems serve both low heat load and high heat load spaces. While separation of high heat load spaces onto dedicated HVAC systems allows low heat load HVAC systems to take full advantage of the variations on air-to-air system energy recovery above, the challenge is that research evolves, and a high heat load space today could be low heat load tomorrow. The opposite is just as likely, with changes removing the advantages of separate systems.

This diversity in equipment loads is described in the *I2SL Laboratory Modeling Guideline using ASHRAE 90.1-2019.* The diversity indicated in the guide suggests load profiles (some at full load with remaining spaces at significantly diversified loads) are consistent with recommendations for right-sizing mechanical systems, while acknowledging that some spaces continue to have high heat loads. For laboratories where heat loads vary from project to project, systems that recover energy from the few high heat load spaces can provide trim heating to low heat load spaces. The following describes such an application.

Figure 4 on page 12 depicts a simplified system schematic concept of one method to recover the heat generated from high heat load spaces. This system takes the heat generated from these spaces (e.g., lab freezer rooms and electrical transformer rooms) using local terminal cooling units (chilled beams, fan coil units) and transfers it through a heat recovery chiller to spaces requiring heating (low heat load offices, corridors, and labs). While similar in intent to distributed heat pump systems, this central heat recovery chiller system does not require the many small compressors associated with distributed heat pump systems, thus reducing maintenance concerns. Careful analysis of cooling versus heating



requirements is required, as those loads seldom match exactly, requiring cooling or heating injection into the system when loads become unbalanced. As spaces will change over time, the design must be adaptable.

Figure 4 above shows that heat recovered from the high load areas by a heat recovery chiller can be used for reheat energy and eliminate the need for a boiler. The chiller is a 30-ton internal-heat-shift chiller operating 8,760 hours per year at 1.2 kilowatts per ton (kW/ton) cooling energy input (including pumps and other auxiliaries). The chiller consumes 315,360 kilowatt hours per year (kWh/yr) to produce 3,154 million metric Btus per year (MMBtu/yr) of cooling and 3,942 MMBTU/yr of heating. In comparison, a 0.6 kW/ton cooling-only chiller consumes 157,680 kWh/yr input energy to meet the cooling load along with a 95% gas-fired boiler plant that consumes 4,149 MMBTU/yr to meet the heating load. Based on a source energy assessment and using a factor of 3 for electrical site-to-source energy from the ENERGY STAR[®] Methodology for Incorporating Source Energy Use paper, the heat recovery chiller reduces source energy by 43.5%, while also reducing onsite combustion and the associated emissions.

For smaller applications, heat recovery chillers may not be commercially available or economical. In those cases, a distributed heat pump system can provide savings in energy due to limiting chiller turndown down capacity, pumping energy, and depending on the distribution of loads.

Additional water-to-water recovery can be considered by recovering heat directly from water-cooled equipment, such as from data centers and condenser water heat recovery. Failure scenarios should be considered with direct connection options, as a component failure could immediately shut down all connected equipment and associated heat recovery.

Design Considerations

Following are some considerations that can help determine whether an air-to-air or water-to-water energy recovery system is feasible for a given project.

Schematic Design

- Determine exhaust air classification per ASHRAE 62.1 2022. This may limit the heat recovery options to be considered based on the exhaust air transfer ratio of the heat recovery device available.
- Assess the risk associated with crosscontamination of the air streams for heat wheels, plate heat exchangers and heat pipes. Purge sections on sensible/enthalpy wheels and proper fan arrangements reduce cross-contamination; however, ASHRAE Research Project Report 1780-RP reported significant cross-contamination with molecular sieves and enthalpy wheels at low velocities. There are no cross-contamination issues with run-around loops and split heat pipe systems. See ANSI/ASSP Z9.5-2022: Laboratory Ventilation (on page 14) and ASHRAE

Classification of Laboratory Ventilation Design Levels for additional details.

