LEED Heating, Ventilating and Cooling Design: Lamb-Miller Field House

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ABSTRACT

A major portion of energy consumed by the United States is through residential and non-residential buildings. Due to the rising costs of natural gas, the finite supply of natural resources, and the threat of climate change, there is a need to build 'greener' more energy efficient facilities. Leadership in Energy and Environmental Design (LEED) is an organization that addresses these issues with a certification process. This project addresses several of the LEED criterions in the design of a Fieldhouse that could take the place of the current Lamb-Miller Fieldhouse at Swarthmore College. This project focuses on the heating, ventilating and cooling aspects of the building. The final design includes a single-duct variable air-volume design, daylighting considerations, and a final duct design.

INTRODUCTION

The objective of this project was to design a new energy efficient Fieldhouse for Swarthmore College. The present facility has had minimal renovations throughout its lifetime. The current wood panel roof has never been renovated, the floors slope dangerously, and there are issues with overheating and ventilation of the building in the summer months. There are several facilities connected to the Fieldhouse, including Tarble Pavilion. The pavilion area has been renovated in the last 20 years and contains new offices and locker rooms. Thus, the area of focus is the main gymnasium, which holds coaches offices, an indoor track, basketball courts, and playing surfaces. The area proposed for renovation is labeled as the "Fieldhouse" on figure 1.

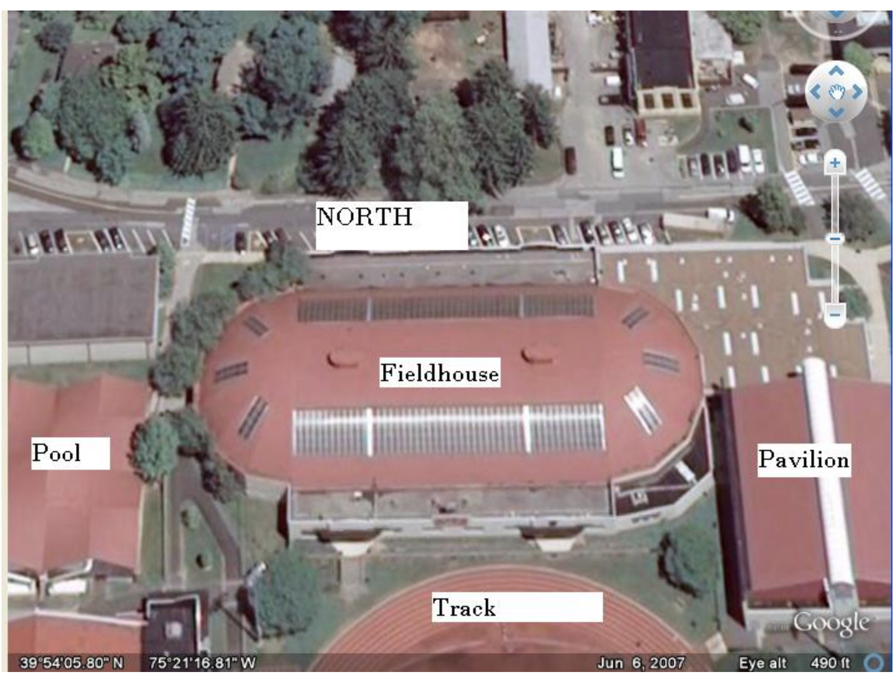


FIGURE 1.AERIAL VIEW OF SWARTHMORE COLLEGE'S ATHLETIC FACILITIES

The design for a new Fieldhouse will meet LEED requirements. LEED stands for Leadership in Energy and Environmental Design, and is a Green Building Rating System™[1]. The ranking system was developed in order to create an incentive for building environmentally conscious buildings. In order to obtain a LEED certification, a building is judged on several categories. These categories are Sustainable Sites, Water Efficiency, Energy and Atmosphere, Material and Resources, Indoor Environmental Quality, and Innovation and Design Process. Point allocation is outlined in Appendix A.

For this design project, the focus is on the third category, Energy and Atmosphere. The main objective of this category is to limit the overall energy consumption and increase the energy performance of a building. Today in the United States, 39% of America's energy and 68% of its electricity is a result of buildings [2]. Thus, with rising fuel costs, it is practical and necessary to build energy efficient buildings. The energy and atmosphere section accounts for 17 of the 69 points or about 25% of the total points. This section focuses on developing heating, ventilating, and cooling systems that minimize energy use. More specifically points are distributed for use of renewable energy (solar, wind, biomass), and energy efficient equipment (lighting, chiller, boiler, furnace, etc.).

The current Fieldhouse is heated through the use of a steam plant and is not cooled. However, if Swarthmore College was to ever build a new facility, cooling would have to be incorporated in the design, thus this design project offers a system that could be used for a new building. The following report discusses the design of a heating, ventilation, and cooling system for a new Fieldhouse. First the building envelope details will be addressed. The building envelope includes everything associated with the skeleton of the building: walls, windows, ceiling, and doors. Following the building envelope, an overview of the calculations performed will be addressed, as well as a description of the calculation software. A brief overview of the theory of heating and cooling loads will also be presented. Finally, both the duct (air distribution) and system design will be discussed for the new building. All these elements make up the primary parts of the heating, ventilation, and cooling system for the proposed building.

BUILDING ENVELOPE

INTRODUCTION/DESIGN LAYOUT

The building is being designed in the same location as the current Lamb-Miller Fieldhouse, so the dimensions are limited to the current area (Table 1). The design calls for the south facing wall to be constructed entirely of glass. A 4-lane, 200 meter indoor track will circle the main part of the gym. The make-up of the building can be broken into three main zones. First there is the main gym, next there are locker facilities for visiting teams, and finally there are coaches' offices. Figure 2, is layout of the floor plan, and figure 3 is a 3-D model of the building.

Building Dimensions		
	ft	*m*
Length	*320*	*97.5*
Width	*170*	*51.8*
Height	*60*	*19*
Area	*54400*	*5057*
Volume	*3264000*	*95959*

