A PROACTIVE DESIGN STRATEGY FOR FACILITY MANAGERS OF LABORATORY ENVIRONMENTS

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A PROACTIVE DESIGN STRATEGY FOR FACILITY MANAGERS OF LABORATORY ENVIRONMENTS

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ABBREVIATIONS

ASHRAE: American Society of Heating Refrigeration and Air Conditioning Engineers.

AMPS: Amperes

BSL: Bio Safety level

BTU: British Thermal Unit

BTUH: British Thermal Units per Hour

CAV: Constant Air Volume

CFM: Cubic Feet per Minute

F: Degrees Fahrenheit

ft^2: Square foot

fpm: Feet per Minute

HVAC: Heating Ventilation and Air Conditioning

HEPA: High Efficiency particle Air filter

Kwh: Kilowatt hour

Kw: Kilowatt

Kw/Hr: Kilowatts per hour

LAT: Leaving Air Temperature

Lbs: Pounds

OSA: Out Side Air

RTU: Roof Top Unit

Sq. ft.: Square foot

VAV: Variable Air Volume

SUMMARY

The Facility Manager of a laboratory environment continuously walks a fine line between safe and economical operation of that facility. The primary responsibility of the laboratory is to provide a safe environment for personnel while optimizing the space for experiment. Energy efficiency is not a necessary goal. Laboratories typically require HVAC systems utilizing 100% outside air to protect the occupants. Facilities demanding the basic design requirement of 100% outside air can result in annual energy costs 4 to 5 times greater than that of the typical office building requiring 20 CFM per person. With energy costs typically representing a substantial part of an organization's operating budget is it prudent for facility managers to seek opportunities to reduce these costs.

The intent of this research is to show that participation of a knowledgeable Facility Manager, during the initial design phase of a laboratory facility, can result in a finished product capable of easily incorporating a variety of energy efficiency technologies. The scope of this research is limited to smaller chemical laboratories supported with less than 20,000 CFM of comfort air.

When the Facility Manager actively participates in the design process for laboratory environments there is potential for increased HVAC energy efficiency.

A substantial portion of this research has been conducted from the author's daily experience and responsibility for a small chemical laboratory. Additional data was collected using personal interviews among industry experts and fellow colleagues working in the Atlanta metropolitan area with significant laboratory experience. This research focused on the mechanical systems supporting laboratories as they represent the largest percentage in first costs, energy consumption, and offer the greatest opportunity for energy reduction.

The results of this research are intended to provide guidance to Facility Managers to incorporate cost effective energy recovery systems in either new construction or at a

future date. The results of this research project the impact of energy consumption in a small chemical laboratory from the hypothetical installation of a customized energy recovery system.

CHAPTER I

INTRODUCTION

Background

The laboratory needs to provide a safe environment for scientists to complete their research and provide answers to questions resulting in new developments for the global community.[1] The laboratory environment has been instrumental for advancements in the medical, pharmaceutical, electronics and transportation industries.

The most important systems supporting the laboratory environment are the heating, ventilation and air conditioning system (HVAC system) and the exhaust system. These mechanical systems carry responsibility for protecting the occupants from exposure to hazards such as chemical vapors or particulates while providing the required environmental conditions necessary for acceptable experiments, products and materials generated from the lab. Routinely, the materials and products within the laboratory are extremely valuable and if not properly protected can result in significant financial loss to an owner.[2] In light of these financial risks, the Facility Manager must be knowledgeable and diligent in proper operation of the mechanical systems to ensure health, safety and comfort of both occupant and product.

The demand for laboratory environments will increase as society seeks further medical advancements, pursues advancement in microelectronics and resolves impact of biological and chemical warfare. Without doubt, demand for the laboratory environments will increase. For the owner of such facilities to remain competitive they will need look to their facility manager to improve operating efficiency while protecting the health and safety of the occupant. Professionally trained Facility Managers recognize that 100% of savings gained through reduced operating expenses and increased productivity go directly to the company’s bottom line, therefore will focus attention on implementing improved technology for a higher level of operating efficiency.

Energy reduction techniques used in buildings have advanced rapidly over the past decade. Although no wholly new HVAC technologies have appeared in that period, many options have improved, become more reliable or dropped in purchase cost. Still, many HVAC technologies that could cut operating costs, such as variable-speed drives and energy management systems, remain underused as building owners remain focused on first cost and the short sided or no thought of life cycle analysis.

Building codes are another impediment to wider adoption of newer HVAC technology and design. Although some states have excellent energy standards built into new construction building codes, and some have extended their coverage to major renovations, most states either have no code or are still using a code based on ASHRAE 90.1-1989, which is now out of date. All states were to have deployed codes adopting the 1989 standard or something equivalent to it by the mid-1990s. But fully a third of them never did, despite a federal law requiring such action. Building codes are in place to define a minimum level of acceptance.

By July 2004, all states are required to adopt standards in their energy and building codes that mirror ASHRAE 90.1-1999. California, Oregon, New York and others have already moved past that standard and are using ASHRAE 90.1-2001 as a benchmark. It is unclear, however, if the new code requirement will be better enforced than the old one.

This research investigates a proactive design strategy for the Facility Manager of laboratory environments resulting in cost-effective installations of energy recovery systems.

Laboratory HVAC designs result in mechanical designers seeking every opportunity to physically separate the supply air intake from the exhaust air discharge, which typically result in large distance separations between the supply and exhaust air ducts.[3]

Air to air energy recovery systems work from the principle of transferring relatively small differences in heat energy between two air streams. To perform effectively, the heat exchanger surfaces are positioned close together, avoiding loss of heat and quickly transferring this energy from one air stream to another. A Large separation of supply and exhaust air streams often renders subsequent installation of most energy recovery systems cost prohibitive. The option to install energy recovery technologies in mechanical systems with large distances between supply and exhaust ducts require expensive modification of the duct paths or the use of a glycol run around loop system.

The knowledgeable Facility Manager will effectively participate in the design development phase for laboratory facilities, paying attention to detail, requiring the design team to justify their recommendations and achieve a laboratory design capable of meeting long term performance needs. A good design incorporates the opportunity for future installations of innovative technologies improving sustainability of the facility.

Laboratory environments are constructed to accommodate both “research” and “manufacturing” activities. Research laboratory activities will likely encompass infinite material combinations, an eclectic use of the facility and require appropriate design criteria for the potential unplanned experiment result. Laboratories for manufacturing activities are typically designed around a known and specific process, developed in the research lab, then scaled up with intent on production volume.

Laboratories are typically classified into one of four categories, each having unique design criteria related to their intended use. The broad range laboratory categories are Biological, Animal, Chemical and Physics & Microelectronics. Additional sub-classifications have been developed within the four groups and further refine the design criteria to accommodate specialized work. For example “Bio-Safety Levels”, (BSL 1 – 4), relate to hazardous biological research laboratories with emphasis on increasing levels of safe containment protecting the scientist.[4]

Fixtures and equipment will vary within the laboratory, depending on the intent and hazard classification of the work, but the fume hood is almost always present. The fume hood is used to create a negatively pressurized compartment where work is performed allowing the operator to stand outside of the hazardous area. This negative environment is created only with the fume hood connected to a properly operating exhaust fan, drawing sufficient air from the laboratory space, through the hood and depositing it outside the facility.[5] Manufacturers of Fume hoods identify very specific air flow rates and or volumes, to ensure hazardous conditions remain within the confines of the fume hood.[6] These air volumes translate into face velocities at the demarcation line or “sash opening” of the hood. Fume hoods are manufactured to wide range of sizes and shapes accommodating the work required in the lab. See figure 1, a typical Bypass fume hood with vertical sash and Bypass air inlet. The fume hoods then represent a substantial portion of the exhaust air stream from the laboratory and often become the largest factor in the design equation determining the capacity of the HVAC equipment.

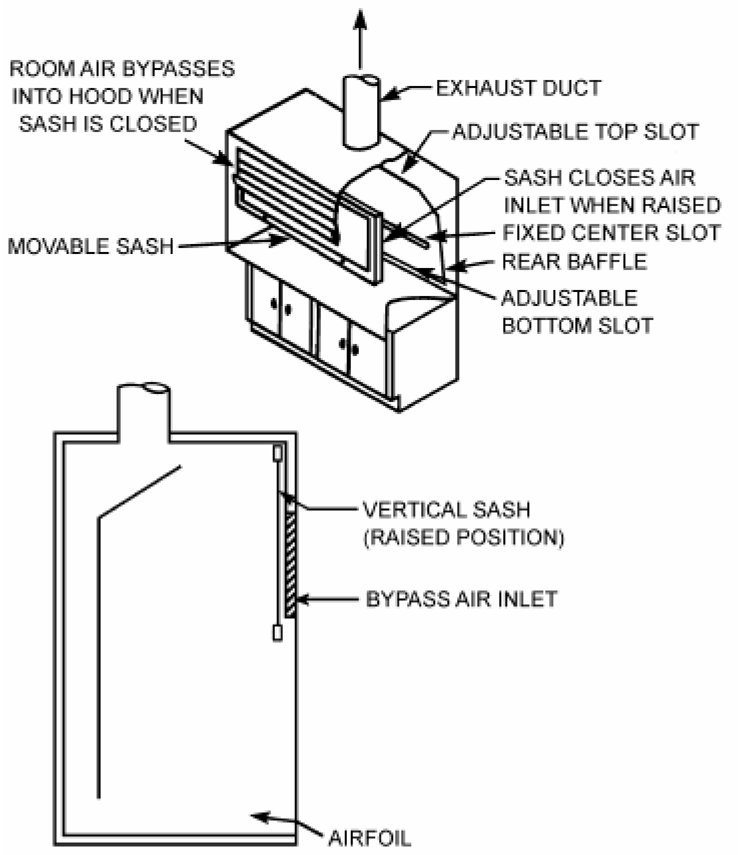

Figure 1 - Bypass Fume Hood with Vertical Sash
and Bypass Air Inlet

The exhaust systems supporting the fume hoods are basically a network of ducts connected to a fan. The design can incorporate either individual fans for each hood or a common manifold system connecting several hoods to a single discharge point. Exhaust air flow can be either constant of variable volume. Selection between these options is often driven by the activities in the lab. In general, the laboratory should operate at a negative pressure so that all discharge air is moving in one direction out the roof. Typically, the exhaust fan is roof mounted and positioned as far away as possible from the air handler to avoid recirculation of the exhaust air.[7]

In order to maintain reasonable comfort or if needed very specific temperature and moisture levels, an HVAC system is incorporated to condition the outside air. The term outside air is appropriate in that most, if not all, of the air supplied to the lab is typically exhausted by way of the fume hood(s). The HVAC system is designed to accommodate multiple criteria such as total volume required for proper fume hood performance, likely a rate between 4 and 12 room air changes per hour and capacity to overcome the cooling load of the work to be performed in the lab. The HVAC system may also be set up as either constant or variable volume air flow, again driven by intent of the laboratory requirements. HVAC systems may be roof mounted or positioned in mechanical areas within the building. Regardless of the position great emphasis is given on locating the air intake away from sources of contamination such as loading docks, cooling towers and of course the lab exhaust itself.[8]

Laboratory mechanical systems have traditionally employed control strategies of constant, variable or combination of the two methods. Constant air volume is a continuous air flow rate into and out of the laboratory. The constant volume approach results in the least amount of controls for system operation, requires larger sized equipment and consumes more energy when compared to the variable volume system. Variable volume systems are designed such that when the lab is not in use, the mechanical systems throttle down, reducing fan speeds and corresponding energy consumption. Variable air volume systems consume less energy to operate, result in smaller sized equipment and require an automated control sequence system to match supply needs to the lab demand. The variable volume system is more economical to operate, it typically results in higher first costs and will certainly require extensive routine maintenance activities to maintain the automated control systems.[9]

Indoor Air Quality

With such large ventilation requirements in the laboratory, one would assume indoor air quality would not to be an issue for these facilities. However, quantifying indoor air quality includes several parameters for consideration. Excessive volumes of air exchange will not necessarily result in acceptable indoor air quality.

The American Society of Heating, Refrigeration and Air Conditioning engineers, "ASHRAE", a voluntary society of engineering professionals focused on the HVAC industry, has been researching Indoor Air Quality for over 30 years. ASHRAE Standard 62 - 2001, "Ventilation for Acceptable Indoor Air Quality", defines; minimum fresh air volumes for a variety of facilities, acceptable moisture levels within conditioned spaces and speaks to acceptable contaminant levels in the fresh air make up supply.

Poor indoor air quality can occur when sufficient levels of contaminants are introduced into a space, perhaps by way of the HVAC system or possibly generated from activities within the space. In case of the former, the outside air stream may be contaminated. Combine poor outside air with an improper filtration application and the indoor air quality is compromised. In case of the later, contaminants can be created within the space, for example microbial growth tied to elevated moisture levels within the space. The facility manager cannot loose sight of their responsibility to deliver and maintain acceptable indoor air quality within the laboratory, even when pursuing energy reduction improvements for the laboratory. Increased costs due to employee absenteeism, productivity or failed experiments can quickly exceed energy savings. The cost of poor productivity can exceed first construction costs in a very short time and should be considered in the design process for any facility.

Laboratory Procurement

The laboratory operating performance is driven by the efficiency of the mechanical systems, specifically the HVAC system responsible for conditioning the outside air. Following a traditional project delivery system of design, bid, and build, the owner will hire an Architectural firm to manage preparation of the construction documents, including initial programming phases. The mechanical engineer is not likely to be a participant in the early design development phases where the size and shape of the facility are defined. Once complete with the design development, changes in size or shape of the facility design can be disruptive and costly to the owner. Based on this project delivery system, mechanical and electrical systems may become limited, impacting future options of additional systems such as energy reduction equipment.

A significant concern for the laboratory owner is the cost associated to the design and construction of laboratory facilities. In new construction the mechanical systems often represent 35% of the total construction budget.[10] If significant emphasis of first costs is a concern of the owner, it is possible that a compromise in the mechanical systems may result since it represents such a large portion of the overall cost. Increased operating costs as a result of poor selection of the initial mechanical systems are not likely to surface in the first year of operation, rather become visible in subsequent years. Costs related to energy consumption, or poor laboratory yield due to inconsistent environmental conditions are likely to occur when the mechanical systems are not properly designed or installed.[11] If moisture levels are poorly managed, the laboratory may serve as a breeding ground for mold.

Research Objectives

Specific objectives of this research include:

Develop a protocol to measure the HVAC system performance as related to HVAC energy efficiency of small chemical laboratories.

Test a design strategy, available to aid Facility Managers, resulting in cost effective installations of energy recovery equipment.

The objectives will challenge the hypothesis "When the Facility Manager actively participates in the design process for laboratory environments there is potential for increased HVAC energy efficiency."

Scope of Study

The scope of this study is limited to:

Chemical laboratories typically found in the pharmaceutical industry.

Small laboratories no more than 6,000 ft.^{2}

Laboratories utilizing 100% outside air.

Laboratories with a total air flow rate of 16,000 CFM.

Laboratories located in the Metropolitan Atlanta, Georgia area.

Laboratories that utilize pressure dependant constant air volume.

Laboratories cooled by chilled water originating from a central chilled water plant.