- Identify energy recovery opportunities. Manifolded exhaust systems are ideally suited to energy recovery because all the potentially available energy can be captured by a single energy recovery system.
- Review internal load profiles for opportunities to reuse heat being generated by lab equipment or other internal load sources.
- Consider the location of the supply and exhaust. If they can be located next to each other, sensible or enthalpy wheels and heat pipes may be considered. Otherwise, modified heat pipes and run-around loops are likely best suited for separate supply and exhaust locations.
- Consider a wrap-around heat pipe or modified run-around loop. If enthalpy wheels are not an option in warm, humid climates where dehumidification can be extensive, assess impact on fan energy of providing higher temperature air to high-load spaces.
- Determine dehumidification considerations. Many labs have a much higher airflow rates, translating to higher discharge air temperatures, and may allow for higher relative humidity (RH) values. Dehumidification energy provides three parts latent and one part sensible for every degree on the saturated curve on the psychrometric chart, so not dehumidifying saves energy. Consider an ASHRAE 55 thermal comfort analysis to take advantage of these conditions. Note, ASHRAE 62.1, Section 5.12 requires a space dewpoint no higher than 60°F, with an exception of space RH no higher than 65% in unoccupied mode not to exceed 12 hours.
- Address the potential for fouling and corrosion of the devices in the exhaust airstream. Routine

maintenance and controls may be sufficient, although the most suitable equipment depends on the particles and chemicals being released into the airstream. Select air filters with a low pressure drop.

- Prepare and review energy models and note where all the energy is going. If heating or cooling is being rejected to the outdoors while cooling or heating energy is used to condition spaces, consider systems that recover energy. This means exhaust air should be discharged at conditions as close to incoming air as possible, which can be accomplished using water-towater energy recovery options.
- Analyze hourly energy modeling output for periods of time where heat is being rejected through a cooling plant while energy is being expended to provide heat in the building.
- Determine space requirements for additional equipment and its impact on design and costs.
- Estimate operation and maintenance costs for the device, as well as replacement costs.
- Calculate the impact of energy recovery on energy costs.
- Include the cost benefit of being able to downsize the heating and cooling systems with energy recovery and redundancy. Benefits include maximizing building square footage due to smaller boilers and chiller plant, piping, pumps, boilers, gas piping and service, chillers, wiring service, switchgear, transformer sizing, and any utility rebates that may be available. Include the increased efficiency for correctly sized equipment versus oversized equipment that will cycle excessively. As all these systems are interconnected, the savings in one discipline can often result in savings from other disciplines.

- Determine control strategies. With system approaches identified, define appropriate control strategies for part-load operation and evaluate recovery systems for potential freezing and frost control methods. The use of bypass dampers or ducts in HVAC equipment reduces fan energy during economizer operation.
- Clearly define the commissioning requirements of the energy recovery devices. An efficient energy recovery system that is not properly controlled will not be able to realize its potential.

Codes and Standards

As with all building components, there are multiple codes and standards that apply to energy recovery. Some standards are for testing the performance of the equipment, while other standards specify when energy recovery must or must not be applied. A brief overview of the relevant codes and standards pertaining to energy recovery are as follows:

- AHRI Standard 1060 for Air-to-Air Energy Recovery Ventilation Equipment rates the sensible, latent, and total effectiveness of equipment, excluding run-around loops. The ratings are performed by an independent laboratory per ASHRAE 84 (see below), except as amended by ARI 1060. The AHRI-certified product directory (latest edition) is a useful resource for identifying various manufacturers and their products and for comparing effectiveness ratings.
- American National Standards Institute (ANSI)/ ASHRAE Standard 84, Method of Testing Air-to-Air Heat Exchangers, specifies the data, equipment, and reporting procedures for testing the sensible, latent, and total effectiveness of air-to-air heat exchangers.

There are similar Canadian and European standards.