TABLE 1. DIMENSIONS OF THE BUILDING

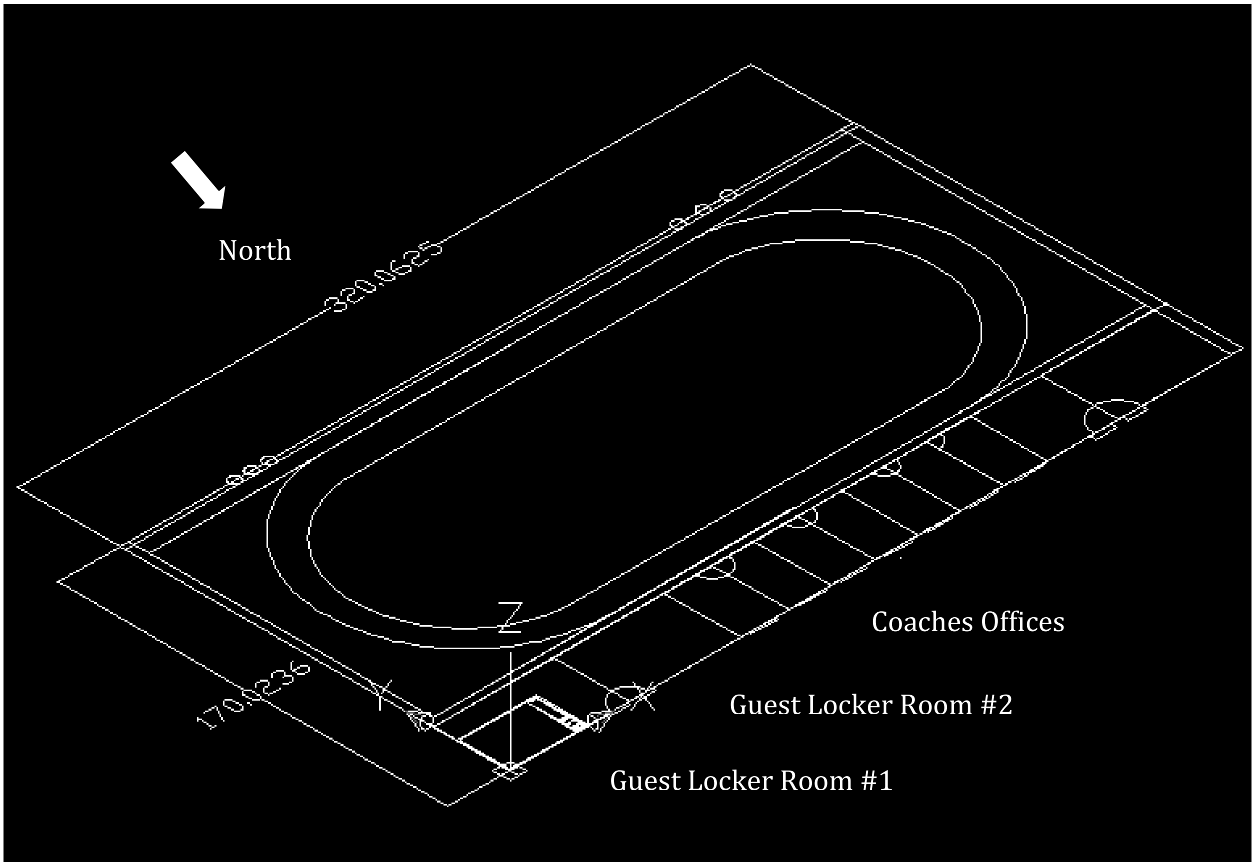


FIGURE 2. COMPUTER AIDED DESIGN OF FLOORPLAN FOR BUILDING

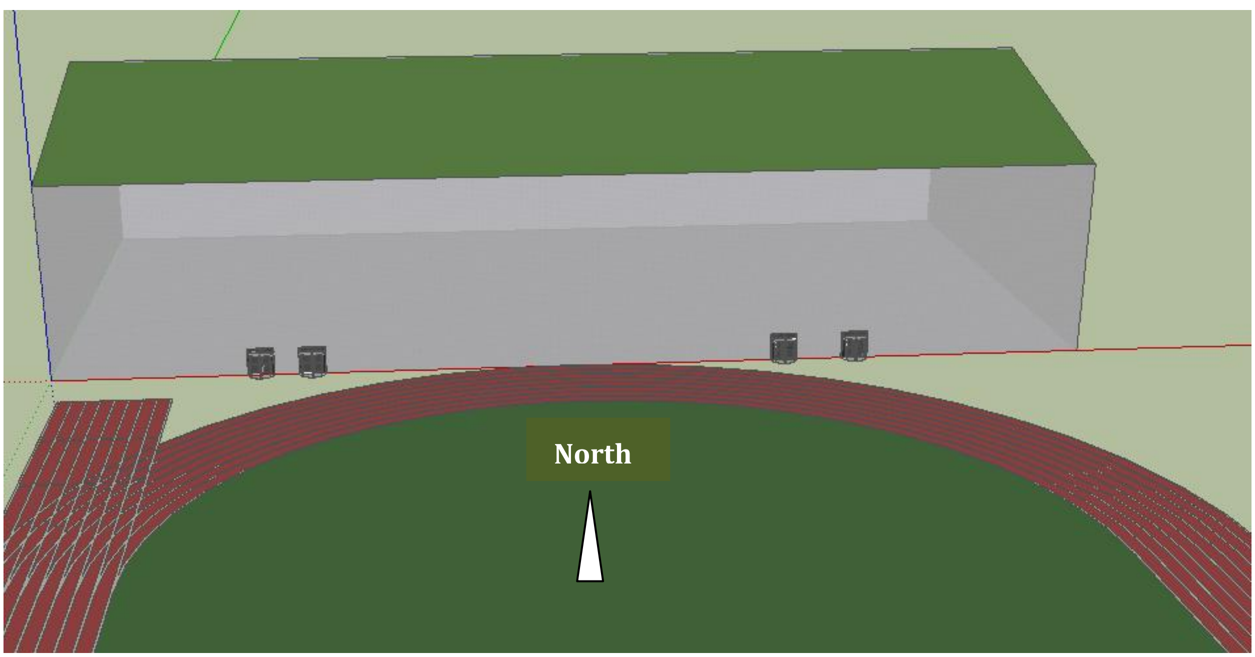


FIGURE 3. PROPOSED "NEW" FIELDHOUSE (SOUTH WALL: WINDOW)

WALLS

The walls of the building contribute to the overall performance of the building. The resistance of the walls affects the overall heating/cooling loads for the building. The resistance refers to how well the building can maintain a certain temperature. The walls should be well insulated in order to prevent heat from escaping during the winter months and the cold air in the summer. For this model, a four-layer wall was considered for the load analysis. The four layers include two 2" concrete layers sandwiching an insulation layer, a vapor barrier, and a plaster board infused with phase changing material board (Figure. 2). While cost is a major part of the design process in the real world, due to the scope of this project, cost will not be considered beyond a superficial level.

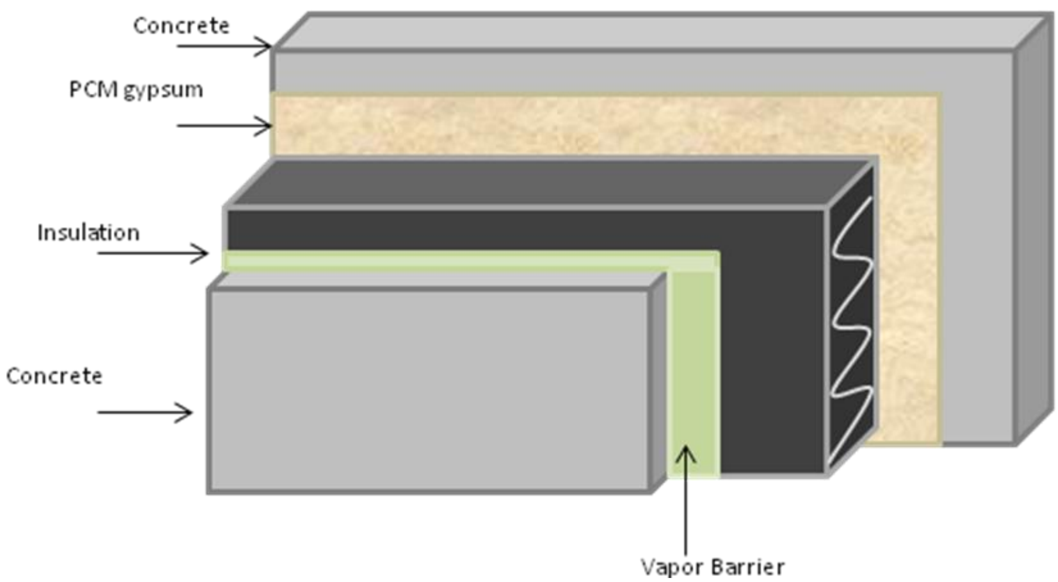


FIGURE 4. WALLL PROFILE FOR BUILDING ENVELOPE

Concrete was chosen for the wall profile of the Fieldhouse because of its durability, workability, and sustainability. LEED design focuses on buildings that will stand the test of time, and concrete is one of the most sustainable building materials. Additionally, concrete is a cheap material, so it is a highly feasible element for building at a college. There is much discussion about the 'greenness' of concrete, because the waste associated with the construction process. Nevertheless, using a panelized system can 'virtually eliminated construction waste' [4]. Therefore, the outer layer will not be poured on site but instead ordered premade. To obtain LEED points, and decrease the environmental impact of using such a material, the proposed concrete will be supplemented with fly ash. Fly ash is the residual waste produced by coal power plants. The powdery substance when mixed with cement produces a much more light weight product. Fly ash contributes approximately 30% more volume of cementitious material per pound when compared with cement [5]. There are several advantages to using this type of concrete. First fly ash is very light weight so the energy required to pump it to its desired location is significantly reduced. Another added bonus to this choice is the fact that water consumption is decreased in the mix with the addition of fly ash. Finally, this product meets the LEED credential for obtaining materials locally, as fly ash is readily available at various locations in Philadelphia and Lancaster.