Laboratories heated by hot water originating from a central hot water plant.

Assumptions of the Subject Laboratory

The exhaust air stream does not contain hazardous chemical components or particulates.

The processes performed in the lab do not result in change to the room temperature.

The lab contains 15 Bypass fume hoods.

Historic weather data collected at the Atlanta International Airport is appropriately matched to a subject laboratory located in Duluth, Georgia.

The information collected from industry experts with first hand responsibility of laboratory operation and design, is a valid research methodology.

CHAPTER II

LITERATURE REVIEW

The review of literature reported includes Laboratory design, HVAC systems, HVAC control strategies and load reduction systems appropriate for Laboratories.

Mechanical system design for Laboratories

HVAC systems for laboratory facilities are one of the most important parts of the building in terms of health, safety, and comfort of the occupants. Identifying the function of the laboratory is the most compelling consideration in determining the appropriate HVAC system design and selection. Air handling, hydronic, control, life safety and heating and cooling systems must all function as a unit and not as independent systems. The HVAC system must conform to applicable safety and environmental regulations. Providing a safe environment for all personnel is a primary objective in the design of HVAC systems for laboratories.[12]

Laboratories typically require 100% outside air which broaden the range of conditions to which the mechanical system must respond. Use of 100% outside air requires an HVAC system to condition the incoming air stream from outdoor conditions to the design discharge for that interior space. The conditioning may require a change in the sensible temperature of 30 or 40 degrees Fahrenheit, depending on the outside air temp. Moisture levels in the outdoor air stream provide additional load on the HVAC system. This compared to a typical office building where 80% to 90% of the conditioned air from the interior space is returned by the HVAC system. In this comparison the load on the Laboratory HVAC system is 80% to 90% greater than the typical office building.

Rarely in less than 1% of all operating hours, are the mechanical systems of 100% outside air designs operating at maximum design conditions, which is equivalent to the absolute hottest or coldest days of the year. More importantly the design engineer will focus attention to the part load conditions that are constantly changing due to variations in the laboratory. Variations are created from internal space loads, fume hood exhaust requirements and the external environmental conditions. Since it is most likely that the laboratory would be modified, for new research projects, the HVAC engineer should consider to what extent redundancy and extended capacity can be included in the current mechanical systems accommodating future needs.[13]

Laboratory construction costs require significant consideration. The mechanical systems alone can represent 36% of the total construction budget, see Figure 2 below.[14]

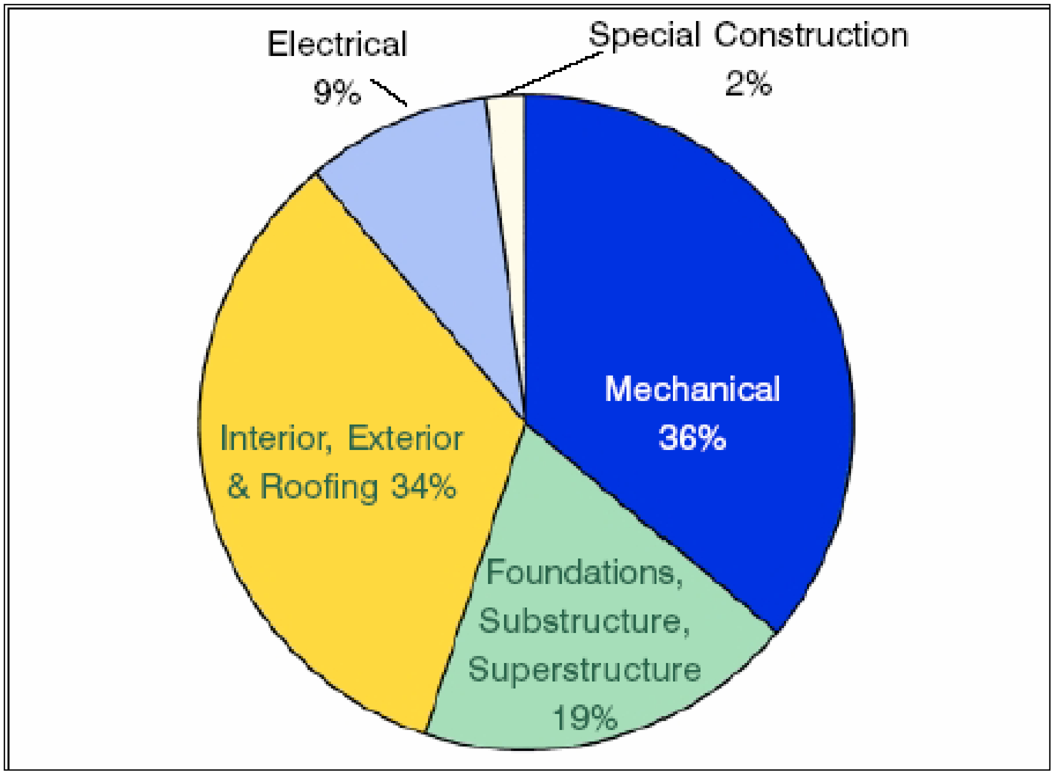

Figure 2 - Laboratory Construction Costs

The laboratory design engineer must consider many details that include but are not limited to; annual weather impact in the geographical area where the lab will operate, the internal heating and cooling loads, the number and size of fume hoods, the location for the mechanical equipment, and the utility services to establish the design parameters of the supporting HVAC system. Initial programming sessions with the owner, are critical to proper design results. The design engineer must take special care in locating the HVAC system to avoid the possibility of air re-entrainment from sources such as laboratory exhaust fans, cooling tower plumes or vehicular traffic associated with loading docks.[15]

Total airflow requirements for a laboratory are generally dictated by one of the following.

Amount of exhaust from containment equipment.

Cooling and heating loads tied to processes within the laboratory.

Minimum ventilation rate requirements as defined by the owner's process.

Fume hoods represent one of the most important pieces of equipment in the laboratory.[16] This equipment creates a ventilated workspace intended to capture, contain and exhaust fumes, vapors and particulate generated by the work performed inside the enclosure. The fume hood represents the return air path; however the air stream should be discharged to the external environment rather than returned to the supply air stream. Many different types of fume hoods exist. Fume hoods have specific exhaust air flow rates, typically between 80 and 120 fpm, to maintain safe conditions within the operator working zone.[17] The exhaust flow rates typically represent the significant factor in the capacity calculation of the air handling and exhaust systems, collectively the mechanical system for the lab.

Minimum air flow rates are generally in the 6 to 10 air changes per hour when the space is occupied. Based upon cooling or heating loads of the processes within the lab it is quite possible the room air change rates exceed 10 and approach 15 per hour. The greater the number of room air changes, the greater the energy consumption to condition the supply air considering the source is typically 100% outside air.[18]

Laboratory ventilation systems may be designed as either constant air volume "CAV" or variable air volume "VAV". Design engineers should carefully suggest CAV or

VAV upon receipt of input from the owner’s maintenance and safety staffs. These critical decisions to be made during initial programming sessions.

Supply air to the lab should be distributed such that temperature gradients and air currents are minimized. Air outlets should not be allowed to discharge directly into or in front of a fume hood or an exhaust device.[19]

Traditional chemistry and physics laboratories commonly use 85% dust spot efficient filters for particulate control in the supply HVAC systems, while Biological and biomedical laboratories seek 85 to 95% dust spot efficiencies. HEPA filtration of the supply air is typically required for laboratories focused on animal research and environmental studies.[20]

Bio Safety Level Labs

Due to the tremendous unrest in the world, with respect to outbreaks of infectious disease and the threat of bio-terrorism, an emphasis on proper design and operation of Bio-safety Level 3 (BSL3) and BSL4 labs is ever increasing. The reasons for developing laboratories at these levels of containment are to protect the user, and protect the environment while providing proper conditions to conduct research. In the BSL4 lab, all supply air and exhaust air for the lab must pass through HEPA filters. To minimize the length of potentially contaminated duct work, the HEPA filters should be located as near as practical to the source. At a minimum, filter housings must allow for filter exchange by a bag in, bag out method.[21]

Design considerations for safe operating laboratories

Paramount to a safe operating laboratory is the exhaust system, responsible for containment, the critical concept of these environments. Described above, exhaust systems will utilize constant or variable air flow, the selection between these two largely depend on the use and activities anticipated within the space. Exhaust air is managed by either the common manifold duct system or individually ducted runs from multiple collection points. Following the design approach of a common manifold, see figure 3, and connecting multiple collectors, (fume hoods), an owner will realize lower ductwork installation costs, fewer components, fewer roof penetrations, a single discharge location, a simple approach to incorporate 100% redundancy at the exhaust fan and opportunity to incorporate energy recovery in new construction or at a future date.[22]

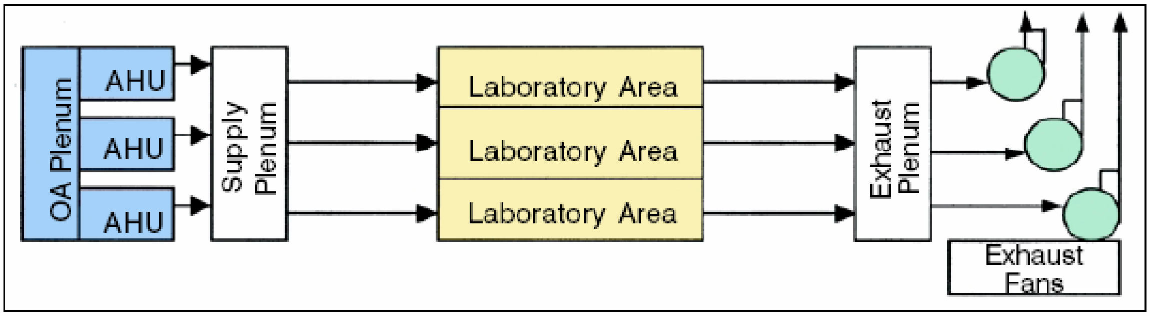

Figure 3 – Common Header Exhaust System

Individually Ducted Systems

Individually ducted systems require unique ductwork from each collection point to the roof and require individual exhaust fans, see figure 4. This approach may overcome concern in loss of use of an entire lab associated to common fan arrangements, but result in extensive first costs related to ductwork, fire rated shafts, loss of floor space, multiple fans and electrical install costs. One inherent problem in this approach; if an exhaust fan stops, reverse air flow is likely in the duct as the laboratory operates in a negative air pressure environment compared to surroundings and inclusion of dampers, fire or back-draft are not permitted in fume hood exhaust ducts.[23]

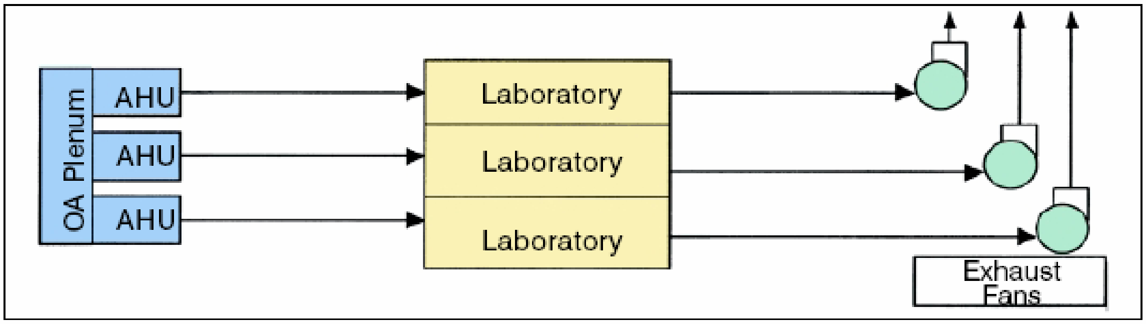

Figure 4 – Dedicated Exhaust System.

Variable Air Volume Control

In the event multiple fume hoods of a laboratory are not expected to be in use at the same time, a design approach of variable volume may be appropriate. The variable volume system requires significant control devices monitoring the use of the fume hoods. Sash positioning is typically used to determine when the hood is in use, providing input to a building automation computer system, automatically adjusting flow control valves, motor frequency drives, fan inlet guide vanes or switching fan speeds from one to another in order altering exhaust air volume to match the need. These systems are referred as pressure independent and require a substantial amount of control and automation which in turn require regimented maintenance programs and a highly skilled labor force to guarantee consistent operation.[24]

Constant Air Volume Control

The constant air volume exhaust, (CAV), is significantly less complicated to install and operate however are typically the least economical to operate. Many laboratories that were considered CAV systems in the past were not truly constant. Variations in air flow of a CAV system may be related to filter loading in the supply or return air stream, changing pressure drops across coils, outside wind speeds, door or window positions inside the lab, belts slippage on the fan(s) and fume hood sash positions. In the most basic form a CAV system may be uncontrolled where by it is not able to adjust devices within the exhaust system compensating changes in air flow.[25]

Slightly more sophisticated is the control system where electronic signals from a pressure transmitter adjust a variable frequency drive at the supply fan and maintain consistent air volume. For laboratories that are not considered hazardous and do not have stringent safety requirements, the uncontrolled approach may be appropriate. Laboratories housing hazardous operations or involvement with toxic substances should incorporate a controlled approach to maintaining the required air volumes.[26] There are several accepted control strategies to accomplish a true CAV system.

Ventilation

Ventilation requirements are quite broad across the various laboratory types. Containment laboratories can require as few as 3 to 4 fresh air room changes per hour, in event of a Biosafety Level 1 lab, or as many as 15 fresh air changes for primate research labs.[27] There are many design criteria that will go into formulating the minimum number of fresh air room changes such as the number and type of fume hoods installed, amount of heat generating equipment to be utilized in the lab and specific safety requirements associated to the materials handled in the lab.

Temperature and humidity control requirements will vary depending on the activities performed in the laboratory and the type of mechanical equipment installed to manage the supply air stream. ASHRAE Standard 62-2001 recommends that the relative humidity in habitable spaces be maintained between 30 and 60% to minimize the growth of pathogenic organisms.[28]

Cost of Poor Performance

"Over the 20-Year life Cycle of a prototypical 100,000 square foot building, 5% of the cost is spent on design and construction, 10% on operation and maintenance and 85% on the salaries of the personnel working in the building. Even a 1% increase in productivity would increase the bottom line exponentially"

"The HVAC system consumes 50 – 60% of the building energy cost and generates 80 – 85% of tenant complaints. "

These statistics were developed by the General Services Administration, (GSA), within their "HVAC Excellence in Federal Buildings" action plan.[29]

Mechanical system and moisture levels in the Laboratory

Indoor air quality is impacted in several ways other than moisture related issues. Poor indoor air quality will result from unhealthy levels of toxic gases such as carbon dioxide or carbon monoxide both which are typically resolved with proper levels of fresh air make up in the ventilation system. Particulate issues can result in unhealthy indoor air quality and likely stem from insufficient filtration and poor filter maintenance programs. Indoor air quality is directly impacted by the quality of the outdoor air supply which may be poor as result of exhaust discharge from neighboring industries.