- ANSI/American Society of Safety Professionals (ASSP) Z9.5-2022 Laboratory Ventilation references the International Mechanical Code (IMC) for guidance on energy recovery and hazardous exhaust systems.
- IECC 2021 Section 403.1.1 Calculation of Heating and Cooling Loads states: "Heating and cooling loads shall be adjusted to account for load reductions that are achieved where energy recovery systems are utilized in the HVAC system in accordance with the ASHRAE HVAC Systems and Equipment Handbook by an approved equivalent computational procedure. The commentary goes on to say "If these heating and cooling load reductions are not factored into sizing the system, it will be oversized, less efficient and less able to control humidity in the cooling mode. This would defeat the purpose and value of the energy recovery system."
- IECC 2021 Section 403.7.4.2 on energy recovery systems requires energy recovery ventilation based on climate zone, minimum outdoor airflow rate, and hours of operation. The exceptions for laboratory fume hood systems include VAV systems that reduce exhaust and makeup air volume to 50% or less, and fume hoods with direct makeup air supply that is 75% or more of the exhaust rate with heating and cooling temperature limitations. Systems with air economizers require bypass or controls for energy recovery to allow for their operation to be suspended.
- IMC 2021 Section 514 on energy recovery systems prohibits the use of energy recovery wheels in "hazardous" exhaust systems as covered in Section 510. Section 510 provides an exception for laboratories as defined, except where flammable material exceeds

25% of the lower flammability limit of the substance or health hazards concentrations exceed 1% of the median lethal concentration of the substance for acute inhalation toxicity. However, there is an exception in 5.14.2 "Exception: The application of ERV equipment that recovers sensible heat only utilizing coil-type heat exchangers shall not be limited by this section." This indicates energy recovery from these sections shall not be prohibited if a run-around loop or heat pipe coil system is used.

- ASHRAE 62.1 2022 Section 5.13 classifies air based on contaminant concentration, sensor irritation intensity, and odor offensiveness and danger. Table 6-1 and 6-2 in ASHRAE 62.1 2022 provide the classification by occupancy. Depending on the classification of the exhaust air, Section 5.13.3 allows varying amounts of Class 1, 2 and 3 air to carry over to the supply airstream. Class 4 air, including lab hood exhaust, does not allow any carryover, therefore requiring run-around loops or split heat pipes for energy recovery.
- National Fire Protection Association (NFPA) Standard 45-2019 Annex A Explanatory Material A.7.4.2 states: Where fume hood exhaust is manifolded with general laboratory exhaust, energy recovery devices should be evaluated to ensure contaminants are not recirculated through an active purge or filtration treatment. Design energy recovery systems with fail-safe alarm(s) and equipment interlocks to prevent cross-contamination or recirculation from occurring, including shutdown of systems if needed.
- ASHRAE Research Project Report 1780-RP studied the five mechanisms contributing to gaseous contaminant transfer: 1) carryover,
 2) leakage, 3) adsorption, 4) absorption,
 and 5) frosting/condensation for silica gel

and molecular sieve recovery wheels. A new performance parameter, exhaust contaminant transfer ratio (ECTR) is introduced to quantify the contaminant transfer from the exhaust side to supply side. High ECTR was reported for several contaminants. Testing velocities of 50 to 295 feet per minute (fpm) were employed, well below normal commercial applications of 450 to 900 fpm. Sensible heat wheels were not included in 1780-RP.

Energy Modeling Load Profiles

To assess the viability of an energy recovery system, the design team must first review load profiles that reflect the anticipated operation of a laboratory building. The Labs21 Modeling Guide developed suggested load profiles that have since been incorporated into the ASHRAE 90.1-2022 User's Manual for use as a starting point for discussions on project-specific profiles. The recommendation is to model a small number of spaces with constant high internal load (10% to 15% of lab spaces), and to model the remaining with a largely diversified load (85% to 90% of lab spaces). The following graphs indicate sample design load profiles for low and high heat load labs and lab support spaces (see Figure 5 below). The lighting and people loads combined are estimated to be less than 2 W/sf between 8:00 a.m. and 6:00 p.m., and less than 0.3 W/sf during unoccupied hours.