The next material of interest is the phase changing material plasterboard insulate. While this technology is relatively new, the benefits of using this material are plentiful. Plasterboard/Gypsumboard infused with salt hydrates, or paraffin are able to absorb large amounts of energy (Table 2). Phase changing materials (PCM)are materials that are integrated into wall systems, as passive heating and cooling elements. PCM materials have a high specific melting heat, which means that it has the ability to absorb a lot of energy. As the PCM material absorbs energy, it slowly changes phase, and in the process it maintains a constant temperature. This allows for the building to also maintain a constant temperature. Generally how this process works, is during a warm summer day where cooling is necessary for a building, as the temperature in the building rises, the PCM absorbs the energy, and melts. Similarly, as the temperature decreases, the PCM releases the stored heat and returns to a solid state. This process would ultimately help to limit the peak utility rates for experienced during the day.

Layers	R-Value ($ft^2 \cdot °F \cdot h/Btu$).
Phase Changing Materials (Plasterboard)	0.5
Fly Ash Concrete	0.8
Vapor Mat	0.68
Fiberglass Insulation	11.0
Total	12.98 (approx. 13)

TABLE 2. MATERIAL RESISTANCE VALUES

DAYLIGHTING/FENESTRATION

Daylighting is a significant part of the LEED certification process, and the ultimate design of the new fieldhouse. Daylighting is the use of windows to bring sunlight into a facility. South facing windows are most advantageous for Daylighting because they contribute light in the winter and decrease the need for lighting, while allowing controlled lighting in the summer [7]. North facing windows are also prime choices for windows because they admit even light [7]. For the present project at hand, it is proposed to have the entire south wall be a window that overlooks the soccer/lacrosse field. Having an expansive window-wall will allow light to enter the building all day. This will limit the need for lighting inside significantly. Additionally the location of this window allows for a lot of light, because there are no shading factors in close proximity. Directly beside this window is a lowered field, thus there are no obstructions affecting the lights entrance. The north side of the building, however, lacks this open space because directly behind the building is a steam plant, and an area with large trees. Thus, large windows are not being considered for this side. The south wall covers approximately 19200 ft^2. This is a large area, so heat gain is a major concern in the design of these windows. Thus a low e-coating, high glazing, or multi-layered window design is required.

GlassX® crystal is the product of choice for the windows. GlassX is a multi-purpose system that integrates 'transparent heat insulation, protection from overheating, energy conversion and thermal storage' [8]. The U-value is approximately 0.48 W/m^2*K or 2.73 $ft^2·°F·h/Btu$, while the industry standard is 1.0W/m^2*K. Thus, this product is a very good insulator, which means low heat loss in the winter, and retention of cooling in the summer. Figure 5 is a diagram of the construction of the window wall. There are some very unique characteristics to this window. The first layer is tempered safety glass which has properties that are suitable for all weather environments. Next, there is a prism plate and inert gas. The gas contributes to the overall resistance value of the window, and the prism directs the light into or away from the building depending on the season. The sun at different seasons approaches the windows at different angles, thus by utilizing this knowledge, windows have the capability to either direct light away from the building, or transmit it into the building. This is helpful if you wish to use the sunlight for solar gain, or you wish to deflect the light for cooling purposes. The next layer is comprised of another layer of glass with low-e coating and more gas. Finally there is a phase-changing material plate. This allows for better control of the temperature in the building, and takes advantage of passive heating and cooling elements. Solar heat absorbed during the day can be released at night time.

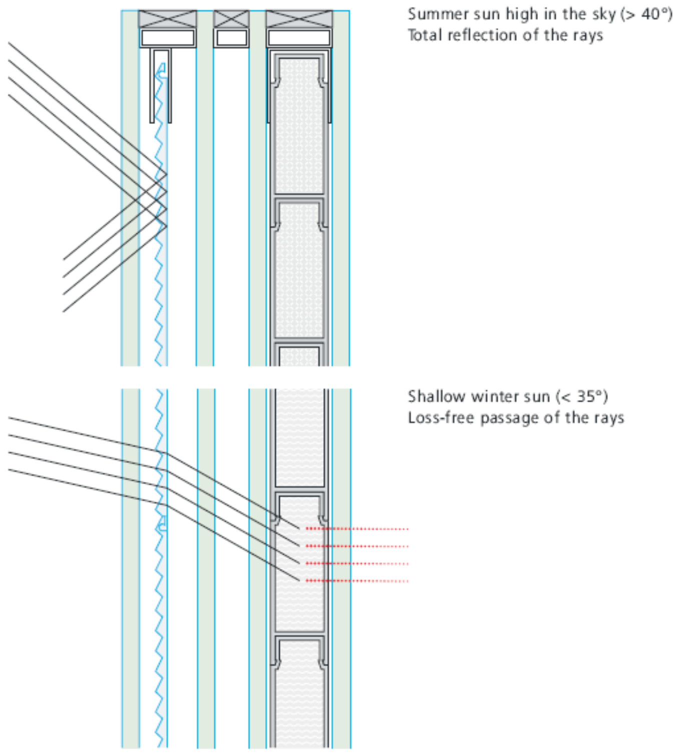


FIGURE 5. GLASSX CRYSTAL WINDOW INSTALLATION

ROOF

Heat mostly escapes from buildings through the roof. The Fieldhouse has a large roof, thus to minimize heat loss, a green roof was chosen. A green roof has many advantages over traditional roofs. First a green roof protects the roof from ultraviolet radiation and harsh weather conditions. The direct result of this is a longer lasting roof. Green roofs typically have longer lifetimes than traditional roofs by 2 to 3 times. Although there is often a startup cost associated with a green roof, the extended lifetime makes up for this and more. Additionally a green roof increases thermal resistance, and decreases the heating and cooling loads for the building. This not only decreases the overall energy use of the building, but also decreases the costs significantly. Finally, LEED allocates points to green roofs because they decrease the heat island effect. The heat island effect is generally associated with urban environments where most of the roofs are black and absorb heat. Thus, around these urban environments excess heat stored increases the temperatures in cities by several temperatures. This is dangerous for health and environmental standards, and thus should and can be avoided. As Swarthmore is a suburban community this is not as big of a problem, but should still be considered because of the large residential population, and the proximity to a urban environment. Table 3, outlines the roof properties.

Roof Area	***45,105 ft^2***
Pitch	***20°***
Load	***28 lbs/ft^2***
Green Medium	***Sedum***

TABLE 3. ROOF PROPERTIES

There are several design aspects to a roof. First, a pitch was utilized in order to avoid heavy loads due to snow and precipitation. Nevertheless, in order to utilize a green roof, the roof had to be a low-sloping roof which means that the slope had to be less than 35°. The green medium of choice was extensive (low-growing) vegetation. Sedum is light weight plant that still has a high water absorbency. This high absorbency rate would decrease the water run-off and ultimately decrease the soil and land erosion nearby. Finally, sedum is a desirable plant because it can withstand drought conditions, and requires very little maintenance. The layers are described in table 4.

Layer	*R-Value*
Steel Deck	*0*
Polyisocyanurate Insulation board	*8*
PVC layer and moisture fabric	*4*
4-6" Growth Medium	*18*
R-Value	*30*

TABLE 4. MATERIAL PROPERTIES FOR THE GREEN ROOF

DOORS

Doors are the main mechanism for infiltration in a building. Infiltration affects a building because as outside air creeps into a building, the settings and temperatures are negatively affected and the building is harder to control. Infiltration is a large part of heating and cooling load calculation. For this structure, infiltration is accounted through the doors. Thus, the doors were chosen to be rotating doors in order to decrease the infiltration in the building. It should be noted for the energy analysis, that the east side of the building is heavily insulated with the Tarble Pavilion. Thus, on the east side there is very little infiltration. Most of the infiltration occurs at the south wall where the most pedestrian traffic is seen. Energy plus accounts for this in a scheduling model for the usage of the building.

ENERGY PLUS™

Energy Plus is the software used to calculate the heating and cooling load for the Fieldhouse. Released by the Department of Energy, this program has the capability to analyze the energy consumption of a building. This software is known for its ability to analyze integrated systems, and produce results that are reliable. A common program in industry, an illustration of EnergyPlus inputs is given in figure 6.