In laboratories, the value and importance of moisture control varies widely. Often the economic value assigned to the experiment or product development within the lab is significant. A prime example being a pair of genetically-modified laboratory mice sold for $750,000 in 1999. This figure is especially startling considering several thousand mice can be house in a relatively small lab. It would be most unfortunate if the HVAC system allowed those creatures to develop a skin rash, or allowed unhealthy fungus to grow in the bedding of their cages. Poorly managed tolerance levels of relative humidity may lead to those costly problems. In contrast a teaching laboratory in high school has less sever relative humidity control requirements.[30]

As mentioned earlier, laboratories have differing performance criteria. Biological laboratories often control humidity to simplify the task of maintaining stable dry bulb or “sensible temperature” in the lab. Depending on the capacity of the mechanical system supporting a given biological lab, if the outdoor relative humidity were to change rapidly in the case of warm afternoon followed by a cool evening the HVAC cooling load would dramatically shift from a high sensible to a high latent load requirement that evening. By mid morning the mechanical system would likely begin to see an increase in the sensible load as the outdoor temperature rises through the day’s progression. The unstable temperatures and relative humidity may influence the rate of reactions in biological studies. These problems are typically solved with focus on additional equipment to dehumidify the outside air stream prior to the inlet of the primary HVAC system.[31]

In animal research facilities the usual purpose of humidity control is to keep the animals healthy against mold and fungal growth. In scale up manufacturing labs the focus is control to maintain environmental conditions identical to those documented in smaller scale laboratories where the initial product development occurred. In other cases humidity is controlled to eliminate buildup of electrostatic charge a fatal condition for physics and electronic research.[32]

The single largest moisture load in the laboratory environment results from the ventilation requirements and is witnessed typically in the summer months with cooling requirements for this air stream. The need of 100% outside air far outweighs the combined total moisture loads from all other sources including people within the space, infiltration, doors and windows, wet sinks / glassware. In the winter months the single largest humidification load comes from the same ventilation requirements requiring significant heating of the air stream.[33]

In the event the mechanical system's control logic is established with the sensible temperature as the primary factor, the worst performance scenario could develop at the time when the sensible temperature of the outside air supply is near that of the indoor set point and the mechanical system is operating in a part load condition. The design goal may be saving energy by throttling back on both cooling and heating capacity, but at the extreme risk of poor indoor air quality related to unmanaged moisture levels introduced to the lab.[34]

In most commercial buildings, the sensible heat loads dominate the design of the cooling systems. But in a laboratory, the huge amount of excess moisture in the ventilation air should increase the attention given by the designer to the latent loads. In all but desert and high altitude climates, the annual latent load in ventilation air outweighs the sensible load by 4:1 or even 6:1. Design engineers should utilize peak dew point values not peak dry bulb values when designing laboratory HVAC systems.[35]

Load Reduction Strategy for the Laboratory HVAC System

With the vast majority of laboratory environments requiring 100% make up air supporting the work stations and production areas they are burdened with the high energy costs for heating and cooling these air streams. One strategy to reduce these costs is to reduce the load on the mechanical system. Another strategy is to reduce the volume of air introduced to the laboratory, thereby reducing the load on the mechanical systems, the variable air volume approach. As explained earlier this solution requires a significant level of electronic supervision, automated controls and a well educated maintenance staff to maintain the performance of variable air volume.[36]

Laboratory owners with older equipment, limited funding, smaller maintenance staffs or older facilities may not be willing or able to incorporate the control infrastructure required for variable air volume. An appropriate solution for this case is the air to air heat exchanger, transferring energy from the exhaust air stream to the supply stream and in turn reducing the load on the mechanical system.

Sensible and Latent Loads

When referring to “load” on HVAC systems there are two components, “Sensible” and “Latent”. Both are always present in the incoming or return air stream, the ratios continuously changing, the ratio is largely dependant on the percentage of outside air in the return air stream and both have influence on the air quality in the space. Latent load is the amount of moisture that needs to be removed from the air, while sensible load is the amount of heat that must be removed to control the temperature. The impact of load each place on an HVAC system is unequal, typically a two to one ratio with the Latent component representing the larger of these two. In summary removing moisture is twice as hard as lowering temperature and both combine for the total load on an HVAC system.

Load Reduction Options

There is a finite group of equipment options for load reduction in HVAC systems, some of which fall under the general category of air to air heat exchangers. This group of equipment includes the likes of rotary heat wheels, cross flow plate heat exchangers, closed coupled water coil loops and heat pipes.[37] There are numerous off takes within the core group with alterations generally involving the method of control utilized, but in the end the design reflects back on one of the core concepts. These air to air heat exchangers may transfer only sensible, only latent or both forms of energy.

Air to air heat exchangers have been used in the HVAC industry for more than 100 years. The application or intent of using an air to air exchanger is simply to capture as much energy from the exhaust air stream as possible and reapply the same to the supply air stream.[38] In one way the load of the incoming air stream is altered prior to reaching the

HVAC equipment. The goal is to reduce load, but this process can have a negative effect if proper control is not followed. See Table 1 for summary comparison of the load reduction options discussed within this research.

Rotary Wheels

Rotary wheels are more frequently selected by mechanical engineers for applications of load reduction in general office or manufacturing environments. They technically have ability to transfer both sensible and latent energy by incorporating exchanger surfaces of treated paper or plastic film able to capture latent, moisture, energy. These wheels, often referred to as "energy wheels", do result in significant levels of cross contamination between the exhaust and supply air streams as such their application in laboratory environments is limited at best and generally unaccepted.[39] Rotary wheel effectiveness is significantly reduced with particulate contamination, therefore requires additional filtration upstream and a regimented preventive maintenance program.

Cross flow Plate Heat Exchangers

The cross flow plate heat exchanger transfers heat from conductance between two air streams. The technology accomplishes the conductive exchange between the air streams on the primary and secondary sides of the exchanger. These heat exchangers are typically single units installed directly inside the HVAC system, requiring the exhaust air to be ducted through the supply air unit. Generally these devices also generate significant pressure drops and are sometimes supplied with new packaged HVAC systems custom built for a particular application. The possibility of cross contamination always exists due to the proximity of the two air streams and is of particular concern in the event of poor or deferred maintenance. Due to maximum ideal transfer efficiencies of 60% the plate type heat exchangers are not commonly used in laboratory load reduction applications.[40]

Aqueous Coil Loops

Closed coupled aqueous coil loops, commonly referred to as runaround loops, consist of a two or more exchangers, coils, interconnected in a closed loop circuit typically with copper tubing. The closed loop circuit requires a circulating pump and is filled with an aqueous solution, typically a glycol and water mixture, acting as the energy transfer media.[41] This approach offers significant strength over wheels and plate exchangers by allowing the designer to separate or leave separated the exhaust air stream from the make up air stream. It does require an additional energy input source for the circulating pump and is easily controlled on and off. This load reduction approach is effective transferring a limited amount of sensible energy but creates additional complexity discouraging many design professionals. However this technology will allow the heat transfer surfaces to be separated as may be required for energy recovery. See Figure 5. The approach also effectively eliminates any concerns of cross contamination between the exhaust and supply air streams and therefore makes it one of the more frequently specified energy recovery systems to reduce ventilation based energy consumption, especially in the winter, for facilities with large outside air requirements such as smoking rooms, assembly rooms, laboratories, operating rooms and clean rooms.[42]

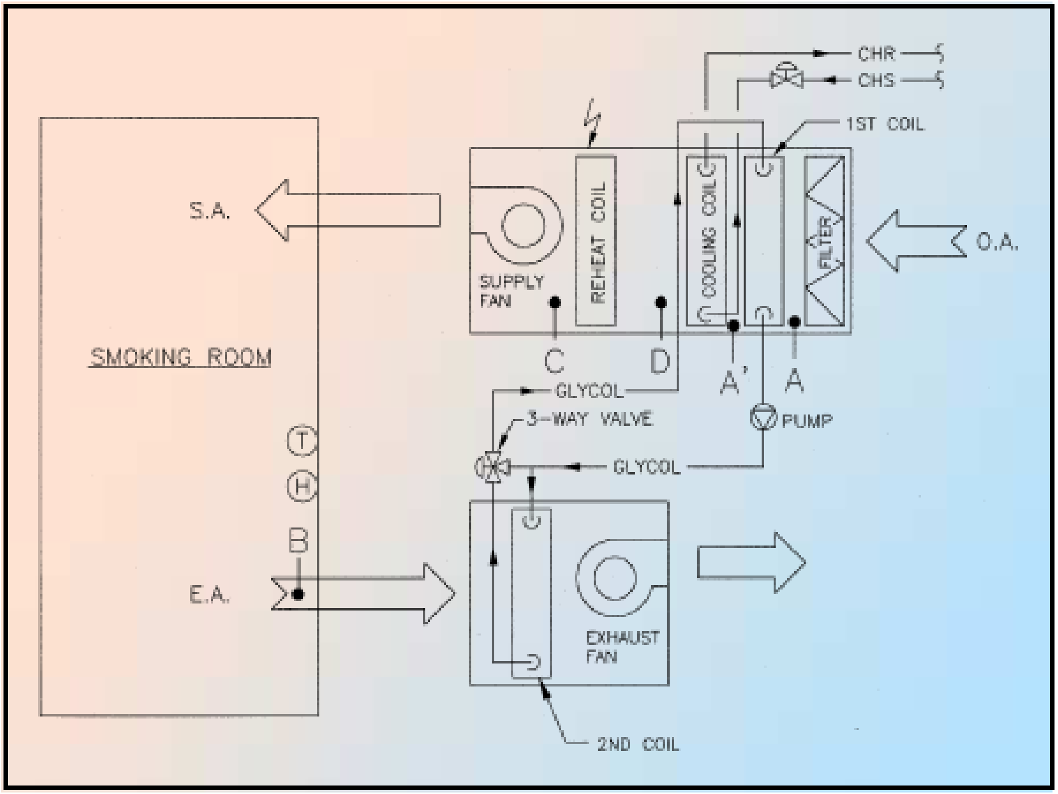

Figure 5 – Runaround loop heat recovery system.

One manufacture in particular, StrobicAir Corporation, located in Harleysville Pennsylvania, and well known in the exhaust fan industry for their Mixed-flow impeller roof exhaust systems, now offers a line of exhaust fans incorporating energy recovery coils within the fan mounting curb. According to Paul A. Tetley, Vice President and General Manager, “Mixed-flow impeller roof exhaust systems have begun to offer an on-board alternative to losing this energy via exhaust. Through the use of unique heat recovery modules, warm or cool air is removed prior to its discharge into the atmosphere, and transferred back into the building's intake ventilation system. As an example of its efficacy, consider that for each 1° F of heat added to outside air, energy costs are reduced about 3% with this method; and it is not unusual to see heating energy cost reductions of 30% or more. Similar savings - although not quite as dramatic - may also be realized for cooling.”[43] The energy recovery modules follow the concept of runaround loop technology as the distance and elevation between the base of the exhaust fans, where the modules are mounted, and the HVAC make up air inlet may be substantial. Pumping a glycol water solution is the only alternative to re-routing air ducts.

Heat Pipes

The final load reduction approach considered in this research is a system incorporating heat pipes. In its simplest form a heat pipe is a sealed tube that has been evacuated, charged with a precise amount of refrigerant then sealed. A pictorial description of the function of a heat pipe is found in figure 6. Refrigerant A absorbs heat from a heat source, in this figure the heat source being warm air passing over. The refrigerant changes state and rises as vapor B. At point C the vapor gives up heat to a heat sink, cool air passing by, when it condenses back to a liquid D. The condensed refrigerant returns, by gravity, completing the energy transfer cycle. This vaporizing and condensing process continues as long as there is a temperature differential between the two ends or sides of the heat pipe.[44]

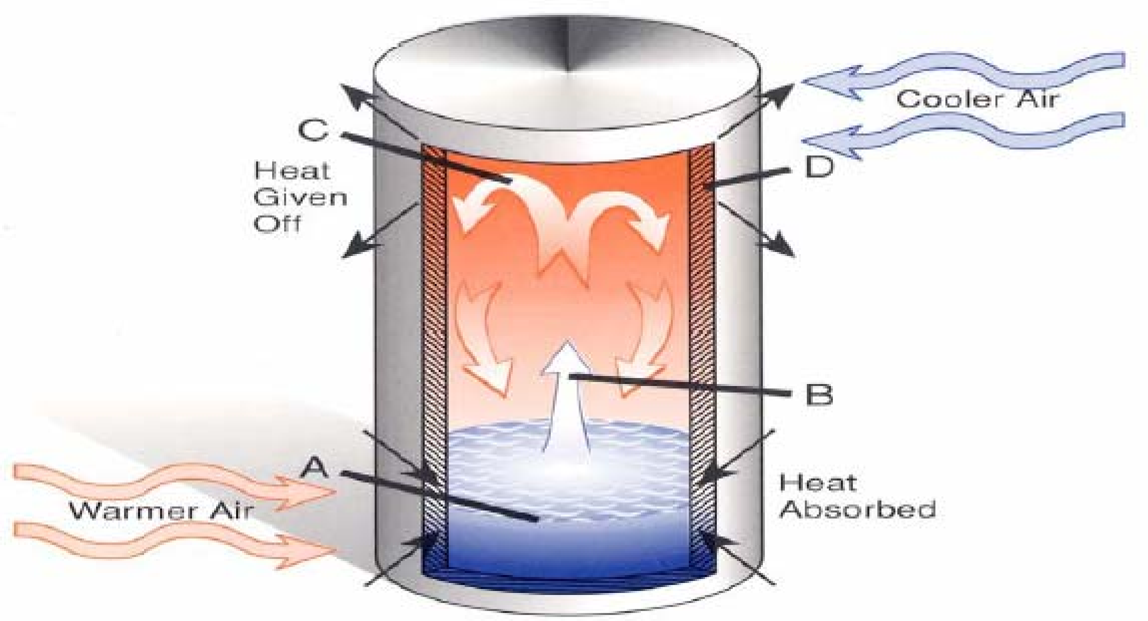

Figure 6 - Heat Pipe Operating Principle

The physical installation of a heat pipe system is similar to that of the runaround loop in that it includes two coils, typically made of copper then surrounded by aluminum fins, one coil is placed in the exhaust air stream and the other in the make up air stream.[45] The heat pipe system then separates its performance from the water based glycol fluid as it requires no pump to transfer the heat between the two coils. Instead it utilizes the principle of change of state in a refrigerant fluid to transfer heat, much like all refrigerant based equipment, without requiring moving parts to transfer the refrigerant from evaporator to condenser and back again. The heat pipe system will require careful consideration during installation to insure the refrigerant gravity flow is proper from one coil to the other. Heat pipe coils may be installed in either a vertical or horizontal position, although in a vertical arrangement energy transfer occurs in only one direction. The two coils may be separated up to a reasonable distance, generally not exceeding 20 feet and can be effectively incorporated into existing HVAC installations.[46]

Table 1 – Over view of Energy Recovery Equipment

	Energy Wheels	Cross Flow Plate Heat Exchanger	Aqueous Coil Loops (Run-arounds)	Heat Pipes
Allows cross contamination of the opposing air streams.	Yes	Yes	No	No
Requires frequent maintenance.	Yes	Yes	No	No
Requires additional energy source to function.	Yes	No	Yes	No
Requires opposing air streams positioned very close together.	Yes	Yes	No	No
Transfers both sensible and latent heat energy.	Yes	No	No	No
Transfers sensible heat energy only.	No	Yes	Yes	Yes

CHAPTER III

METHODOLOGY

This author has selected a research methodology of triangulation to effectively quantify the value of a proactive design approach by the Facility Manager. Triangulation is the use of two or more research methods to investigate the same thing, such as experiment and interviews in a case study project. A postal or other questionnaire to a generalized, representative sample of respondents would assist the researchers to appreciate the general validity of the findings from the particular case study and would serve to aid understanding of its unique and generally applicable features. The triangulation methodology is recognized as an effective methodology by Fellows and Liu, in their text “Research Methods for Construction”, specifically in approaches to empirical work.[47] The methods employed by this author include the literature review, collection and analysis of empirical and extrapolated data from a subject laboratory and Expert Interviews, conducted from a limited group of professionals having daily responsibilities either designing or operating laboratory environments similar to the subject laboratory.