The next step is to assess the cooling load capacity of the ventilation air being provided. Figure 6 on page 17 shows an overlay of the cooling capacity from an occupied/unoccupied ventilation reset system and the diversified internal loads of labs with low-load spaces and a typical office. As the graph demonstrates, there is a large portion of the day when the ventilation cooling capacity (gray line) exceeds the internal loads of these low heat load spaces (orange line), assuming an occupied



Figure 5. Sample Internal Heat Load Profiles for Laboratory and Laboratory Support Spaces





ventilation rate of six ACH and an unoccupied ventilation rate of four ACH. It is these spaces that drive reheat energy use.

While these low-load spaces require reheat, most designs also have a small number of consistently high heat load spaces where internal cooling requirements can be met by supplemental cooling units rather than increased ventilation air. These supplemental cooling units can be a potential source of recovery from heat generated in these spaces. Since the location of these spaces likely varies over the life of the building, they likely cannot be isolated to a dedicated system, so alternative methods are needed.

Figure 7 on page 18 shows the benefit to a building if energy from the high heat load spaces can be shifted to the spaces requiring reheat and result in lower ventilation cooling capacity. The reheat can be mostly eliminated if the heat generated by lab or other equipment (e.g., electric room transformers) in high heat load spaces can be transferred to low heat load spaces. For this example, specifically note that on an overall building average basis, the cooling provided by the total ventilation air only exceeds the averaged internal cooling load for short durations (6:30 a.m. to 7:00 a.m. +/- 7:00 p.m. to 7:30 p.m.). This highlights why models using average loads instead of the *Labs21 Modeling Guide*-recommended approach do not accurately predict reheat needed because there will be spaces needing reheat, as shown in Figure 6 above, while high heat load spaces still require cooling.

Performance Examples

Air-to-air energy recovery lowers energy use and can significantly reduce heating and cooling demands. A large installation of enthalpy wheels in 1991 at the Johns Hopkins Ross Research Building 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 as the hot water and chilled water systems could be downsized (see *Engineered Systems*, September 1995). The enthalpy wheels have performed so well that Johns Hopkins installed enthalpy wheels in its new lab buildings, including the Ross and Cancer Research Buildings.

In 2002, an <u>energy analysis</u> of enthalpy wheels, heat pipes, and run-around loops was performed.

The study analyzed a typical 100,000-square-foot (sf) laboratory in Minneapolis, Denver, Seattle, and Atlanta. Energy costs have been updated below to reflect average electricity and natural gas costs in the United States in 2021 of \$0.112/kWh and \$1.0/therm, respectively.

Figure 6. Sample Assessment of Ventilation Cooling Capacity vs. Internal Loads



Figure 7. Overall Sample Building Ventilation Cooling vs. Internal Load: Eliminates Reheat

- With the move to renewable energy and electrification, these numbers may change substantially.
- Air-to-air energy recovery reduces gas usage for space heating and reheat for dehumidification by more than 35% in all climates (see Table 3 on page 20).
- Savings in peak electricity demand with an enthalpy wheel depend on climate (see Table 4 on page 20). No peak cooling electricity demand savings are predicted for heat pipes and run-around loops because the demand savings are offset by the increase in peak electricity demand from the fans.
- Annual energy cost savings are \$0.42/cfm to \$3.29/cfm of fan air flow (see Table 5 on page 20). Enthalpy wheels, with sensible and latent heat recovery, appear to be cost-effective in all climates. The cost savings obtained with heat pipes and run-around loops are relatively small in warm, humid climates; however, using these devices as wrap-around loops for dehumidification may be cost-effective.

- Only in the hot, humid climate of Atlanta did annual electricity savings occur with the enthalpy wheel; in the other climates, the increased annual fan energy offset the annual electricity savings.
- The greatest reduction (approximately 20%) in cooling plant size occurs with enthalpy wheels in humid climates; the savings are approximately half this amount with sensibleonly recovery devices. In the dry Denver climate, the potential cooling plant size reduction is 10% with all three devices, as the energy recovery devices have limited effect on the design humid cooling day.
- The minimum reduction in heating plant size is 15% with any of the devices. If the building is also being humidified in the winter, the additional latent energy recovery with enthalpy wheels results in an up to 50% reduction in heating and humidification requirements.
- As designs explore applications for electric heating as part of a decarbonization strategy, the cost effectiveness of energy recovery will improve in terms of lower first and operating costs.