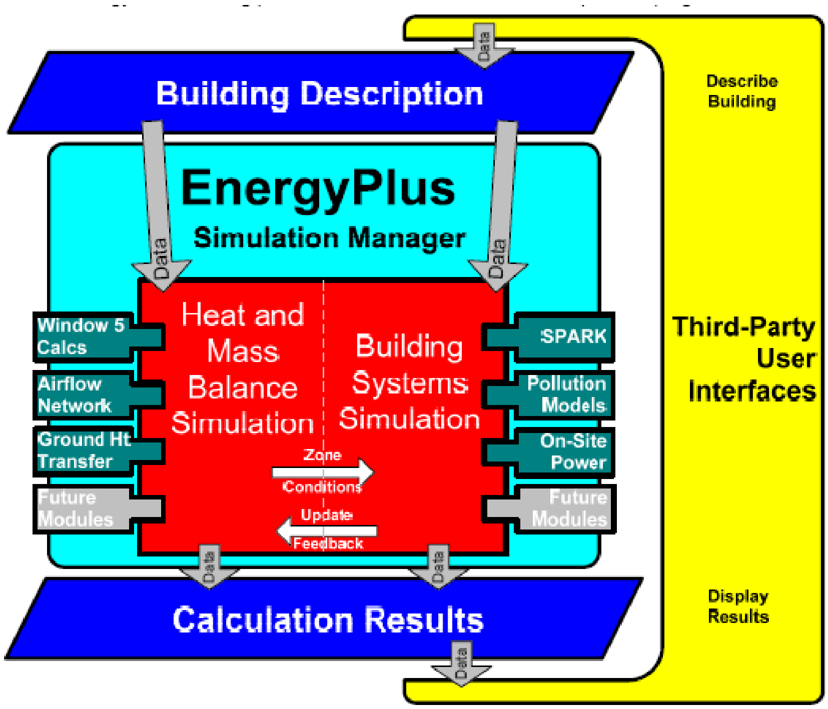


FIGURE 6. ENERGY PLUS INPUT/OUTPUT DIAGRAM

The program requires a list of inputs, and the user can designate what they want to evaluate. There is a comprehensive database of weather locations so that the user can obtain accurate environmental data. This program evolved in the 70's when it became apparent that energy consumption by buildings was a major issue, and that there had to be a better way to analyze various construction characteristics.

For the Swarthmore College Fieldhouse, the primary inputs analyzed were wall construction, location, orientation, doors and windows. EnergyPlus was principally used for obtaining the heating and cooling loads for the building.

HEATING LOAD

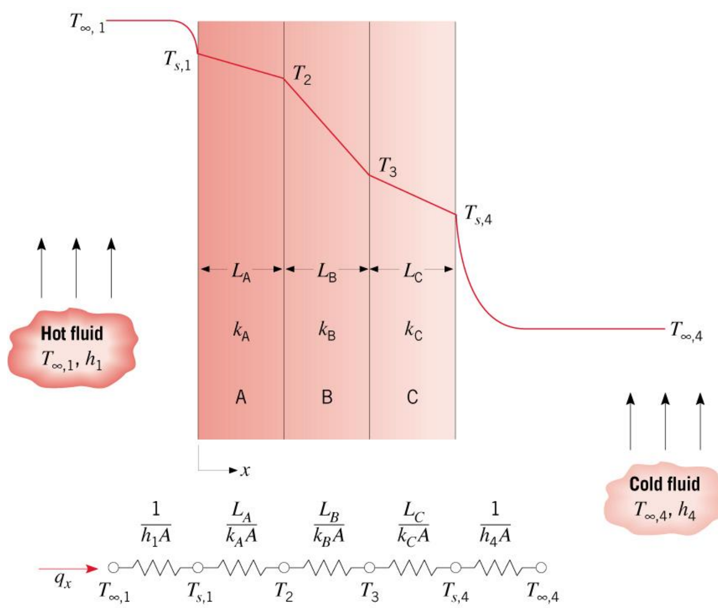
There are two kinds of heat losses that contribute to the overall heating load of a building:

1. Heat transmitted through the walls, roof, floor, fenestration, and doors
2. Heat required to warm outdoor air entering the space (Infiltration and ventilation)

The sum of (1) and (2) is the heating load of a building. Heat can be calculated on a steady state assumption during the winter because there are sustained periods of very cold, cloudy, stormy weather, with relatively small variation in outdoor temperature. Ideally the amount of heat required to heat a building is equivalent to the amount of heat loss of the building.

In analyzing heat transferred through windows, walls, floors, and any exterior surface of a building equation [1] can be used. Equation 2 is the same as equation 1, but represented as resistance through the wall. Refer to nomenclature section (Appendix C) for further information on variables. The general procedure for determining the heating load is a calculation of the resistance of the different surfaces. The resistance (R-value) represents how easily heat can penetrate a wall/roof/window. The higher the value, the less likely heat will be lost to the atmosphere.

$$\dot{q} = UA(t_i - t_o) \qquad (1)$$



$$q = \frac{T_{\infty,1} - T_{\infty,4}}{\sum R^T} \qquad (2)$$

$$R = \left[\frac{1}{h_1A} + \frac{L_A}{k_AA} + \frac{L_B}{k_BA} + \frac{L_C}{k_CA} + \frac{1}{h_4A}\right] \qquad (3)$$

The cooling load is an important factor because it represents the rate at which energy must be extracted from a zone to maintain a comfortable temperature. The cooling load is much more difficult to approximate than the heat load, because the convection and radiation occur. The process of radiation is absorbed by thermal mass, and then released in a time sequence. This causes a time lag in approximating heat load, which results in a dampening effect. Depending on the surface emissivity, estimated radiant time series have to be estimated in order to calculate the cooling load over a period of a day. The radiant time series method is the method used to calculate the cooling load.

EnergyPlus utilizes the Radiant Time Series (RTS) method for distinguishing building cooling loads. This procedure involves calculating 'solar intensities' for each hour for each surface, obtaining sol air temperatures, and then using wall/roof conduction time series to calculate heat gain per hour [3]. The radiant time series accounts for both conduction and radiation time series through a series of coefficients outlined in the ASHRAE Fundamentals handbook as radiant time factors and conduction time factors. The first part of this process is extensive, because it involves a lot of solar relations in order to first find the sol-air temperature in order to find the conductive heat input for the surface. The sol-air temperature is the "outdoor temperature that in the absence of all radiation changes gives the same rate of heat entry into the surface." [3] The formula for sol-air temperature is given below (4):

$$t_e = t_o + \frac{\alpha E_t}{h_o} - \frac{\varepsilon \Delta R}{h_o} \quad (4)$$

$$\varepsilon \Delta R = 0 (\text{for vertical surfaces})$$

The equation for the conduction input at a surface is:

$$\frac{q}{A} = \alpha E_t + h_o (t_o - t_s) - \varepsilon \Delta R \qquad (5)$$

$$\frac{q}{A} = h_o (t_e - t_s) \quad (6)$$

Thus the first part of the process is finding the sol-air temperature to then find the conduction input on an hourly basis. The process is pretty extensive though to obtain the total solar radiation. The general outline of the procedure is outlined below:

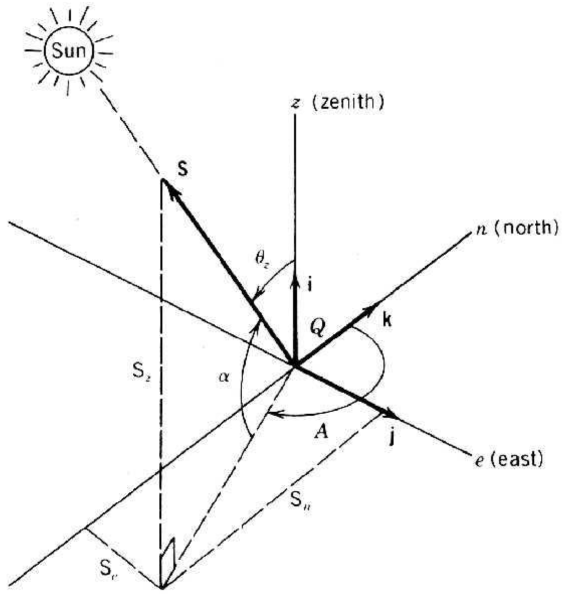


FIGURE 7 . SOLAR ANGLES [15]