This author, being a practicing facility manager for the CIBA Vision Corporation, will utilize a real chemical laboratory for the collection and analysis of empirical data in this research. He was involved in the original design and construction management of this laboratory and over the past 2 years has monitored the operating performance of the lab. The author intends to recommend CIBA Vision employ an energy recovery strategy offering reasonable return on investment at the conclusion of this research.

The Subject Laboratory

In the Spring of 2001 a leading manufacturer of contact lens and lens care products initiated a capital project relocating two existing Formulary laboratories to a new manufacturing facility located in Duluth, Georgia. The existing process included steps of distillation, mixing, filtering and cold storage to manufacture formulations from which two unique contact lens products are cast. Raw materials used to produce these formulations included solvents with minimal flammability concerns, inhalation limits and general odor concerns for the lab technicians. There were no pH or particulate issues associated with the process. The original laboratory performance was quantified as inconsistent, prior to the relocation, with emphasis placed on fume hood capture velocities and lab temperature and humidity stability. The Facility Manager of the proposed site was selected to manage the design and construction of the new laboratory space.

Capital planning for the project had been prepared a year earlier. The project excluded funding to purchase new fume hoods and was extremely efficient in allocation of both time and money. The proposed location offered 6,000 ft^2 of unfinished space with minimal lighting and fire protection. The space being on the top floor offered direct roof access.

Discovery phase of the project revealed performance issues related to the fume hood velocities and general environmental conditions were identified. The original comfort air system included a variable air volume, direct expansion, roof top air handling unit without consideration for room pressure control. A total of fifteen (15) fume hoods and vent sinks incorporated individual exhaust fans with a cut off switch located at each unit. The mechanical systems were inappropriate for the process requirements and business continuity risk from the potential loss of a formulary batch and the subsequent down time to the lens manufacturing floor.

The mechanical design engineer recommended a mechanical system of constant air volume exhaust and supply, the supply incorporating 100% outside air and individual zone reheat coils. The HVAC supply system would be connected to an existing central chilled and hot water plant. The 6,000 ft^2 layout would be divided into five compartments or zones, including raw material and finished goods storage, incoming material quality assurance, a batch color blending process and the two base formulary labs. The two formulary labs accounted for over 80% of the total conditioned floor space. Based on the design recommendations the facility manager knew that energy consumption would be substantial compared to other areas within the facility. Conversely maintenance requirements should be relatively low and performance reliable. The approach being a constant air volume configuration was determined best to overcome the performance issues in the current building, especially considering that no capital dollars were budgeted to replace the existing fume hoods.

The initial mechanical equipment layout followed traditional design requirements by placing the supply air handler along the eastern edge of the roof area and the redundant exhaust fan set along the western edge of the roof, see figure 7. Both supply and exhaust systems incorporated a manifold duct arrangement with balanced branch lines leading to a final collection header and turning up through the roof directly under the air handler or exhaust fans. The design goal was clear, maximum separation of supply and exhaust air streams, minimal exposed ductwork on the roof. Cost projections were within budget allocations, yet the design did not meet the project requirement for energy efficiency and at this point time allocation for the design process had nearly expired.

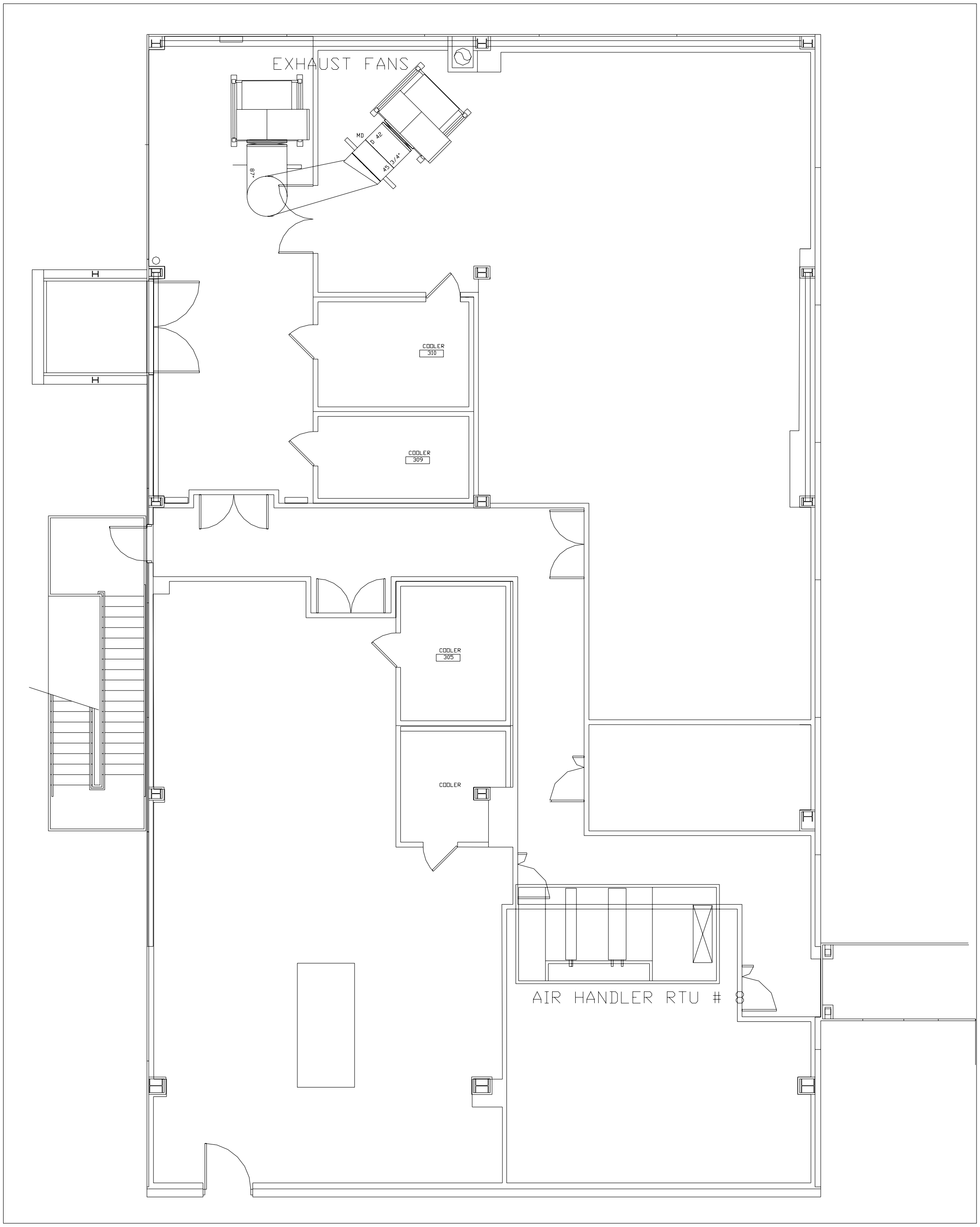

Figure 7 - Initial mechanical system layout

At the conclusion of the design phase the Facility Manager and the mechanical engineer had reworked the mechanical system layout developing a proactive idea resulting in a design strategy offering easy installation of several types of energy recovery systems on a future date. The results were repositioning the supply air handler to a central location on the roof, requiring a change in the supply duct positioning but without change in cost of sheet metal. Additionally the final exhaust air discharge header would be positioned parallel to the outside air handler, once extended to the roof level, upstream of the fresh air intake, routed directly beside and in plane with the air handling unit. Once past the air handler, the exhaust header would be angled towards and connected to the redundant exhaust fan set. The exhaust fans did require repositioning to overcome a weight concerns on the roof joist, an outcome from repositioning of the air handler. See figure 8.

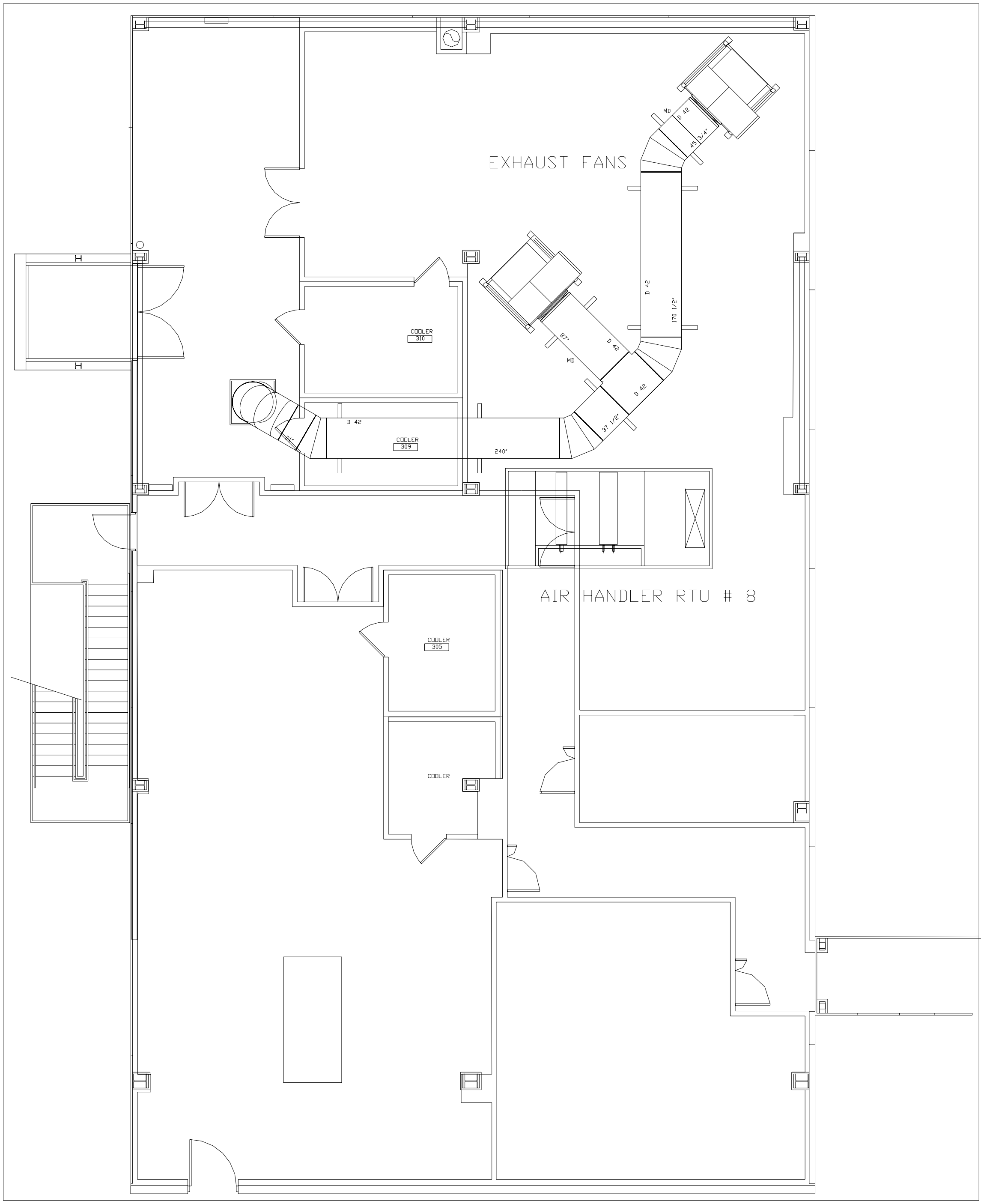

Figure 8 - Final layout of mechanical systems.

The revised exhaust duct layout required an additional 15 feet of 42” diameter duct and an additional 90° fitting while the supply air duct was shortened. The sum of the two changes resulted in no increase to the construction costs. In January of 2002 the laboratories were successfully relocated to the Duluth site.

The final mechanical system of the subject lab resulted in two (2) single speed exhaust fans with capacity of 16,000 CFM each. The roof top air handler, (RTU) was connected to existing chilled and hot water loop systems and has a fan capacity of 15,700 CFM. Both supply and exhaust systems are constant air volume resulting in consistent fan energy consumption year round, regardless of an energy recovery system. The only systems consuming energy, which offer opportunities for reduction, are at the chilled and hot water coils of the HVAC system. With both chilled and hot water distributed from a loop system, the best opportunity of energy savings is to reduce the load placed on these respective loops and ultimately realized in the central plant. The Author makes the assumption these central loops will continue supplying water to a multitude of other use points through out the building, reductions in water flow at this specific air handler will be insignificant. Any load removed from the central water loops is less work at the primary central plant system and are the energy reductions achieved.

Data Collection

In August of 2003 the request was made to install additional sensors in the exhaust and supply air streams of the subject lab, quantifying the actual performance of the air streams and allowing calculation of energy consumption at each step in the air conditioning process. Figure 9 depicts the final instrumentation layout added to both the supply air handler, RTU 8, and the exhaust air streams. Table 2 includes the specifics of each measuring devices. The descriptions noted in the “Sensor symbol” column are a direct reference to Figure 9.

Table 2 - Sensor List

Sensor symbol	Function	Technical Specifications
EA-T and EA-H	Temperature and Humidity of the exhaust air stream	Johnson Controls TrueRH Humidity Element with Temperature Sensors. Model HE-67N2-0N00P.
PH-T	Pre-Heating coil discharge temperature	Johnson Controls Averaging Temperature Sensor model TE-6316P-1
OA-T, OA-H, PH-H, CC-T, CC-H, DA-T, DA-H	Temperature and humidity measurements within the air handler	Johnson Controls Surface-mount duct Humidity/Temperature Sensors. Model HE-67N2-0N0GS
ZN-T and ZN-H	Temperature and Humidity measurements in the lab space	Johnson Controls TrueRH Humidity Element with Temperature Sensor, model HE-67N2-1N00W.
SA-FLOW	Supply fan air velocity. Calculating air handler volume.	EBTRON model STx104-F, fan inlet airflow measurement.
EA-FLOW	Exhaust air velocity, calculating exhaust air volume.	Paragon model FE-1000 Airflow measuring element.