Key Issues Concerning 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 run-around loops. Another approach is isolating the fume hood exhaust and recovering energy from the general exhaust only. Total energy recovery is the most efficient option in general exhaust. Note that the chemicals in the fume hood exhaust may become too concentrated and may require additional treatment or special duct construction throughout if separated.

Space requirements and duct adjacencies: Enthalpy wheels and most types of heat pipes require the main supply and exhaust ducts to be located next to each other; run-around loops do not. Additional space is required for the energy recovery device, typically in the makeup air unit and main exhaust duct. Run-around loops also require space for a pump.

Hazardous chemicals: If isolating the fume hood exhaust or condensate from an energy recovery device results in too high a concentration of volatile organic compounds, disposal could become a problem. Potential hazardous waste issues need to be addressed early on. The applicable mechanical code includes specific items that cannot be manifolded.

Humidity: If humidity is being controlled, humidification energy can increase overall steam or hot water energy use by an estimated 25%. The potential energy savings with energy recovery increases, as do the possible alternatives. Desiccant wheels can be used for dehumidification, wrap-around 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. Fixed plate heat exchangers and heat pipes appear to have the lowest maintenance requirements, followed by energy recovery wheels, tilting heat pipes, then run-around loops. Periodic cleaning needs depend on the fouling and corrosion potential of the exhaust air, but cleaning is critically important to maintaining optimum performance.

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

Redundancy: Laboratories usually have redundant cooling and heating systems to ensure control over the labs' environmental conditions at all times. Downsizing their capacity due to energy recovery is required by code, will limit oversizing, and will prevent these systems from being abandoned in place due to limited use. Note that chillers and boilers will operate very inefficiently at low part-loads.

Table 3. Percent Gas Savings

	Minneapolis	Denver	Seattle	Atlanta
Enthalpy Wheel	65%	58%	49%	48%
Enthalpy Wheel With VAV	75%	64%	62%	68%
Heat Pipe	41%	36%	41%	36%
Run-Around Loop	44%	36%	42%	38%

Table 4. Peak Electricity Demand Savings With Enthalpy Wheel (W/sf)

	Minneapolis	Denver	Seattle	Atlanta
Enthalpy Wheel	3 W/sf	1 W/sf	0%	3 W/sf
Enthalpy Wheel With VAV	3 W/sf	1 W/sf	0%	4 W/sf

Table 5. Annual Energy Cost Savings (\$/cfm/yr)

	Minneapolis	Denver	Seattle	Atlanta
Enthalpy Wheel	\$2.45	\$1.54	\$0.80	\$0.90
Enthalpy Wheel With VAV	\$3.29	\$1.91	\$1.37	\$1.78
Heat Pipe	\$1.30	\$0.80	\$0.55	\$0.39
Run-Around Loop	\$1.42	\$0.77	\$0.56	\$0.42

In 2003, at the 120,000-sf Fox Chase Cancer Center in Philadelphia, heat pipes with bypass sections were installed in two 30,000-cfm air handling units. The incremental cost for heat pipes with the indirect evaporative cooling option on the exhaust was \$490,000 in 2023 dollars. Anticipated energy cost savings were \$120,000 in 2023 dollars, resulting in a simple payback of around 4 years. In addition to the typical air-to-air energy recovery systems, an assessment for a 100,000-sf biomedical research building in Massachusetts identified significant energy cost benefits using an internal heat recovery or heat shift chiller (see Table 6 below) as compared to either an all-air system or a system using terminal cooling units to reject heat from, rather than reusing within the building. The increased cooling energy and cost for the terminal units Table 6. Comparison of Heat Shift Chiller to Either an All-Air VAV System or Terminal CoolingSystems With 100% Outside Air Units (but without an energy recovery chiller)