Apparant solar Time, AST

$$AST = LST + ET / 60 + (LSM - LON) / 15 \quad (7)$$

$$H = 15(AST - 12) \quad (8)$$

$$\sin(\beta) = \cos(L)\cos(\delta)\cos(H) + \sin(L)\sin(\delta) \quad (9)$$

$$\cos(\phi) = (\sin\beta \sin L - \sin\delta) / (\cos\beta \cos L) \quad (10)$$

$$\cos\theta = \cos\beta \cos g \sin\Sigma + \sin\beta \cos\Sigma \quad (11)$$

$$E_{DN} = [A / \exp(B / \sin\beta)]CN \quad (12)$$

$$E_D = E_{DN} \cos\theta \quad (13)$$

$$Y = .55 + .437\cos\theta + .313\cos^2\theta \quad (14)$$

$$E_d = CYE_{DN} \quad (15)$$

$$E_r = E_d + E_D + E_r \quad (16)$$

The program has to take into account the solar affect on the building, which involves looking at the sun's relationship to the building at different times of the day (Figure. 7). The ultimate goal is to find the total solar radiation incident on the surface demonstrated in equation 16. Then using equation (5), the heat gain can be calculated.

The next part of the process takes these hourly values and multiplies them by conduction time series coefficients. Essentially the conduction time series takes into account the lag that exists from the time that the sun is actually hits the surface, until it penetrates the zone. At night when obviously there is not solar effect, the coefficients are zero. Thus, a heat gain for a wall can be calculated. The same process with the conductive wall coefficients is used for radiant time series. The sum of the radiant cooling load and the conductive cooling load is the total wall cooling load.

Using the same methodology, a hand calculation was performed for a simple structure. This was done in order to verify that the program produced results that were sound. The process however did not take into account the conduction time series coefficients, and just considered the system to be at steady state. The calculations were approximately 8% off from the programs results. This validated the use of the program for this project.

The program was run according to the designated design set points described in table 5.

Gym Design Set points	
Cooling	*75°F*
Heating	*68°F*
Heating Night Setback	*58°F*

TABLE 5. BUILDING SET-POINTS USED IN ENERGY PLUS ANALYSIS

The heating/cooling load obtained from the program was:

BTU/hour	
Heating Load	**Cooling Load**
200306	**274439**

TABLE 6. HEATING AND COOLING LOADS (ENERGY PLUS)

These loads represent the worst case scenario for the building. Four design days were considered (January, April, July, and October). The loads were calculated hourly, and the numbers presented in Table 6, represent the highest loads exhibited. The system has to be sized in order to satisfy the worst case scenario, thus these values were used for sizing the system.

DUCT DESIGN

Zone	Area (SF)	People	Ventilation CFM/person	Total Ventilation CFM
Main Gym	39000.00	300.00	20.00	6000.00
Lockers	4500.00	100.00	6.0 ACPH/ .5 CFM/SF	7832.06
Offices	10800.00	30.00	20.00	600.00

TABLE 7. VENTILATION REQUIREMENTS FOR EACH AREA

Ducts are required for air distribution. There are several factors that affect duct design. First of all there is the issue of noise in a facility. For the present project, the Swarthmore College Fieldhouse, noise is not a limiting factor, since the space is going to be used for athletic practices. Another factor that affects the design of ducts in a building is duct material. The material chosen will affect the noise, infiltration, lifetime, and constructability. More recently flexible ducts have been used due to their ease in construction. The down side of the flexible ducts is the high pressure losses and lack of durability. Since the building will be used for athletic purposes, where equipment has the chance of being damaged, durability is an important concern. Therefore, flexible ducts will not be considered.

In duct design, the first step is to decide the basic flow pattern for the air distribution. Diffuser location can be important for maintaining a comfort level. ASHRAE standards define five groups of diffusers, and for the fieldhouse, the best match is Group A(Figure 8). Group A encompasses all diffusers that are mounted near the ceiling and discharges air horizontally. Group A diffusers work well in commercial buildings, are areas with a large amount of open spaces. Additionally, the horizontal throw is important because the fieldhouse is being used for athletic events, where performance could be hindered with a vertical airstream.

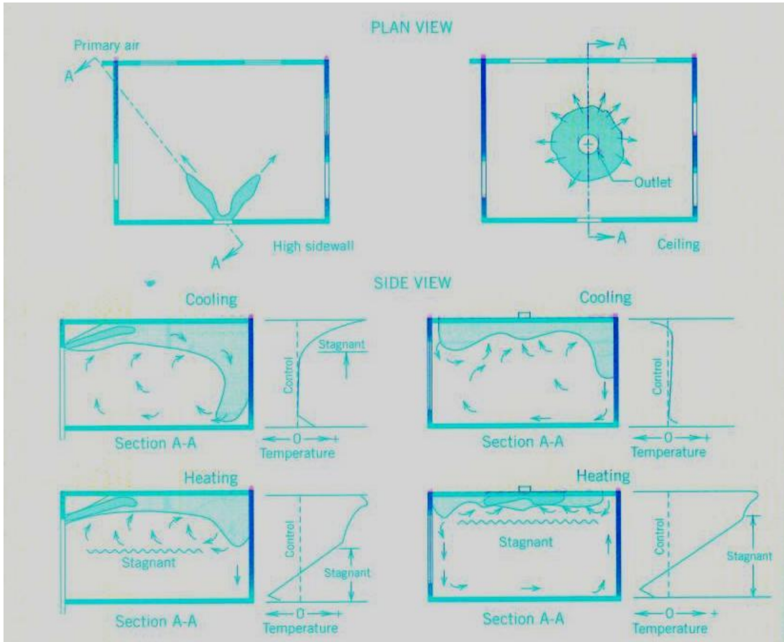


FIGURE 8. AIR MOTION CHARACTERISTICS OF GROUP A DIFFUSERS

The next part of duct design was to size each zone appropriately to its use. The use of the main gym is significantly different from offices and locker room. Thus, it makes sense that their ventilation requirements are different. Table 7 outlines the different requirements for each location. The total ventilation, in cubic feet per minute, plays a large role in the sizing of the ducts.

There are two methods for sizing ducts. The first is the equal friction method, and the second is the balanced capacity method. Both methods were used in the process of sizing the ducts. The basic objective of the equal friction method is to have equal pressure loss per foot of duct, throughout the entire system [6]. The procedure entails selecting a velocity, and then the pressure can be found for each branch of the ducting system accordingly. Basically, the balanced capacity makes the pressure equal for all duct runs from fan to outlet, while considering the flow rate. A pressure function can be defined:

$$P_{01} - P_{02} = \Delta P_f = f \frac{L_e}{D} P_v \qquad (17)$$

Pressure drop can also be written as a function of flow rate, and equivalent length of the duct:

$$P_{01} - P_{02} = \Delta P_f(\dot{Q}, L_e) \qquad (18)$$

Based on our air ventilation flow rates calculated in table 7, and a given equivalent lengths, the pressure change can be calculated, and thus the diameter of the ducts can be determined.

A program called *HVAC Book* was used to size the duct by these two methods, and the balance capacity method data is included in table 8. Complete data is included in Appendix B, for the sizing of the ducts.