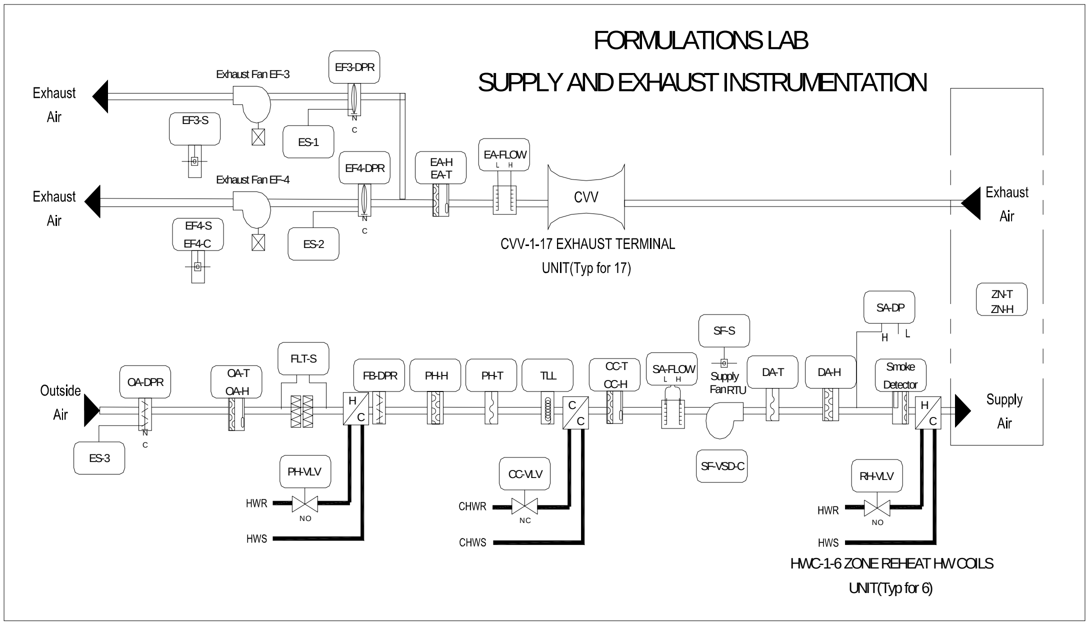

Figure 9 - RTU Expanded Instrumentation

The instruments were successfully installed in late September, 2003 with data collection beginning early October of 2003. One data point was collected each hour, on the hour, from each instrument. The data was captured and stored using the facility's existing computerized building automation system which is a Johnson Metasys, release 11.00. The data was off loaded to a spread sheet application at the end of each month. The data was then analyzed to determining the minimum, maximum, median and average value for each instrument. A total of 4 months data are summarized in table form in Appendix D.

Data Extrapolation

The author's goal, from the data collection, is to identify true cost benefit from incorporating a specific type of energy recovery technology into the subject laboratory. To do so will require calculation in annual load reduction from the proposed energy recovery system. With only 4 months of empirical data available, the author will need to extrapolate the remaining 8 months data impact.

The subject laboratory being 100% outside air requires the air handling unit, RTU #8, to respond to the continuous changes of the outdoor environment. The author has obtained access to a combined 23 year historical data base of weather data from the Air Force combat Climatology Center, (AFCCC). The data was collected from the World Meterological Organization station, (WMO) # 722190, located at the Atlanta International Airport, Georgia. The period of record is from 1973 to 1996. The data is assembled in "bins" of 5 degree Fahrenheit increments, beginning at -10 and increasing up to 104. The data base is an average of the 23 year history providing 8,760 observations within the appropriate bin segments. This 23 year historical summary is included in Appendix E. To avoid potential overlap in the number of hours a given outdoor temperature occurred in the year, the author has decided to utilize only the outdoor dry and wet bulb bin temperatures from the Atlanta weather data base to represent an entire year's impact in supply air to the RTU. This data and two accepted engineering formulas will allow accurate calculation in energy consumption of the existing mechanical system. The formula will also accommodate accurate calculation of energy reductions from a proposed energy recovery system.

The final mechanical system of the subject lab resulted in two (2) single speed exhaust fans with capacity of 16,000 CFM each. The roof top air handler, (RTU) was connected to existing chilled and hot water loop systems and has a fan capacity of 15,700 CFM. Both supply and exhaust systems are constant air volume resulting in consistent fan energy consumption year round, regardless of an energy recovery system. The only systems consuming energy, which offer opportunities for reduction, are at the chilled and hot water coils of the HVAC system. With both chilled and hot water distributed from a loop system, the best opportunity of energy savings is to reduce the load placed on these respective loops and ultimately realized in the central plant. The Author makes the assumption these central loops will continue supplying water to a multitude of other use points through out the building, reductions in water flow at this specific air handler will be insignificant. Any load removed from the central water loops is less work at the primary central plant system and are the energy reductions achieved.

The energy calculations are representative of actual energy consumed by the central energy plant, operating in a primary - secondary mode to support the subject lab. All cost projections will be used consistently to benchmark operating costs in the current mode of operation and with hypothetical installation of the proposed energy recovery system.

Based on fact the mechanical systems supporting the subject lab operate in a constant air volume mode and will remain the same with successful incorporation of an energy recovery system, the author makes the assumption there is no change in energy consumption at the fans, dampers or valves.

Expert Interviews

Following the text “Research Methods for Construction”, by Richard Fellows and Anita Liu the author prepared a list of interview questions specific to laboratory mechanical systems. A specific group of 15 respondents were selected based upon their professional responsibility and experience of laboratory environments. Of the 15 experts selected, 13 responded to the questionnaire, the results are summarized in the results chapter.

The range of experts included Professional engineers, typically mechanical engineering backgrounds, having first hand experience in the design of laboratory mechanical systems and Facility Managers having daily operating and maintenance responsibilities for the laboratory. Professional interviews were conducted with, primarily, a line of closed ended questions focused on clarifying design and equipment options known to improve operating efficiency for the laboratory.

Each interview was conducted by forwarding the questionnaire, by email, to the respondent, allowing them 24 to 48 hours to prepare their responses, the author then called the interviewee and collected their response via telephone conversation. The list of questions included a total of 24 closed ended questions followed with a single opened ended question. The full questionnaire is included in Appendix A. The line of questioning was designed to quantify recent industry attention in the following areas. 1) Indoor Air Quality of Laboratories, 2) Interest level for energy recovery in laboratories, 3) Identify typical design parameters employed for safe laboratory operation and 4) Develop an order of rank in the five (5) most common energy recover techniques to multiple scenarios. From an overview perspective the line of questioning is designed to qualify support of the author's supposition that a design paradigm exists which typically renders future installations of most energy recovery techniques cost prohibitive due to the installation distance between the supply and exhaust air ducts.

The final open ended question was designed to identify the frequency at which the group of experts would agree in installation of the same energy recovery technique proposed by this author. Results of the expert interviews are summarized in the following chapter.

CHAPTER IV

FINDINGS

Data from the Subject Laboratory

Performance data collected over the four month period of October, November, December 2003 and January 2004 provide clear visibility in consistency of operation across the subject laboratory's mechanical system. The data consists of over 61,650 measurements and has been condensed to a minimum, maximum, median and average value for each sensor category, by month. A table of these condensed values is included in Appendix D.

A summation of the data highlights are as follows:

The lab air supply (RTU) averages 15,500 CFM.

The lab exhaust air averages 15,600 CFM.

The lab as a whole is under negative pressure with respect to the outside environment.

The exhaust rates from subject laboratory #1 equal 27 room air changes per hour.

The exhaust rates from subject lab #3 equal 10 room air changes per hour.

Labs 1 and 3 combined account for over 80% of the total air volume managed by the HVAC system.

The excessive room air change rates require the incoming air streams to be heated by zone reheat coils equal to the desired room temperature.

The leaving exhaust air temperature is equal to the space temperatures.

The zone reheat water valves are open an average of 45% to 60% of full position, all four months, suggesting the need for continuous reheat.

Realizing the supply air discharged form the air handler remains the same temperature year round, the author expects these zone reheat valves to be open year round providing sensible zone reheat in the subject laboratory.

Based upon the four month data collection there is confirmation the air handler is constantly adding energy to an outside air stream in the form of cooling or heating to provide a 55 degree Fahrenheit discharge air temperature to the individual zone laboratories. The individual laboratory zones then add heat energy to achieve the desired space temperature. The key variable driving the energy requirements of the air handler is the outside air stream. The key variable driving the energy requirements of the individual zone reheat is the room air change rate. The data supports the information covered in the literature search indicating economical benefit from the addition of an energy recovery technology.

Annual cost of operation for the Subject Laboratory

Calculation of the annual energy cost for the subject laboratory was completed using the historical Air Force weather data to calculate an energy requirement, BTU, then converting to therms for amount of heating energy and the resulting costs. For cooling energy, Kilowatts were defined followed by the resulting costs. The author has calculated the annual operating costs, associated to the HVAC system supporting the subject laboratory, to be $67,867. A table summarizing the laboratory performance results, project inputs and financial results is included in Appendix F.

Proposed Heat Pipe System

With consideration of cross contamination concerns, review of the expert interview responses and proximity of the existing exhaust air stream to the air handling unit, this research calculates the effects from installation of a unique heat pipe system. A customized Heat Pipe is best suited for this application, requiring three (3) heat transfer coil sections. By incorporating three transfer coils a reasonable amount of energy is collected from the exhaust stream, two thirds of this is transferred to precondition the incoming outside air stream and one third is transferred to the cooling coil discharge air stream. In the cooling coil discharge air a small amount of reheat is introduced which reduces the load on the down stream zone reheat coils. The energy transfer to the outside air stream is economical when the temperature of the outside air is below 50 degrees Fahrenheit or above 65 degrees Fahrenheit. Incorporating a custom energy recovery system maximizes the return on investment for the owner. The opportunity to economically apply multiple energy recovery systems, as well as a customized system has become possible as result of a proactive request by the Facility Manager, in the initial design and construction phase of these laboratories, routing the common exhaust air manifold along side the air handling unit. Had the request to route this 42” diameter, insulated, exhaust duct along side and within 5 feet of the air handler, not happened, the total project cost would double as result of exhaust duct re-routes under roof level, roofing repairs and additional exhaust pipe. These projected cost increases do not take into account extended down time for the lab in general as the above changes would be addressed.

One recommended energy recovery configuration would include (1) 42 ft^2, 6 row heat pipe consisting of copper tube and aluminum fin. The 6 row section would be installed in the exhaust air stream, within 10 feet of the air handler. One (1) 42 ft^2, 2 row heat pipe section would be installed after the air handler cooling coil, in front of the supply fan, providing a small amount of final reheat. One (1) 42 ft^2, 4 row, heat pipe section would be installed before the current pre-heat coil section of the air handler, providing pre-conditioning of the outside air stream. See figure 10, a block diagram of the recommended energy recovery approach.

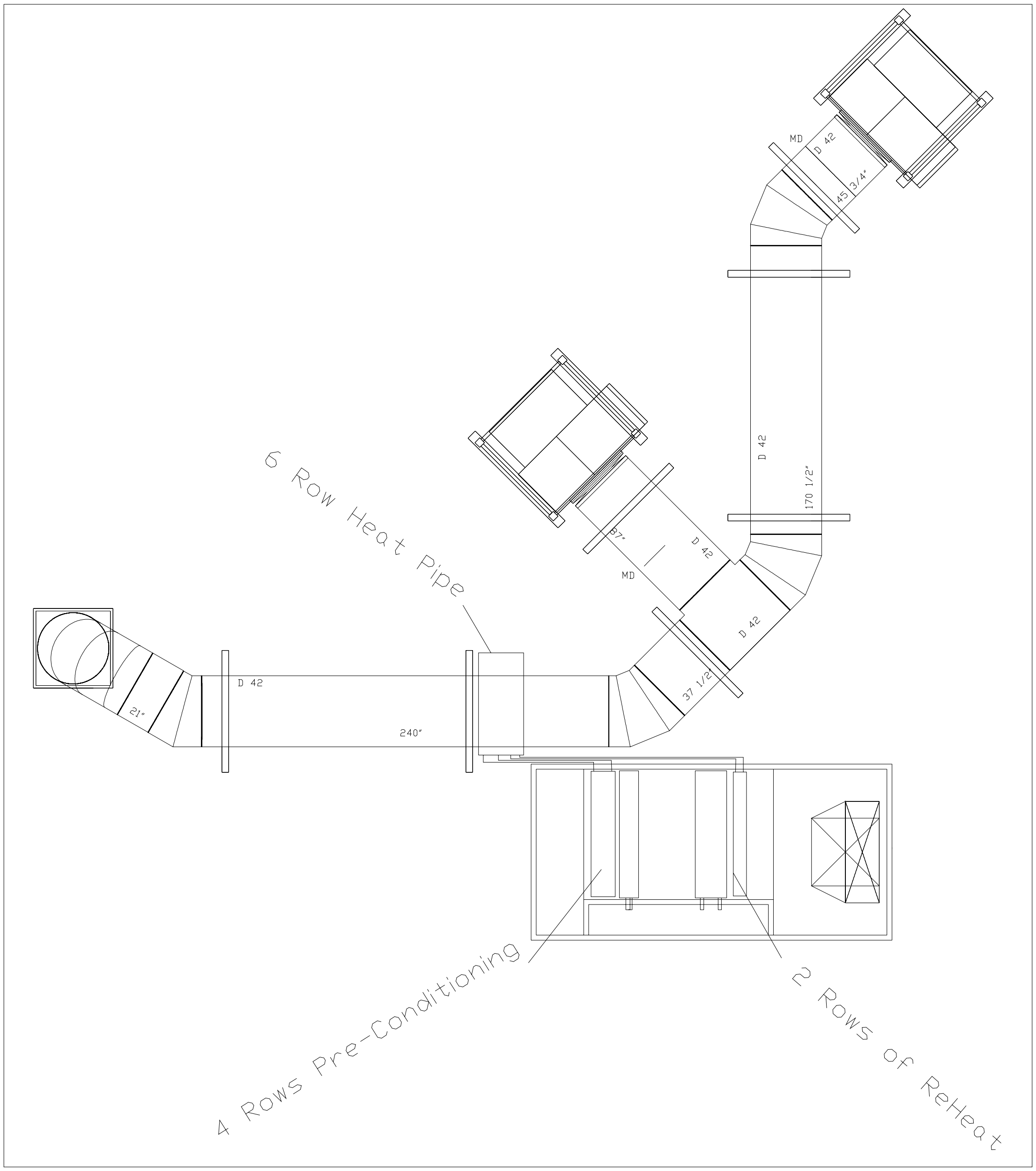

Figure 10 - Block diagram of proposed energy recovery system.

Energy savings from this customized installation would be realized at two locations in the supply air handler. First, 2 rows of sensible reheat, installed after the cooling coil, would reduce the BTU load on each of the down stream zone reheat coils providing cost savings 365 days per year at the boiler plant. See calculations in Appendix G. Second, 4 rows of sensible pre-conditioning, installed prior to the pre-heat coil section, would reduce the BTU load on the pre-heat coil any time the outside air temperature is below 54° F and reduce the BTU load on the cooling coil any time the outside temperature is above 65° F. See calculations in Appendix H.

Collection and analysis of HVAC performance data from small chemical laboratories, following the exhibits found in Appendix F, G and H then result in a protocol by which the Facility Manager can measure the HVAC system performance.