All Air System					
Cooling Campus Chilled Water	318	MMBTU	\$11,934		
Heating	3,942	MMBTU	\$144,536		
Fan Power	257,280	kWh	\$48,343		
		Total	\$204,813		
Terminal Cooling With Campus Ch	illed Water				
Cooling	3,154	MMBTU	\$118,255		
Heating	3,942	MMBTU	\$144,601		
Fan Power	30,243	kWh	\$5,683		
		Total	\$268,538		
Terminal Cooling With a 50-Ton Heat Shift Chiller (Operating at 30-Ton Average)					
Cooling Campus Chilled Water	0	MMBTU	\$0		
Heating	0	MMBTU	\$0		
Fan Power	30,243	kWh	\$5,683		
Chiller Power	315,260	kWh	\$59,237		
		Total	\$64,920		

with campus chilled water is due to the reduction in airside free cooling economizer hours and the year-round chilled water demand from campus. The reduced fan energy with the terminal cooling options is due to the smaller 100% outside air ventilation system airflow combined with low pressure drop local terminal cooling units (i.e., 100% outside air units with recovery have higher pressure drop than local cooling units). In conclusion, selecting appropriate energy recovery devices for the climate and application, properly designing the recovery systems for all operating modes, meeting the applicable codes, and commissioning the system are all important aspects of a successful installation. When an energy recovery system is designed, installed, and operated correctly, it provides significant energy, cost, and environmental benefits.

For More Information

The various types of air-to-air energy recovery devices are discussed in numerous sources. For example, the ASHRAE Heating, Ventilating, and Air-Conditioning Systems and Equipment Handbook covers a wide range of devices, compares their performance, and identifies appropriate applications. The ASHRAE Laboratory Design Guide 2nd Edition includes a chapter on energy recovery and discusses laboratory-specific concerns. Several other good sources of information are listed below.

Air-to-Air Energy Recovery Ventilation Equipment Certified Product Directory. Air Conditioning and Refrigeration Institute (ARI). Arlington, Virginia (<u>www.ahrinet.org</u>).

ARI Standard 1060. Rating Air-to-Air Energy Recovery Ventilation Equipment. ARI. Arlington, Virginia.

ANSI/ASHRAE Standard 84. *Method of Testing Air-to-Air Heat Exchangers*. ASHRAE. Atlanta (<u>www.ashrae</u>. <u>org</u>).

ASHRAE Research Project Report 1780-RP, Test method to evaluate cross-contamination of gaseous contaminants within total energy recovery wheels. ASHRAE. Atlanta (www.ashrae.org).

ANSI/ASSP Z9.5-2022: Laboratory Ventilation, American National Standards Institute.

Classification of Laboratory Ventilation Design Levels. ASHRAE (www.ashrae.org).

International Mechanical Code (2021). International Code Council, Washington, DC.

National Fire Protection Association 45, 2019. *Standard on Fire Protection for Laboratories Using Chemicals*. NFPA. Quincy, Massachusetts.

Reilly, S., and Van Geet, O., 2003. Laboratories for the 21st Century Energy Analysis. <u>https://www.nrel.gov/docs/fy03osti/33410.pdf</u>

Roland Charneux. 2015. *High efficiency heat recovery for laboratories vs IAQ Seminar 19*. Presented June 29, 2015, ASHRAE Annual Meeting, Atlanta, GA.

Authors and Acknowledgements

Otto Van Geet, P.E., NREL <u>otto.vangeet@nrel.gov</u>

Sue Reilly, P.E., Group14 Engineering sreilly@group14eng.com

Michael Fulton, P.E., Western Mechanical Solutions <u>mfulton@westernmechanicalsolutions.com</u>

I2SL thanks Michael Walsh of R.G. Vanderweil Engineers, LLP, who provided updates for a previous revision of this guide.