Pressure at Diffuser	*0.04 in. wg*
Flow Rate at Diffuser	*4700 cfm*
Pressure in Wye/Tee	*0.054 in. wg*
Pressure along straight Duct	*0.043 in. wg*

TABLE 8. DUCT PROPERTIES

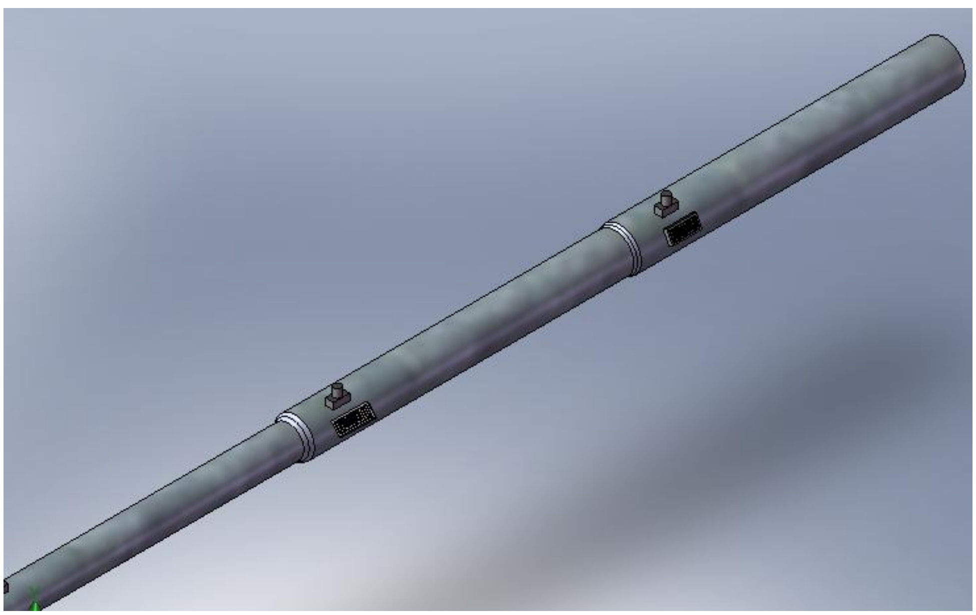


FIGURE 9. BASIC SET-UP OF DUCT RUN ALONG NORTH WALL OF BUILDING

HVAC SYSTEM DESIGN

The HVAC system was the focus of this design project. The process of heating, cooling and ventilating a building involves the greatest amount of energy consumed by a building. Thus, creating a system that is energy efficient has the ability to greatly reduce the carbon footprint of an existing or new building. Everything from the selection of the fans, to the sizing of the furnace and chillers can dramatically affect the overall load the building requires. Figure 5, is a schematic of the final system that will run the building.

A single-duct variable-air volume reheat system was selected because of the system setup. A fieldhouse mainly facilitates air movement in one large expansive space. Due to the fact that this one area receives much of the heating and cooling load, a single duct could facilitate all the air distribution needed if the diffusers were placed accordingly.

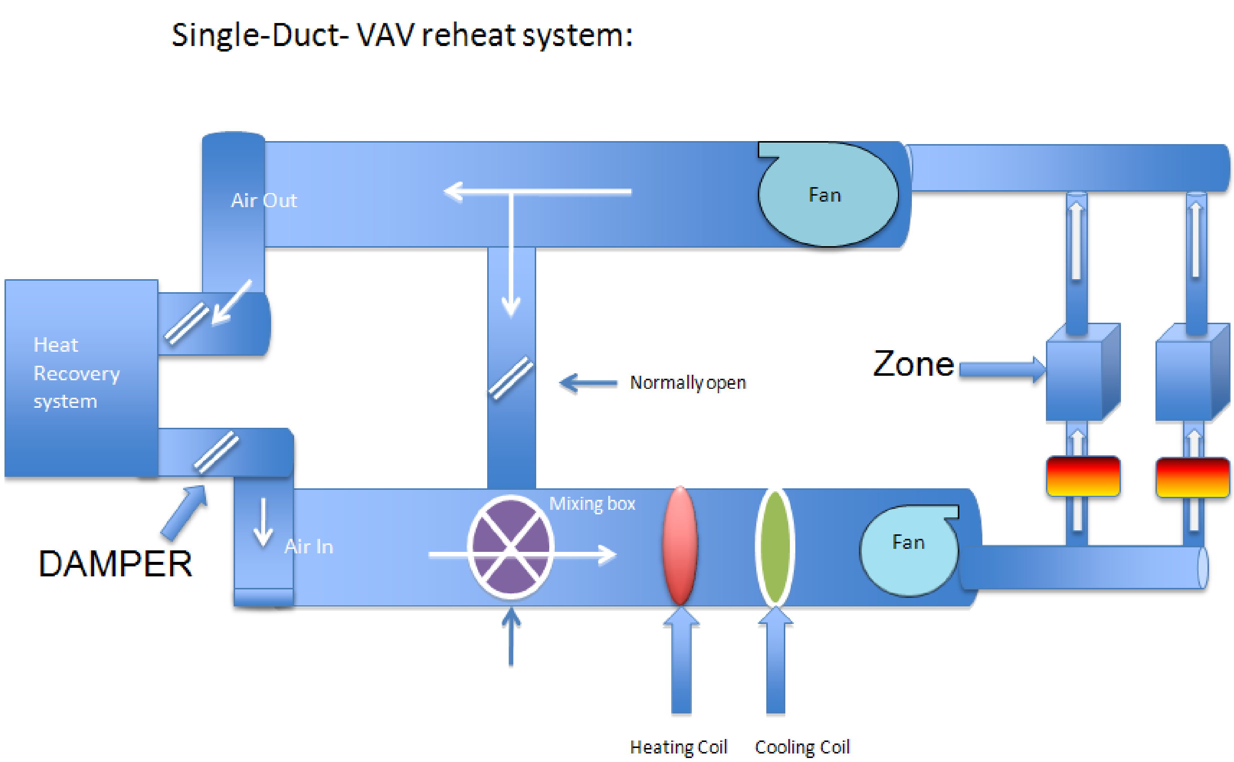


FIGURE 10. PROPOSED SINGLE-DUCT VARIABLE-AIR-VOLUME SYSTEM WITH REHEAT

FANS

The system is initiated by fans at the supply and exhaust locations of the ducting. The system was designed to have the fans to work for the entire time that the building is occupied. Generally this time frame is 9am-9pm, during the weekdays, with reduced hours during the weekend. Scheduling will fluctuate with use, so the system will be able to be manipulated manually, but during the school year a controlled system would be preferable. The system will be mainly controlled by programmable thermostats. The building will be programmed in order to maintain heating night setback. Heating night setback is the process of dropping the temperature a few degrees during the night in order to reduce energy consumption in a building. A set thermostat will do this automatically when it is controlling the fans. Energy savings typically amount to 2% per degree decrease [9].

MIXING BOX

A mixing box is a part of the air handling unit, where return air, and new incoming air is mixed before entering the zone. It consists of three sets of dampers whose 'operation is coordinated to control the fraction of the outside air in the supply air while maintaining the supply airflow rate approximately constant' [11]. To have a system run properly the air leaving the mixing box should be homogenous in temperature so that once it reaches the room it will emit a constant temperature. Fluctuation in temperatures would cause problems with the sensors, and may lead to inefficient heating/cooling.

HEATING COIL

A heating coil is used to in the system to heat air, through the ducts. Heating only occurs while the fan is running, and is fed from a furnace. A control valve regulates the heat into the coil, and thus regulates how much heat the building receives.

COOLING COIL

The cooling coil works in the same manner as the heating coil, except for the fact that it is connected a chiller. When the fieldhouse is occupied, and the fan is running, the system modulates a control valve to regulate the temperature. Nevertheless, when the building is unoccupied, the valve is closed, and no cooling occurs. There is a chance that when the building is not occupied that the fan may still be required to run, thus it is important that this distinction is made.

FURNACE

In a furnace air is heated directly by hot combustion gases, obtained from burning 'hydrocarbon fuel', such as natural gas [6]. For large buildings like the fieldhouse the heat exchange is does through the use of a heating coil. The air in filter from outside, or recycled from the room, and then is drawn through the heating and cooling coil. To determine an appropriate furnace for the building, the heating load described must be analyzed. The heating load represents the maximum heating requirement for the building, so the furnace much be large enough to satisfy this requirement, but not too large to maintain energy efficiencies.

CHILLER

Similar to the furnace, the chiller is sized according to the necessary cooling load. The cooling coil is often applied in an air handler in series with the heat coil. While the two are located in series they are never used at the same time.