The total annual energy savings related to the proposed energy recovery installation described above are projected at $12,412 and the summary calculations are identified in Appendix I. A $12,412 reduction in annual energy costs, when compared to the original annual energy costs of $67,867, relates to an 18.3% reduction in the energy costs related to the HVAC system. This reduction is made possible by transferring the waste heat energy within the exhaust air stream to the supply air stream and is safely accomplished by incorporating a customized heat pipe solution.

Going further in the analysis of the proposed solution, an installation project cost estimate of $48,500 was obtained from a reputable heat pipe integrator to install the custom arrangement. Comparing this capital outlay to the projected annual energy savings of $12,412 results in a return on investment of 25.59%, see Appendix I, the inverse of this being a payback of 3.9 years. These results support very positive results to the Facility Manager of the laboratory environment who incorporates the design strategy exploited within this research.

Expert Interview Data Analysis

The questionnaire was proctored to the expert interviewees over a two month time period. As mentioned earlier all responses were collected by telephone conversation. The 24 closed ended questions were separated into 5 focus groups, each group containing no less than 4 unique questions addressing that subject. Table 3 below contains the results concerning the area of "Importance / Concern of indoor air quality of laboratories". Industry experts point to impact in productivity as the major concern for poor indoor air quality and experience improper maintenance as the key cause of poor air quality followed closely behind by low makeup / fresh air volume and moisture problems. None of the experts acknowledged using any energy recovery technique to resolve a poor indoor air quality issue.

Table 3 – Importance / concern of indoor air quality in laboratories.

#	Question	Response Options	Total points	Rank / Incidence
1	Do you acknowledge the principles defined in ASHRAE Standard 62.1-2001, "Ventilation for Acceptable Indoor Air Quality" and apply these principles for laboratory environments?	Yes	13	100.0%
		No	0	0.0%
5	From your experience, poor indoor air quality will have the greatest impact on which of the following performance measurement?	Absenteeism	3	23.1%
		Medical Claims	1	7.7%
		Long Term Litigation	1	7.7%
		Productivity	8	61.5%
12	What methodology does your company employ to quantify IAQ performance?	Data from BAS	4	30.8%
		Data from 3rd Party	2	15.4%
		On a complaint basis	7	53.8%
13	Issues responsible for unacceptable indoor air quality are typically related to: rank in order from most (5) to least (1) likely.	Low makeup Air	46	3.5
		Improper Maintenance	50	3.8
		Unhealthy Outdoor Air	22	1.7
		Poor Mechanical Design	32	2.5
		Moisture penetration / Mold	45	3.5

24	Have you experienced a project where one of the five energy recovery systems mentioned earlier was utilized to resolve an unacceptable Indoor Air Quality issue in a Laboratory facility?	Yes	0	0.0%
		No	10	76.9%

Table 4 captures the results questioning “Interest level of Energy Recovery In laboratories”. Industry experts confirm the motivation to incorporate energy recovery is to cut operating costs and the owner or owner’s representative is typically the first to request the concept. Conversely the owner or owner’s representative is typically the first to cut this portion of a new project, a process commonly referred to as “Value engineering”. While this author can understand and appreciate the need for cost cutting measures by the owner, he highly suggests and has proven employing a proactive design strategy with air stream ducts in the initial capital project will afford efficient future installations of several type energy recovery systems later.

Table 4 - Interest Level of Energy Recovery in Laboratories.

#	Question	Response Options	Total points	Rank / Incidence
2	The key motivation to incorporate Energy Recovery technologies?	Operating Cost Savings	11	84.6%
		Indoor Air Quality	2	15.4%
		life Cycle Improvement	0	0.0%
		Other	0	0.0%
3	Which group is typically first to request consideration to incorporate an energy recovery technology into a new project?	Owner / Owners Rep	8	61.5%
		Architect	0	0.0%
		Mechanical Engineer	5	38.5%
4	Which group is typically first to defer incorporating an energy recovery technology in a new project?	Owner / Owners Rep	12	92.3%
		Architect	0	0.0%
		Mechanical Engineer	1	7.7%
8	Concerning your most recent laboratory construction / improvement program was energy consumption / operating cost analysis requested as a deliverable in the design phase?	Yes	8	61.5%
		No	5	38.5%
14	In the past 10 years what percentage of laboratory facilities has incorporated air to air energy recovery systems?	0 - 10%	6	46.2%
		11 - 25%	3	23.1%
		26 - 50%	2	15.4%
		50+%	2	15.4%

Table 5 captures the results concerning "Issues related to energy consumption and recovery in the laboratory". Industry experts agree the majority of capital costs in new laboratory construction are assignable to the mechanical systems, which also have the largest impact on the annual operating costs. Unfortunately technologies available to reduce an owner's operating expense are also mechanical systems, adding further capital costs. On a positive note, owners seem to be relaxing their cost payback expectations, especially when energy recovery equipment is the consideration. When possible an owner should embrace variable air volume control strategies to minimize annual operating expenses of laboratories.

Table 5 - Issues related to Energy Consumption and Recovery in Laboratories

#	Question	Response Options	Total points	Rank / Incidence
7	Which system represents the larger portion of the capital costs for constructing laboratory facilities?	Electrical	0	0.0%
		Mechanical	12	92.3%
		Structural	0	0.0%
		Interiors	1	7.7%
		Other	0	0.0%
9	What is your maximum acceptable payback term for approval of capital investment?	Less than 2 years	1	7.7%
		Less than 3 years	3	23.1%
		Less than 5 years	7	53.8%
		Less than 7 years	2	15.4%
10	Does the nature of the capital investment, i.e. reduced energy consumption, have impact in the acceptable term of the payback?	Yes	10	76.9%
		No	3	23.1%
23	Considering economical impacts / operational costs of laboratory environments, which HVAC control methodology is better suited for the owner?	Variable Air Volume	7	53.8%
		Constant Air Volume	3	23.1%

Table 6 captures the "Traditional design parameters for safe laboratory operation". Industry experts agree the constant air volume delivery system is by far the safest approach for the owner due to the simplicity. No special controls expertise required to maintain it, however at the expense of energy consumption. The design engineer has an overwhelming desire to position the supply intake and exhaust discharge points as far away from each other as possible, which typically results in the two air streams being routed out of the building at opposite ends. Conversely this same group of experts agrees that in order to efficiently install most energy recovery systems the two air streams must pass within 10 feet of one another. Returning to this author's thrust, without a proactive design strategy from the owner's representative, the owner will likely face significant installation costs related to duct work changes and roofing repairs to incorporate future energy recovery equipment. These high costs will likely render future additions of energy recovery systems cost prohibitive.

Table 6 - Traditional Design Parameters for Safe Laboratory Operation.

#	Question	Response Options	Total points	Rank / Incidence
22	Considering operational / health risks of laboratory environments, which HVAC control methodology is better suited for the owner?	Variable Air Volume	1	7.7%
		Constant Air Volume	9	69.2%
6	Mechanical systems are held to strictly enforced code requirements much like electrical or life safety systems?	Yes	2	15.4%
		No	11	84.6%
11	Spatial positioning of the supply air inlet and exhaust air discharge streams of laboratory facilities should be?	As close as Possible	1	7.7%
		Some what close together	0	0.0%
		As far apart as possible	12	92.3%
		Is of no concern	0	0.0%
15	What is the maximum acceptable distance, between two opposing air streams (supply vs. Exhaust), to efficiently install most air to air energy recovery equipment?	0 ~ 10 feet	10	76.9%
		10 ~ 25 feet	2	15.4%
		25 ~ 50 feet	0	0.0%
		No Limit	1	7.7%

Table 7 captures “Comparisons of Energy Recovery Techniques”. Industry experts identify the wheel technologies as the most effective heat transfer media. They also recognize that same wheel technology presents a significant concern of cross contamination and as result wheels are only employed when general room exhaust streams are separated from fume hood exhaust streams and the wheel is inserted in the general exhaust air stream. To avoid issues of cross contamination heat pipes and or glycol run around loops are the best applications. The experts agree that use of wheel technologies require higher first costs, are more complex to operate and result in the highest maintenance costs. The glycol run around loops and heat pipes have lower first install costs and require minimum routine maintenance.

Table 7 - Comparison of Energy Recovery Techniques.

#	Question	Response Options	Total points	Rank 5 ~ 1
16	Rank the technologies below, in order of high (5) to low (1), employed to reduce energy consumption of laboratory environments?	Sensible Heat Wheel	43	3.3
		Enthalpy Heat Wheel	56	4.3
		Heat Pipes	30	2.3
		Glycol run around loops	44	3.4
		Fixed Plate, cross flow	22	1.7
17	Rank these systems in order, high (5) to low (1), for which of the following systems presents the greatest risk of cross contamination between supply and return air streams of laboratory facilities.	Sensible Heat Wheel	50	3.8
		Enthalpy Heat Wheel	63	4.8
		Heat Pipes	24	1.8
		Glycol run around loops	16	1.2
		Fixed Plate, cross flow	36	2.8
18	Rank these systems in order, high (5) to low (1), for the amount and complexity of additional supporting infrastructure, (fans, ducting, controls and routine maintenance), to yield an effective air to air energy transfer function.	Sensible Heat Wheel	50	3.8
		Enthalpy Heat Wheel	63	4.8
		Heat Pipes	18	1.4
		Glycol run around loops	26	2.0
		Fixed Plate, cross flow	38	2.9
19	Rank these systems in order, high (5) to low (1), for first install costs, (equipment, installation and start up), in a new laboratory facility.	Sensible Heat Wheel	49	3.8
		Enthalpy Heat Wheel	61	4.7
		Heat Pipes	33	2.5
		Glycol run around loops	15	1.2
		Fixed Plate, cross flow	36	2.8
20	Rank these systems in order, high (5) to low (1), cost (equipment, install and startup), in a retro-fit installation for an existing laboratory facility.	Sensible Heat Wheel	50	3.8
		Enthalpy Heat Wheel	61	4.7
		Heat Pipes	28	2.2
		Glycol run around loops	27	2.1
		Fixed Plate, cross flow	41	3.2
21	Rank these systems in order, high (5) to low (1), in terms of their routine maintenance requirements. Consider issues of wear parts, complexity and likely access to each.	Sensible Heat Wheel	54	4.2
		Enthalpy Heat Wheel	64	4.9
		Heat Pipes	15	1.2
		Glycol run around loops	35	2.7
		Fixed Plate, cross flow	31	2.4

A single open ended question describing the parameters of the author's subject laboratory was asked. The respondents were asked to recommend an energy recovery system, from one of the five energy recovery techniques mentioned previously in the questionnaire, for the subject laboratory. Two systems were identified most frequently. The heat pipe was recommended 54% of the time, the glycol run around loop 31% of the time, heat wheels 8% of the time and one respondent did not feel qualified to make a recommendation for the final 8% of the time. Many of the respondents explained they had previous experience using glycol loops and felt more comfortable in that approach over the heat pipe. Another frequent comment was their uncertainty in the equipment costs for the heat pipe technology. They were concerned of potential high costs for the refrigerant charge, thereby making the glycol system more economically attractive.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Laboratory facilities exist for the benefit of research and safety of the occupants working within; their first priority is not energy efficiency. From the protocol developed, as part of the findings in this research, it can be concluded with as little as 15 degrees Fahrenheit difference in temperature between the exhaust and outside air streams, it is possible to reduce the HVAC energy consumption of small chemical laboratories by 18.3% using air to air energy recovery techniques.

Based on merits of no additional energy source(s) required to function, low maintenance requirements and avoidance of cross contamination in the opposing air streams, the heat pipe was selected as the best energy recovery solution for this small chemical laboratory.

The findings reveal an Investment analysis of the proposed heat pipe energy recovery solution for the subject lab generating a 25.6% return on investment or 3.9 year payback on the capital outlay. The investment results support the author’s hypothesis in a design strategy by the facility manager resulting in efficient placement between the exhaust and supply air streams offering economical installation of multiple energy recovery systems.

Industry experts overwhelmingly agree that constant air volume systems are the safest approach for the laboratory owner, acknowledging this approach is the least energy efficient. Furthermore they agree efficient installations of air to air energy recovery equipment require distance between exhaust and supply air streams be no more than 25 feet. And finally they agree the heat pipe energy recovery technique requires the least amount of additional infrastructure and routine maintenance to function efficiently.

Recommendations for Further Study

1. The focus of this research considered quantitative value gained in reduction of operating costs of smaller laboratory facilities. There is likely a qualitative value to be gained from incorporation of these air to air energy recovery systems, such as reduction in relative humidity levels in the supply air streams of 100% outside air systems. Relative humidity levels, during the summer months, are likely to exceed 80% in the supply ducts when no sensible heat is added post cooling coil. The addition of reheat through an air to air exchanger likely eliminates this concern, improving the indoor air quality. Additional study of this impact would be most beneficial to the practicing Facility Manager.
2. This research effort was conducted with intent in the use of Heat Pipe Technology. Thirty one percent of the experts interviewed indicate their typical selection would be the use of the glycol run around loop technique. Their rational was not having familiarity with heat pipe systems. Further study to develop a framework within which the Facility Manager can efficiently select between energy recovery technologies for specific project applications would be beneficial.
3. The protocol developed in this research effort was specific to the smaller size chemical laboratory. Further study in the application of this protocol to other facilities such as larger labs, high tech manufacturing and health care may result in additional tools for the facility manager to reduce the HVAC operating expenses.
4. Further study of the impact on Life Cycle Costing in the HVAC systems, associated to small chemical laboratories, incorporating air to air energy recovery may yield valuable supporting evidence for the installation of energy recovery equipment.

APPENDIX A

Interview Questionnaire:

Goal:

This questionnaire has been designed with intent to determine the current and frequent practices among industry professionals applying solutions to reduce energy consumption and improve sustainability of small sized laboratory environments.

The target interviewees will be limited to three types of professionals; The Owner's engineer, the Facility Manager and the Consulting engineer.

The intent of the research is to challenge and identify a design approach for the small laboratory facility that will allow immediate or future incorporation of a wide range of energy recovery techniques by the laboratory owner.

The questionnaire is a combination of closed and open ended questions intended to discover the respondent's professional experience of the subject matter. Each question is asking for "actual / collective experience" rather than theory or opinion of the respondent.

Background information of interviewee:

Name: _________________________ Date: _______________________

Professional Responsibility: (circle one)
Owner's engineer Facility Manager Consulting engineer

May I use your name and company affiliation be used in the publishing of this research paper?

YES? NO?

If Yes,
Name: ________________________________
Company: _____________________________

1. Do you acknowledge the principles defined in ASHRAE Standard 62.1-2001, “Ventilation for Acceptable Indoor Air Quality” and apply these principles for laboratory environments?

   Yes
   No

2. The key motivation to incorporate Energy Recovery technologies?

   Operating Cost Savings
   Indoor Air Quality performance
   Life Cycle improvement
   Other

3. Which group is typically first to request consideration to incorporate an energy recovery technology into a new laboratory project?

   Owner / Owners Rep
   Architect
   Mechanical engineer

4. Which group is typically first to defer incorporating an energy recovery technology in a new laboratory project?

   Owner / Owners Rep
   Architect
   Mechanical engineer

5. From your experience, poor indoor air quality will have the greatest impact on which of the following performance measurement?

   Absenteeism
   Medical claims
   Long term litigation
   Productivity

6. Mechanical systems are held to strictly enforced code requirements much like electrical or life safety systems?

   Yes
   No

7. Which system represents the larger portion of the capital costs for constructing laboratory facilities?

   Electrical
   Mechanical
   Structural
   Interiors
   Other

8. Concerning your most recent laboratory construction / improvement program was energy consumption / operating cost analysis requested as a deliverable in the design phase?

   Yes
   No

9. What is your maximum acceptable payback term for approval of capital investment?

   Less than 2 years
   Less than 3 years
   Less than 5 years
   Less than 7 years

10. Does the nature of the capital investment, i.e. reduced energy consumption, have impact in the acceptable term of the payback?

    Yes
    No

11. Spatial positioning of the supply air inlet and exhaust air discharge streams of laboratory facilities should be?

    As close together as possible.
    Some what close together.
    As far apart as physically possible.
    Is of no concern.

12. What methodology does your company employ to quantify IAQ performance?

    Data analysis from samples collected through a building automation system
    Data analysis from grab samples collected through a 3rd party service provider.
    No routine sampling, responds to complaints on case by case basis.

13. Issues responsible for unacceptable indoor air quality are typically related to: (rank order from most / high (5) to least / low (1) likely.

    Insufficient make up air volume
    Improper maintenance of the mechanical systems
    Unhealthy outdoor air source
    Poor design of the mechanical system
    Moisture penetration and mold growth

14. In the past 10 years what percentage of laboratory facilities has incorporated air to air energy recovery systems?

    0 – 10%
    11 – 25%
    26 – 50%
    Greater than 50%

15. What is the maximum acceptable distance, between two opposing air streams (supply Vs. Exhaust), to efficiently install most air to air energy recovery equipment?

    0 ~ 10 feet
    10 ~ 25 feet
    25 ~ 50 feet
    No limit

16. Rank the technologies below, in order of high (5) to low (1), employed to reduce energy consumption of laboratory environments?

    Sensible Heat Wheel
    Enthalpy Heat Wheel
    Heat Pipes
    Glycol run around loops
    Fixed Plate Cross flow exchangers

17. Rank these systems in order, high (5) to low (1), for which of the following systems presents the greatest risk of cross contamination between supply and return air streams of laboratory facilities.

    Sensible Heat Wheel
    Enthalpy Heat Wheel
    Heat Pipes
    Glycol run around loops
    Fixed Plate Cross flow exchangers

18. Rank these systems in order, high (5) to low (1), for the amount and complexity of additional supporting infrastructure, (fans, ducting, controls and routine maintenance), to yield an effective air to air energy transfer function.

    Sensible Heat Wheel
    Enthalpy Heat Wheel
    Heat Pipes
    Glycol run around loops
    Fixed Plate Cross flow exchangers

19. Rank these systems in order, high (5) to low (1), for first install costs, (equipment, installation and start up), in a new laboratory facility.

    Sensible Heat Wheel
    Enthalpy Heat Wheel
    Heat Pipes
    Glycol run around loops
    Fixed Plate Cross flow exchangers

20. Rank these systems in order, high (5) to low (1), costs (equipment, install and startup), in a retro-fit installation for an existing laboratory facility.

    Sensible Heat Wheel
    Enthalpy Heat Wheel
    Heat Pipes
    Glycol run around loops
    Fixed Plate Cross flow exchangers

21. Rank these systems in order, high (5) to low (1), in terms of routine maintenance requirements. Consider issues of wear parts, complexity and likely access to each.

    Sensible Heat Wheel
    Enthalpy Heat Wheel
    Heat Pipes
    Glycol run around loops
    Fixed Plate, Cross flow exchangers

22. Considering operational / health risks of laboratory environments, which HVAC control methodology is better suited for the owner?

    Variable Air Volume
    Constant air Volume

23. Considering economical impacts / operational costs of laboratory environments, which HVAC control methodology is better suited for the owner?

    Variable Air Volume
    Constant air Volume

24. Have you experienced a project where one of the five energy recovery systems mentioned earlier was utilized to resolve an unacceptable Indoor Air Quality issue in a Laboratory facility?

    Yes
    No

25. Please take a moment to summarize a recommended solution assuming you are the owner of an existing laboratory facility incorporating a "CAV" HVAC system with 100% outside make up air and a "CAV" exhaust system with a common header connected to several fume hoods. The laboratory is relatively small with total air movement just under 20,000 CFM. The goal being to retrofit an energy recovery technique that provides good energy efficiency without increased health risk to the occupants and achieve full return on investment in less than 5 years.

    What additional information is critical?
    Which energy recovery technique is best suited for the case?
    Provide a brief description of the final connected system and its function.

APPENDIX B

Carolina Heat Pipe, Inc.

There are few companies in the world truly specializing in custom applications of heat pipe technology. One such company is Carolina Heat Pipe Incorporated. Located in Charleston, South Carolina and under the direction of Mr. Richard W. Trent, president, Carolina Heat Pipe has successfully patented several applications incorporating the “Thermosyphon” heat pipe for energy recovery. Their web site is www.carolinaheatpipe.com.

APPENDIX C

ASHRAE Standards Appropriate to this Research

The author having many years of experience as a Facility Manager has realized great success calling upon the American Society of Refrigeration, Heating and Air Conditioning engineers, (ASHRAE), for professional literature, guidance and support when dealing with HVAC related issues. The Author is a member in good standing of ASHRAE. Knowing well in advance this research is a focused study in the HVAC discipline of Laboratories the author has reviewed the range of current ASHRAE standards appropriate to this research:

ANSI / ASHRAE Standard 55-1992. Thermal Environmental Conditions for Human Occupancy.

ANSI / ASHRAE Standard 110-1995. Method of Testing Performance of Laboratory Fume Hoods.

ANSI / ASHRAE Standard 62 – 2001. Ventilation for Acceptable Indoor Air Quality.

ANSI/ASHRAE Standard 90.1-2001. Energy Standard for Buildings Except Low-Rise Residential Buildings.

APPENDIX D

Empirical Data Summary Table

	October				November			
	minimum	maximum	median	average	minimum	maximum	median	average
Outside Air Temperature	42.4	82.9	63.2	62.7	28.5	83.0	58.5	57.5
Outside Air Relative Humidity	15.4	50.6	38.3	36.8	9.6	50.8	34.1	34.2
Preheat Temperature (F)	48.4	84.9	61.9	63.3	34.3	89.5	59.7	60.5
Preheat Relative Humidity (%)	8.8	36.7	27.7	26.8	5.8	49.8	28.8	29.3
Preheat Valve Position (% open)	0.0	33.2	0.0	3.9	0.0	100.0	0.0	14.0
Cooling Coil Temperature (target = 54 ~ 56F)	53.8	69.7	55.3	55.4	39.2	64.5	54.4	54.0
Cooling Coil Relative Humidity (%)	19.9	54.6	45.7	45.3	9.9	53.9	42.3	38.8
Cooling Coil Valve Position (% open)	0.0	16.8	7.1	6.7	0.0	67.7	6.4	11.4
Supply Airflow (CFM)	14498	16072	14867	14935	454	16609	15077	15043
Discharge Air Temperature (F)	53.0	65.4	55.9	56.2	41.3	72.3	55.8	55.3
Discharge Air Relative Humidity (%)	26.1	47.4	44.7	42.2	10.1	48.0	40.3	36.1

LAB 1 Temperature (F)	64.4	78.1	71.9	71.9	56.5	72.6	72.1	71.2
LAB 1 Relative Humidity (%)	42.4	49.5	44.2	44.5	10.2	53.0	45.2	39.6
LAB 1 Valve Position (%open)	0.0	100.0	43.7	44.5	39.0	100.0	48.5	58.2
LAB 3 Temperature (F)	68.4	74.3	73.3	72.8	61.6	74.7	73.4	72.8
LAB 3 Relative Humidity (%)	29.2	61.2	48.4	46.7	901.0	54.5	41.7	37.2
LAB 3 Valve Position (%open)	0.0	89.1	21.1	22.4	0.0	100.0	38.4	42.8
Exhaust Air Temperature (F)	64.2	80.7	70.0	70.6	60.0	79.1	69.5	69.6
Exhaust Air Relative Humidity (%)	21.6	76.8	49.7	51.9	6.8	79.6	43.4	42.8
Exhaust Air FLOW (CFM)	357	16185	14980	14946	357	16185	14980	14946

	December				January			
	minimum	maximum	median	average	minimum	maximum	median	average
Outside Air Temperature	24.9	63.3	41.4	42.9	18.0	70.7	40.7	42.1
Outside Air Relative Humidity	7.9	50.4	33.0	32.5	7.3	50.8	31.4	32.3
Preheat Temperature (F)	33.9	91.4	54.4	53.6	43.3	71.4	55.2	56.4
Preheat Relative Humidity (%)	3.6	45.4	18.0	18.3	2.0	48.6	13.5	16.4

Preheat Valve Position (% open)	0.0	100.0	43.8	45.5	0.0	100.0	41.5	39.7
Cooling Coil Temperature (target = 54 ~ 56F)	39.9	88.0	56.1	55.7	52.0	63.6	56.4	56.2
Cooling Coil Relative Humidity (%)	5.2	51.3	20.8	21.7	3.0	52.7	18.2	21.5
Cooling Coil Valve Position (% open)	0.0	17.5	3.1	3.0	0.0	29.0	4.1	5.3
Supply Airflow (CFM)	434	17084	14647	14875	15521	16778	16179	16173
Discharge Air Temperature (F)	41.1	75.3	55.9	55.6	51.5	62.4	55.9	55.9
Discharge Air Relative Humidity (%)	6.8	46.3	21.5	22.6	4.5	47.2	19.4	22.1
LAB 1 Temperature (F)	52.9	72.7	72.1	70.8	65.9	72.4	72.1	71.9
LAB 1 Relative Humidity (%)	8.1	51.5	23.1	23.8	2.0	51.6	20.0	22.7
LAB 1 Valve Position (%open)	0.0	100.0	46.2	53.5	46.0	100.0	52.6	58.7
LAB 3 Temperature (F)	56.9	74.7	73.6	72.6	67.0	74.7	73.9	73.5
LAB 3 Relative Humidity (%)	5.9	49.1	21.0	21.8	1.1	52.1	17.8	20.7
LAB 3 Valve Position (%open)	20.5	100.0	54.2	63.8	0.0	100.0	47.5	53.7
Exhaust Air Temperature (F)	47.5	73.1	64.4	64.6	55.5	72.9	64.7	65.0
Exhaust Air Relative Humidity (%)	3.7	64.8	24.9	25.7	1.2	69.6	20.2	24.7

Exhaust Air FLOW (CFM)	337	16987	14550	14779	15424	16681	16083	16077

APPENDIX E

Atlanta Georgia Weather History (Bin Data)

Temperature Range (°F)	Total Observations	Mean Calculated
100 / 104	2	77.7
95 / 99	28	75.5
90 / 94	148	74.4
85 / 89	386	72.6
80 / 84	636	70.5
75 / 79	878	68.5
70 / 74	1225	66.2
65 / 69	976	61.2
60 / 64	851	56.1
55 / 59	768	51.2
50 / 54	699	46.6
45 / 49	643	42.1
40 / 44	549	37.7
35 / 39	428	33.1
30 / 34	295	28.5
25 / 29	144	23.7
20 / 24	60	19.2
15 / 19	28	14.9
10 / 14	12	10.4
5 / 9	4	5.8
0 / 4	2	0.7
-5 / -1	0	-3.6
-10 / -6	1	-7.1

APPENDIX F

Laboratory Performance Results

ANNUAL ENERGY CONSUMPTION
CIBA Vision Corporation
West Wing Formulary Laboratory
HVAC & Exhaust Systems combined

System Description

CAV Exhaust system
CAV Supply Air system (RTU #8)
Exhaust is common header to single discharge on roof
RTU #8 supplied by Chilled and Hot water secondary loops

Project Specific Data

Weather Data Provided by:	Air Force Combat Climatology Center. (AFCCC)
Weather Data based on:	World Meteorological Organization (WMO) # 722190, Located at: Atlanta Intl Airport, Georgia.
Supply Air Volume (CFM)	15,600
Exhaust Air Volume (CFM)	15,500
Daily hours of operation =	24
Calendar days of operation =	365
Cost of Electricity (kwh)=	$0.032
Cost of Natural Gas (Therm) =	$0.855

Mechanical System Performance Requirements

Space (Zone) Temperatures (F) =	71.0
RTU Pre-Heat coil exit temp. (F) =	55.0
RTU Cooling coil (LAT) temp. (F) =	55.0
Enthalpy (BTU/Lbs.) @ LAT 55 F =	22.31
Exhaust Air exit temp. (F) =	70.0

SUMMARY PERFORMANCE

Financial Results

	Annualized Costs	% of Total
Cooling Costs =	**$27,507**	40.5%
Pre-Heat Costs =	**$11,419**	16.8%
Zone heating Costs =	**$20,532**	30.3%
RTU Fan Operation =	**$6,727**	9.9%
Exhaust Fan Operation	**$1,682**	2.5%
Total	**$67,867**	100.0%

Detail Analysis

Cooling Load

Outside Air Conditions from Official Weather Data (F)	Hours observed in temp. bin	Enthalpy of Air (BTU/Lbs of dry air)	BTU / 1 hour	Annual BTU	Total Cooling Load (kwh)	Annual Cooling Cost
100/104	2	41.01	1,312,740	2,625,480	769.26	$25
95/99	28	38.86	1,161,810	32,530,680	9531.40	$305
90/94	148	37.86	1,091,610	161,558,280	47336.15	$1,515
85/89	386	36.23	977,184	377,193,024	110516.56	$3,537
80/84	636	34.41	849,420	540,231,120	158286.29	$5,065
75/79	878	32.76	733,590	644,092,020	188717.26	$6,039

70/74	1,225	30.96	607,230	743,856,750	217948.07	$6,974
65/69	976	27.25	346,788	338,465,088	99169.38	$3,173
60/64	851	23.87	109,512	93,194,712	27305.80	$874

Annual Cooling Cost **$27,507**

Pre Heating Load

Outside Air Conditions from Official Weather Data (F)	Hours observed in temp. bin		BTU / 1 hour	Annual BTU	Total Pre-Heating Load (therms)	Annual Pre-Heating Cost
50/54	699		301,320	210,622,680	2106.2	$1,800.82
45/49	643		385,020	247,567,860	2475.7	$2,116.71
40/44	549		468,720	257,327,280	2573.3	$2,200.15
35/39	428		552,420	236,435,760	2364.4	$2,021.53
30/34	295		636,120	187,655,400	1876.6	$1,604.45
25/29	144		719,820	103,654,080	1036.5	$886.24
20/24	60		803,520	48,211,200	482.1	$412.21
15/19	28		887,220	24,842,160	248.4	$212.40
10/14	12		970,920	11,651,040	116.5	$99.62
5/9	4		1,054,620	4,218,480	42.2	$36.07
0/4	3		1,138,320	3,414,960	34.1	$29.20

Annual Pre-Heating Cost **$11,419**

Zone Re-Heat Load

Zone 1 (Hema Lab) Discharge Temp (F)= **73.0**

Inlet Air Temp (F)	Hours of operation	Air Volume (CFM)	BTU / 1 hour	Annual BTU	Total Pre-Heating Load (therms)	Annual Pre-Heating Cost
55	8760	9692	188,412	1,650,493,325	16504.9	$14,111.72