REHEAT SYSTEM

The chosen cycle is a single duct system. In order to deal with fluctuations in demands in different rooms/zones, and unequal a reheat system has to be in place. Depending on what the room, a load may be increased by anything from human activity, different lighting schedules, and use of electronics and computers. Thus, to allow for inequalities, a reheat box is placed before each individual unit, and is activated through sensors. These sensors could be thermostats in each area. When a location falls below a comfortable level, the reheat units can e turned on. This will prove helpful in heating the many offices and locker rooms where different loads may be exhibited.

VARIABLE-AIR-VOLUME

A major component of this system is the presence of a variable air-volume system. This system controls temperature through the influx of outside air. Air is moved throughout the system in a cyclical manner. Dampers control where the air is funneled next in the system. Air can be exhaust to the outside, or air is brought in through a series of fans. Usually, the system has the dampers to the outside closed to limit infiltration, and the air is cycled throughout the internal closed loop. VAV systems are very common in comparison to constant volume systems, because it has the ability to feed different demands. Also, VAV systems increase the energy efficiency of a system because the total airflow is reduced, decreasing the energy demand on the fans. Similar to the reheat system, the airflow is monitored and run by the temperature sensors that determine the appropriate fan speed and the timing of the dampers.

ECONOMIZER ORIENTATION

The economizer is another energy saving part of the cycle. Essentially the economizer involves circulating air from the outside and using it for cooling when the temperature outside is lower than the temperature inside the building. This is controlled again by a temperature sensor which then directs the motion of the dampers.

HEAT RECOVERY SYSTEM

In the heating process, air is circulated around a closed loop, constantly being reheated to meet the requirement for the surrounding zone. Ideally heating would be limited if you could just continue to cycle the air that was already heated. This however does not satisfy indoor air quality standards, thus it is necessary to exhaust 'stale' air, and introduce clean air into the system. This produces waste heat because heated air is exhausted to a cold surrounding, and the new cold air has to be heated. An air to air heat recovery system can decrease this inefficiency, by enabling a heat exchanger system to capture that heat and reuse it. Figure 11, demonstrates how this waste heat can be used to heat the incoming air without recycling stale air. A system like this decreases the heating load tremendously.

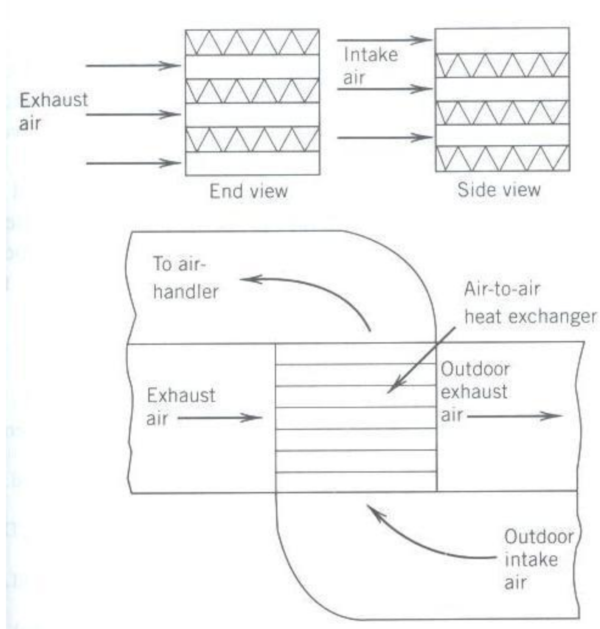


FIGURE 11. AIR TO AIR HEAT RECOVERY SYSTEM

In summary, a heating, ventilating and cooling system was designed for a Fieldhouse. LEED credentials were addressed in the process of designing an energy efficient fieldhouse. In order to design the HVAC system, the building envelope had to be considered, and heating and cooling loads determined based on these inputs.

FUTURE WORK

There are three areas that could be addressed in order to further the LEED certification and improve the energy efficiency of the building. First, the continued use of thermal energy storage devices could increase the efficiency of the HVAC system. More specifically, the cooling system can be improved with the design of chilled water or ice storage. Cooling the building requires the largest load, so any method to decrease this load should be looked into. Loosely this system would entail running chillers on off peak time, and then storing the cold water or ice to be used for cooling in on peak times. The advantage of this method is your chiller size is greatly reduced, reducing your energy consumption significantly.

Another area which could be addressed if this project were to be embellished is in the water delivery for the building. This was not addressed in this project because it is not included in the energy and atmosphere section of the LEED point allocation. Nevertheless, the use of solar heated water could be used to decrease the load of the locker rooms that require copious amounts of water.

Finally, the last focus point that could be explored as an offshoot to this project is a feasibility study of ground-water heat pumps. Ground water heat pumps are highly efficient for cooling large buildings because of the constant temperature exhibited by the ground.

CONCLUSIONS

LEED offers incentives for constructing 'green' eco-friendly buildings. Tax incentives have been enacted in many states in order to further support the efforts of LEED. Despite these measures, people still reject the idea of green building casting it aside and claiming of its 'expense'. While there are often additional costs to build more energy efficient buildings, the benefits down the line are plentiful.

This senior design project opened my eyes to the vast field that exists in energy management, and energy auditing. Simple retrofitting activities can significantly decrease energy consumption in buildings. While, exploring the LEED standards I was impressed by their comprehensive address of all the aspects of the building process. Nevertheless, I was somewhat dismayed at the actual process of accruing these points. The entire system is designed to be paper based, meaning that points are all achieved through application form and no one actually checks up on the sites to inspect the level of energy efficiency. This process could produce skewed results. Also there appears to be some hypocrisy in the system. Schools, companies, and government groups pay substantial sums in order to achieve this rating, when that money could be invested to create a more energy efficient building.

Nevertheless, the system is a start for building more energy efficient facilities. The benefits are bountiful, and as more and more individuals catch on, energy consumption will be more managed.

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Project Checklist

Sustainable Sites

14 Possible Points

Y			Prereq 1	**Erosion & Sedimentation Control**	Required
Y	?	N	Credit 1	**Site Selection**	1
Y	?	N	Credit 2	**Urban Redevelopment**	1
Y	?	N	Credit 3	**Brownfield Redevelopment**	1
Y	?	N	Credit 4.1	**Alternative Transportation,** Public Transportation Access	1
Y	?	N	Credit 4.2	**Alternative Transportation,** Bicycle Storage & Changing Rooms	1
Y	?	N	Credit 4.3	**Alternative Transportation,** Alternative Fuel Vehicles	1
Y	?	N	Credit 4.4	**Alternative Transportation,** Parking Capacity	1
Y	?	N	Credit 5.1	**Reduced Site Disturbance,** Protect or Restore Open Space	1
Y	?	N	Credit 5.2	**Reduced Site Disturbance,** Development Footprint	1
Y	?	N	Credit 6.1	**Stormwater Management,** Rate and Quantity	1
Y	?	N	Credit 6.2	**Stormwater Management,** Treatment	1
Y	?	N	Credit 7.1	**Heat Island Effect,** Non-Roof	1
Y	?	N	Credit 7.2	**Heat Island Effect,** Roof	1
Y	?	N	Credit 8	**Light Pollution Reduction**	1

Water Efficiency

5 Possible Points

Y	?	N	Credit 1.1	**Water Efficient Landscaping,** Reduce by 50%	1
Y	?	N	Credit 1.2	**Water Efficient Landscaping,** No Potable Use or No Irrigation	1
Y	?	N	Credit 2	**Innovative Wastewater Technologies**	1
Y	?	N	Credit 3.1	**Water Use Reduction,** 20% Reduction	1
Y	?	N	Credit 3.2	**Water Use Reduction,** 30% Reduction	1

Energy & Atmosphere

17 Possible Points

Y			Prereq 1	**Fundamental Building Systems Commissioning**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**CFC Reduction in HVAC&R Equipment**	Required
Y	?	N	Credit 1	**Optimize Energy Performance**	1–10
Y	?	N	Credit 2.1	**Renewable Energy,** 5%	1
Y	?	N	Credit 2.2	**Renewable Energy,** 10%	1
Y	?	N	Credit 2.3	**Renewable Energy,** 20%	1
Y	?	N	Credit 3	**Additional Commissioning**	1
Y	?	N	Credit 4	**Ozone Depletion**	1
Y	?	N	Credit 5	**Measurement & Verification**	1
Y	?	N	Credit 6	**Green Power**	1