Zone 2 (Materials Storage) Discharge Temp (F)= **55.0**

Inlet Air Temp (F)	Hours of operation	Air Volume (CFM)	BTU / 1 hour	Annual BTU	Total Pre-Heating Load (therms)	Annual Pre-Heating Cost
55	8760	947	0	0	0.0	$0.00

Zone 3 (SEE 3 Lab) Discharge Temp (F)= **71.0**

Inlet Air Temp (F)	Hours of operation	Air Volume (CFM)	BTU / 1 hour	Annual BTU	Total Pre-Heating Load (therms)	Annual Pre-Heating Cost
55	8760	3113	53,793	471,223,526	4712.2	$4,028.96

Zone 4 (Corridor) Discharge Temp (F)= **71.0**

Inlet Air Temp (F)	Hours of operation	Air Volume (CFM)	BTU / 1 hour	Annual BTU	Total Pre-Heating Load (therms)	Annual Pre-Heating Cost
55	8760	577	9,971	87,342,106	873.4	$746.78

Zone 5 (QA Lab) Discharge Temp (F)= **71.0**

Inlet Air Temp (F)	Hours of operation	Air Volume (CFM)	BTU / 1 hour	Annual BTU	Total Pre-Heating Load (therms)	Annual Pre-Heating Cost
55	8760	447	7,724	67,663,642	676.6	$578.52

Zone 6 (Opaque Lab) Discharge Temp (F)= **71.0**

Inlet Air Temp (F)	Hours of operation	Air Volume (CFM)	BTU / 1 hour	Annual BTU	Total Pre-Heating Load (therms)	Annual Pre-Heating Cost
55	8760	824	14,239	124,731,187	1247.3	$1,066.45
					Annual Zone Re-Heat Cost	**$20,532**

Fan Energy Costs (RTU)

Hours of Operation	Supply voltage	Actual Amps	Power factor	KW / Hr	Annual KW	Annual Operating Cost
8760	480	34	0.85	24.0	210227.4	$6,727.28

Fan Energy Costs (Exhaust)

Hours of Operation	Supply voltage	Actual Amps	Power factor	KW / Hr	Annual KW	Annual Operating Cost
8760	480	8.5	0.85	6.0	52556.8	$1,681.82
					Annual Fan Energy Costs	**$8,409**

APPENDIX G

2 Rows of Sensible Reheat

ANNUAL ENERGY RECOVERY POTENTIAL
West Wing Formulary Laboratory
HVAC & Exhaust Systems combined
Addition of a 2 Row Re-Heat Energy Recovery Coil
Downstream of the RTU Cooling Coil

System Description

CAV Exhaust system
CAV Supply Air system
Exhaust is common header to single discharge on roof
RTU supplied by Chilled and Hot water secondary loops
RTU # 8

Project Specific Data

Weather Data based on:	N/A
Supply Air Volume (CFM)	15,600
Exhaust Air Volume (CFM)	15,500
Daily hours of operation =	24
Calendar days of operation =	365
Cost of Electricity (kwh)=	$0.032
Cost of Natural Gas (Therm) =	$0.855

Mechanical System Performance Requirements

Space (Zone) Temperatures (F) =	71.0

RTU Pre-Heat coil exit temp. (F) =	55.0
RTU Cooling coil (LAT) temp. (F) =	55.0
Enthalpy (BTU/Lbs.) @ LAT 55 F =	22.31
Exhaust Air exit temp. (F) =	70.0
Proposed Heat Pipe Effectiveness =	0.32
Heat Pipe Area (sq. ft.) =	42.0
Heat Pipe Face Velocity (fpm) =	400

SUMMARY PERFORMANCE

Financial Results

		Annualized Costs	% of Total
	Re-Heat Savings =	**$3,401**	100.0%
	Total Savings	**$3,401**	

Heat Pipe Installation

	Install Cost Estimate =	**$13,500**
	Payback (years) =	**4.0**
	Return On Investment =	**25.2%**

Detail Analysis

Zone Re-Heat Load Reduction
(Year Round)

Exhaust Air Conditions (F)	Hours observed	Cooling Coil Discharge Temp (F)	Energy recovered by Heat Pipe (BTUH)	Annual BTU	Total Re-Heat reduction (therms)	Annual Zone Heating Savings
70.0	8760	55.0	45,412	397,807,718	3978.08	$3,401
					Annual Zone Heating Costs Saved	**$3,401**

This system offers the continuous addition of 4.5 F (sensible heat) to the discharge air of the RTU cooling coil.
Thereby reducing the BTU input required at the zone re-heat coils in the various space compartments.

APPENDIX H

4 Rows of Sensible Pre-Conditioning

ANNUAL ENERGY RECOVERY POTENTIAL
West Wing Formulary Laboratory
HVAC & Exhaust Systems combined
Addition of a 4 Row Pre-Conditioning Energy Recovery Coil
Upstream of the existing Pre-Heat Coil

System Description

CAV Exhaust system
CAV Supply Air system
Exhaust is common header to single discharge on roof
RTU supplied by Chilled and Hot water secondary loops
RTU # 8

Project Specific Data

Weather Data based on:	Atlanta WEATHER DATA
Supply Air Volume (CFM)	15,600
Exhaust Air Volume (CFM)	15,500
Daily hours of operation =	24
Calendar days of operation =	365
Cost of Electricity (kwh)=	$0.032
Cost of Natural Gas (Therm) =	$0.855

Mechanical System Performance Requirements

Space (Zone) Temperatures (F) =	71.0
RTU Pre-Heat coil exit temp. (F) =	55.0
RTU Cooling coil (LAT) temp. (F) =	55.0
Enthalpy (BTU/Lbs.) @ LAT 55 F =	22.31
Exhaust Air exit temp. (F) =	70.0
Proposed Heat Pipe Effectiveness =	0.49
Heat Pipe Area (sq. ft.) =	42.0
Heat Pipe Face Velocity (fpm) =	400

SUMMARY PERFORMANCE

Financial Results

		Annualized Costs	% of Total
	Pre-Heat Savings =	**$5,595**	62.1%
	Cooling Savings =	**$3,415**	37.9%
	Total Savings	**$9,011**	100.0%

Heat Pipe Installation

	Install Cost Estimate =	**$35,000**
	Payback (years) =	**3.9**
	Return On Investment =	**25.7%**

Detail Analysis
Pre-Heat Load Reduction

(Heating Season)

Outside Air Conditions from Official Weather Data (F)	Hours observed in temp. bin		Energy recovered by Heat Pipe (BTUH)	Annual BTU	Total Pre-Heating Load (therms)	Annual Pre-Heating Savings
50/54	699		147,647	103,205,113	1032.05	$882
45/49	643		188,660	121,308,251	1213.08	$1,037
40/44	549		229,673	126,090,367	1260.90	$1,078
35/39	428		270,686	115,853,522	1158.54	$991
30/34	295		311,699	91,951,146	919.51	$786
25/29	144		352,712	50,790,499	507.90	$434
20/24	60		393,725	23,623,488	236.23	$202
15/19	28		434,738	12,172,658	121.73	$104
10/14	12		475,751	5,709,010	57.09	$49
5/9	4		516,764	2,067,055	20.67	$18
0/4	3		557,777	1,673,330	16.73	$14
					Annual Pre-Heating Costs Saved	**$5,595**

Cooling Coil / Chiller Load Reduction

(Cooling Season)

Outside Air Conditions from Official Weather Data (F)	Hours observed in temp. bin	Exhaust air Temp (F)	Energy recovered by Heat Pipe (BTUH)	Annual BTU	BTU to KWH	Annual Pre-Cool Savings
100/104	2	65.0	297,302	594,605	174.22	$6

95/99	28	65.0	257,126	7,199,539	2109.45	$68
90/94	148	65.0	216,950	32,108,659	9407.75	$301
85/89	386	65.0	176,774	68,234,918	19992.65	$640
80/84	636	65.0	136,598	86,876,582	25454.61	$815
75/79	878	65.0	96,422	84,658,867	24804.82	$794
70/74	1,225	65.0	56,246	68,901,840	20188.06	$646
65/69	976	65.0	16,070	15,684,710	4595.58	$147
					Annual Cooling Savings	**$3,415**

This system incorporates 4 rows of an energy recovery coil that reduces the (sensible) BTU load on the Pre-Heat coil every time temps are below 50 F and reduces (sensible) BTU load on the cooling coil every time temps are above 65 F.

APPENDIX I

Annual Energy Improvement

ANNUAL ENERGY IMPROVEMENT
West Wing Formulary Laboratory
HVAC & Exhaust Systems combined

Baseline Operations

	Annualized Costs	% of Total
Cooling Costs =	**$27,507**	40.5%
Pre-Heat Costs =	**$11,419**	16.8%
Zone heating Costs =	**$20,532**	30.3%
RTU Fan Operation =	**$6,727**	9.9%
Exhaust Fan Operation	**$1,682**	2.5%
Total	**$67,867**	100.0%

Savings from 4 Row Pre-Conditioning

		Annualized Costs	% of Total
	Pre-Heat Savings =	**$5,595**	62.1%
	Cooling Savings =	**$3,415**	37.9%
	Total Savings	**$9,011**	100.0%

Savings from 2 Row Re-Heat

		Annualized Costs	% of Total
	Re-Heat Savings =	**$3,401**	100.0%
	Total Savings	**$3,401**	
	Total Energy Savings	**$12,412**	
	Reduction in Annual Operating Expense	**18.3%**	

Capital Investment

	Capital Costs	% of Total
4 Row Heat Pipe "Pre-Conditioning" Energy Recovery System	**$35,000**	72.2%
2 Row Heat Pipe "Re-Heat" Energy Recovery System	**$13,500**	27.8%
Total Capital Outlay	**$48,500**	100.0%
Payback (years)	**3.9**	
Return On Investment	**25.59%**	

REFERENCES

[1] The ASHRAE Handbook CD, 2003 HVAC Applications, Laboratories, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2003, p. 14.1, [CD-ROM].

[2] Lew Harriman, Geoffrey W. Brundrett, and Reonhold Kittler, Humidity Control Design Guide for Commercial and Institutional Buildings, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p.427.

[3] Ian B.D. McIntosh, Chad B. Dorgan, and Charles E. Dorgan, ASHRAE Laboratory Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p. 37.

[4] The ASHRAE Handbook CD, 2003 HVAC Applications, Laboratories, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2003, p. 14.17, [CD-ROM].

[5] Ian B.D. McIntosh, Chad B. Dorgan, and Charles E. Dorgan, ASHRAE Laboratory Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, pp. 67 - 73.

[6] Ibid.

[7] The ASHRAE Handbook CD, 2003 HVAC Applications, Laboratories, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2003, [CD-ROM].

[8] Ian B.D. McIntosh, Chad B. Dorgan, and Charles E. Dorgan, ASHRAE Laboratory Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p 32.

[9] The ASHRAE Handbook CD, 2003 HVAC Applications, Laboratories, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2003, p. 14.12 and 14.13, [CD-ROM].

[10] Bernard Blazewicz, P.E., "Designing HVAC For Pharmaceutical Research Facilities," ASHRAE Journal, October 2000, pp. 45 - 49.

[11] Ibid.

[12] Ibid.

[13] Ibid.

[14] Ibid.

[15] The ASHRAE Handbook CD, 2003 HVAC Applications, Laboratories, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2003, p. 14.12 and 14.13, [CD-ROM].

[16] Ian B.D. McIntosh, Chad B. Dorgan, and Charles E. Dorgan, ASHRAE Laboratory Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p 67.

[17] Ian B.D. McIntosh, Chad B. Dorgan, and Charles E. Dorgan, ASHRAE Laboratory Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, pp. 67-81.

[18] The ASHRAE Handbook CD, 2003 HVAC Applications, Laboratories, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2003, p. 14.8, [CD-ROM].

[19] Ian B.D. McIntosh, Chad B. Dorgan, and Charles E. Dorgan, ASHRAE Laboratory Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p. 84.

[20] The ASHRAE Handbook CD, 2003 HVAC Applications, Laboratories, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2003, p. 14.9, [CD-ROM].

[21] Jonathan T. Crane, AIA, "Hot Zone Laboratories," ASHRAE Journal, June 1999, pp 28-31

[22] Bernard Blazewicz, P.E., "Designing HVAC For Pharmaceutical Research Facilities," ASHRAE Journal, October 2000, pp. 45 - 49.

[23] Ibid.

[24] Ian B.D. McIntosh, Chad B. Dorgan, and Charles E. Dorgan, ASHRAE Laboratory Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p. 98.

[25] The ASHRAE Handbook CD, 2003 HVAC Applications, Laboratories, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2003, p. 14.12, [CD-ROM].

[26] Ibid.

[27] The ASHRAE Handbook CD, 2003 HVAC Applications, Laboratories, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2003, p. 14.17, [CD-ROM].

[28] ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 2001, p. 5.

[29] U.S. General Services Administration, HVAC Excellence in Federal Buildings, October 2000 pp. 3-6.

[30] Lew Harriman, Geoffrey W. Brundrett, and Reonhold Kittler, Humidity Control Design Guide for Commercial and Institutional Buildings, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p.427.

[31] Lew Harriman, Geoffrey W. Brundrett, and Reonhold Kittler, Humidity Control Design Guide for Commercial and Institutional Buildings, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, pp.427-430.

[32] Ibid.

[33] Ibid.

[34] Ibid.

[35] Lew Harriman, Geoffrey W. Brundrett, and Reonhold Kittler, Humidity Control Design Guide for Commercial and Institutional Buildings, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p.434.

[36] Ian B.D. McIntosh, Chad B. Dorgan, and Charles E. Dorgan, ASHRAE Laboratory Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p. 98.

[37] The ASHRAE Handbook CD, 2003 HVAC Applications, Laboratories, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2003, p. 14.19, [CD-ROM].

[38] Robert Besant, P.E., Air to Air Exchangers, ASHRAE Journal, April 2003, p.43.

[39] Ian B.D. McIntosh, Chad B. Dorgan, and Charles E. Dorgan, ASHRAE Laboratory Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p. 139.

[40] Ibid.

[41] Ian B.D. McIntosh, Chad B. Dorgan, and Charles E. Dorgan, ASHRAE Laboratory Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p. 138.

[42] Somchai Paarporn, P.E., Runaround Loop Heat Recovery With Dehumidification System, ASHRAE Journal, June 1999, pp. 32-38.

[43] Paul A. Tetley, New Discovery for Heat Recovery, Engineered Systems, July 2001.

[44] Richard W. Trent, Heat Pipe Background, Presented in section I-3 of the Carolina Heat Pipe Inc. product catalog, 2004.

[45] Ian B.D. McIntosh, Chad B. Dorgan, and Charles E. Dorgan, ASHRAE Laboratory Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2001, p. 138.

[46] Richard W. Trent, President of Carolina Heat Pipe Inc., “Custom Heat Pipe Applications,” interviewed by Darrell Sandlin, Charleston, South Carolina, February 8, 2004.

[47] Richard Fellows and Anita Liu, Research Methods for Construction (Blackwell Science, 1997) p. 95.