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Materials & Resources

13 Possible Points

Y			Prereq 1	**Storage & Collection of Recyclables**	Required
Y	?	N	Credit 1.1	**Building Reuse**, Maintain 75% of Existing Shell	1
Y	?	N	Credit 1.2	**Building Reuse**, Maintain 100% of Shell	1
Y	?	N	Credit 1.3	**Building Reuse**, Maintain 100% Shell & 50% Non-Shell	1
Y	?	N	Credit 2.1	**Construction Waste Management**, Divert 50%	1
Y	?	N	Credit 2.2	**Construction Waste Management**, Divert 75%	1
Y	?	N	Credit 3.1	**Resource Reuse**, Specify 5%	1
Y	?	N	Credit 3.2	**Resource Reuse**, Specify 10%	1
Y	?	N	Credit 4.1	**Recycled Content**, Specify 5% (p.c. + 1/2 p.i.)	1
Y	?	N	Credit 4.2	**Recycled Content**, Specify 10% (p.c. + 1/2 p.i.)	1
Y	?	N	Credit 5.1	**Local/Regional Materials**, 20% Manufactured Locally	1
Y	?	N	Credit 5.2	**Local/Regional Materials**, of 20% in MRc5.1, 50% Harvested Locally	1
Y	?	N	Credit 6	**Rapidly Renewable Materials**	1
Y	?	N	Credit 7	**Certified Wood**	1

Indoor Environmental Quality

15 Possible Points

Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke (ETS) Control**	Required
Y	?	N	Credit 1	**Carbon Dioxide (CO_2) Monitoring**	1
Y	?	N	Credit 2	**Ventilation Effectiveness**	1
Y	?	N	Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
Y	?	N	Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
Y	?	N	Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
Y	?	N	Credit 4.2	**Low-Emitting Materials**, Paints	1
Y	?	N	Credit 4.3	**Low-Emitting Materials**, Carpet	1
Y	?	N	Credit 4.4	**Low-Emitting Materials**, Composite Wood	1
Y	?	N	Credit 5	**Indoor Chemical & Pollutant Source Control**	1
Y	?	N	Credit 6.1	**Controllability of Systems**, Perimeter	1
Y	?	N	Credit 6.2	**Controllability of Systems**, Non-Perimeter	1
Y	?	N	Credit 7.1	**Thermal Comfort**, Comply with ASHRAE 55-1992	1
Y	?	N	Credit 7.2	**Thermal Comfort**, Permanent Monitoring System	1
Y	?	N	Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
Y	?	N	Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Innovation & Design Process

5 Possible Points

Y	?	N	Credit 1.1	**Innovation in Design**	1
Y	?	N	Credit 1.2	**Innovation in Design**	1
Y	?	N	Credit 1.3	**Innovation in Design**	1
Y	?	N	Credit 1.4	**Innovation in Design**	1
Y	?	N	Credit 2	**LEED™ Accredited Professional**	1

Project Totals

69 Possible Points

Certified 26-32 points **Silver** 33-38 points **Gold** 39-51 points **Platinum** 52-69 points

APPENDIX B: DUCTING SIZING AND LAYOUT

ID	Fitting Type		Diameter (in)	Q (cfm)	Velocity (ft/min)	Delta P in wg.
1	Air Handling Unit		0	42300	0	0
2	Elbow		50.1	42300	3085.1	0.027
3	Tee/Wye	main	50.1	37600	2742.3	0.014
		branch	14.8	4700	3925.9	0.486
		common	50.1	42300	3085.1	
4	Straight Duct		14.8	4700	3925.9	0.121
5	Diffuser/Grille			4700		0.04
6	Straight Duct		50.1	37600	2742.3	0.043
7	Tee/Wye	main	47.7	32900	2656.6	0.014
		branch	45.4	4700	417.2	0.547
		common	50.1	37600	2742.3	
8	Straight Duct		45.4	4700	417.2	0
9	Diffuser/Grille			4700		0.04
10	Straight Duct		47.7	32900	2656.6	0.014
11	Tee/Wye	main	44.9	28200	2560.9	0.054
		branch	16.6	4700	3141.9	0.477
		common	47.7	32900	2656.6	
12	Straight Duct		16.6	4700	3141.9	0.069
13	Diffuser/Grille			4700		0.04
14	Straight Duct		44.9	28200	2560.9	0.043

15	Tee/Wye	main	41.9	18800	2452	0.05
		branch	23.4	4700	1572	0.44
		common	44.9	233500	2560.9	
16	Straight Duct		23.4	18800	1572	0.012
17	Diffuser/Grille			4700		0.04
18	Straight Duct		41.9	23500	2452	0.043
19	Tee/Wye	main	38.5	18800	2324.7	0.045
		branch	15.8	4700	3456.3	0.302
		common	41.9	23500	2452	
20	Straight Duct		15.8	4700	3456.3	0.088
21	Diffuser/Grille			4700		0.04
22	Straight Duct		38.5	18800	2324.7	0.043
23	Tee/Wye	main	34.5	14100	2169.9	0.038
		branch	23.4	4700	1572	0.272
		common	38.5	4700	2324.7	
				18800		
24	Straight Duct		23.4	4700	1572	0.012
25	Diffuser/Grille			4700		0.04
26	Straight Duct		34.5	14100	2169.9	0.043
27	Tee/Wye	main	29.6	9400	1968.3	0.032
		branch	27.2	4700	1169.9	0.227
		common	34.5	14100	2169.9	
28	Straight Duct		27.2	4700	1166	0.006
29	Diffuser/Grille			4700		0.04
30	Straight Duct		29.6	9400	1968.3	0.043

31	Tee/Wye	main	22.8	4700	1664.4	0.024
		branch	28.3	4700	1075.6	0.019
		common	29.6	9400	1968.3	
32	Straight Duct		28.3	4700	1075.6	0.005
33	Diffuser/Grille			4700		0.04
34	Straight Duct		22.8	4700	1664.4	0.043
35	Elbow		22.8	4700	1664.4	0.021
36	Diffuser/Grille			4700		0.04

APPENDIX C: NOMENCLATURE

$\alpha =$ absorptance of surface for solar radiation

β=Solar Altitude

ε=hemispherical emittance of surface

ϕ=Solar Azimuth

θ=Incidence Angle

δ=Declination

γ=Surface Solar Azimuth

A=cross-sectional area

$AST =$ Apparent Solar Time

$E_d = Diffuse\ Irradiance$

$E_D =$ Surface Direct Irradiance

E_{DN}=Direct Normal Irradiance

$E_t = total\ solar\ radiation\ incidenton\ surface$

ET=Equation of Time

$H = hour\ angle$

$h_o = coefficient\ of\ heat\ transfer\ by\ long\text{-}wave\ radiation\ and\ convection\ at\ outer\ surface,\ Btu/h \bullet ft^2$

$h_2 =$ convection heat transfer coefficient of inner surface

$k_A =$ conduction heat transfer coefficient of outer surface

$k_B =$ conduction heat transfer coefficient of insulation surface

$k_C =$ conduction heat transfer coefficient of plasterboard surface

$L = thickeness$

$L_e =$ Equivalent Length(run)

LST=Local Standard Time

$P_{01} = \Pr essure\, Pt.1$

$P_{02} = \Pr essure\, Pt.2$

t_i=temperature in

t_o=temperature out

$t_e =$ sol air temperature

t_o = outdoor temp

$\dot{Q}$ = flow rate (cubic feet per minute)

$\Delta R = \textit{difference between long wave radiation incident on surface from sky and surroundings and radiation emitted by blackbody at outdoor air temperature } Btu/h \bullet ft^2$

U = u-factor-the heat transfer coefficient, the inverse of the resistance of the wall or window. A high number indicates that heat easily transfers throught the wall; it is desirable to have a low u-factor

Y = ratio of sky diffuse radiation on vertical surface to sky