Energy Efficiency Improvement of an Air Handling Unit at a Pharmaceutical Facility by Integration of an Economizer Cycle

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ABSTRACT

This project presents the design of an economizer cycle for an existing Air Handling Unit (AHU) located at a pharmaceutical facility. At certain low temperatures, the integration of the economizer cycle will allow the AHU to make use of cold outside air to condition a product's temporary storage area inside the plant. For the project, historical weather data is used to analyze the environment's suitability for the new system and to estimate the number of potential operation hours and energy savings. The design focuses on the zone's requirements for proper integration of the system and the conditions under which the cycle is activated. The cost of the components and materials required for implementation is also presented.

INTRODUCTION

Most manufacturing facilities require air conditioned cooling throughout the year for both their product processes and employees. However, this can account for a high percentage of the plant's energy costs [1]. Therefore, any measures taken to reduce air conditioning energy consumption are beneficial to the facility. The addition of an economizer cycle to an AHU is such an alternative, since its purpose is to use cold outside air to reduce the cooling load inside a conditioned zone.

The selected AHU for the project is responsible for cooling a product's temporary storage area inside a pharmaceutical facility located in Jayuya, PR. Because of the site's high altitude and colder weather, the economizer's integration provides a high potential for energy savings. Figures 1 and 2 show the selected AHU and its schematic, respectively.

Figure 1: *AHU Considered for Economizer Implementation*

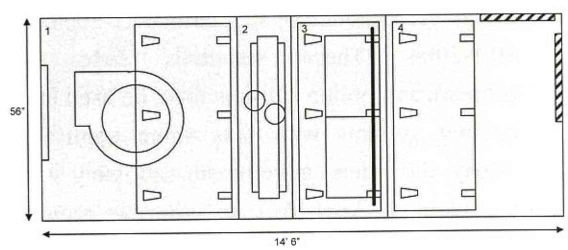

Figure 2: *AHU Schematic*

BACKGROUND

The following sections provide some basic definitions relevant to the project's expected development. They represent the primary body of knowledge related to the integration of an economizer cycle.

- ***Air Handling Unit (AHU):*** In an HVAC system, the AHU is responsible for conditioning and delivering air through the system. An AHU is generally made up of one or more supply and return fans for maintaining air flow, heating and cooling coils, filters, and dampers for controlling the ratio of outside air that is mixed with return air.

- ***Economizer***: An economizer is an HVAC control strategy that uses outside air under suitable climate conditions to reduce the required mechanical cooling. When the outside air temperature is less than the required supply air temperature during cooling periods, the economizer allows a building's mechanical ventilation system to use up to 100% outside air, thereby reducing the energy required to cool the mixture of outside air and warm recirculated air under normal operating conditions [3].

- ***ASHRAE***: The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) is an international organization which develops standards related to refrigeration processes and the design and maintenance of indoor environments [2].

  ASHRAE guidelines for economizer cycle design are included in standards 62.1-2004 and 90.1-2004. These standards state that economizer cooling systems must be used in all cooling systems with fans when applicable. Today, the federal government and many states are adopting ASHRAE guidelines as required building code laws, thus underlining the importance of considering the integration of economizer cycles in HVAC systems [5].

METHODOLOGY

In order to accomplish the objectives of the economizer cycle integration project, a set of structured steps were developed. Since the project's nature centers mainly around automation and control system design, most of the approaches listed below are straightforward and follow a step-by-step path toward its completion.

The research project's methodology is composed of seven main stages, as illustrated in Figure 3:

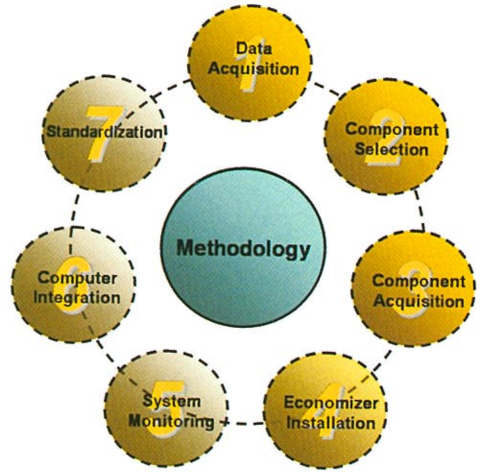

Figure 3: *Economizer Cycle Integration Methodology*

- ***Data Acquisition Phase:*** The first step in the methodology is to gather temperature, humidity, and AHU energy consumption data (both for outdoors and inside conditioned area) in order to establish trends for maximum energy reduction periods. During this stage it is important to ensure that all sensors function properly and are calibrated by the Critical Systems department at the plant.
- ***System Design and Component Selection Phase:*** The next step is to develop an appropriate economizer cycle for the AHU based on the climate characteristics obtained, while at the same time maintaining the room's temperature requirements. The appropriate components and materials needed for the implementation of the design are also chosen during this phase.
- ***Component Acquisition Phase:*** This methodology stage includes procurement for the purchase of the selected components.
- ***Economizer Installation Phase:*** At this point the economizer components are installed, including any additional dampers, actuators, control modules, enthalpy sensors, and wiring.
- ***System Monitoring Phase:*** This step consists of observing and analyzing the performance of the Economizer cycle over a 2-week period and

calculating the new consumption of the AHU in order to determine the extent of any energy reduction.

- ***Computer Integration Phase:*** An additional stage of the methodology is to develop an option for the Economizer cycle to be controlled from an existing PC graphic display (remote control) and time-of-day scheduling, in addition to local control. This will allow authorized plant personnel such as operators, HVAC technicians and engineers to override the economizer cycle's local control in case they deem it necessary.
- ***Standardization Phase:*** Finally, upon successful completion of the project, all the steps undergone and feedback obtained will be used to establish guidelines for further economizer cycle integration in other AHUs at the facility, thus generating further energy reductions.

The scope for this project consists of the first 3 steps of the methodology. The remaining phases are presented to ultimately give an idea of the project's overall goal and are scheduled to be performed over the following months.

RESULTS AND DISCUSSIONS

By carrying out the methodology steps listed in the previous section, the following results were obtained.

DATA ACQUISITION

The first step consists of collecting all information that would potentially be required for the economizer cycle implementation. This gathering of data will serve to give a preliminary idea of the benefits and will be useful in selecting components.

According to ASHRAE, the inherent humidity and high temperatures found in Puerto Rico make the island a less than ideal environment for this kind of project [5]. However, cold weather like the one present in the town of Jayuya offsets this general rule. In fact, due to its altitude (1,200 meters above sea level) the town possesses one of the coldest climates in the island.

In order to have a clear understanding of the town's weather, daily temperature values were obtained from the National Oceanic and Atmospheric Administration (NOAA) and Accuweather.com. Both organizations have average low temperature readings, which usually refer to the overnight low point, available in their online databases. These values were plotted along with the overnight area setpoint, as seen in Figure 4. Although the trends show a small variation among them, it can be observed that there is a definitive potential for the use of cold outdoor air for cooling purposes.

Of significant benefit to the project's undertaking is the fact that a control module for

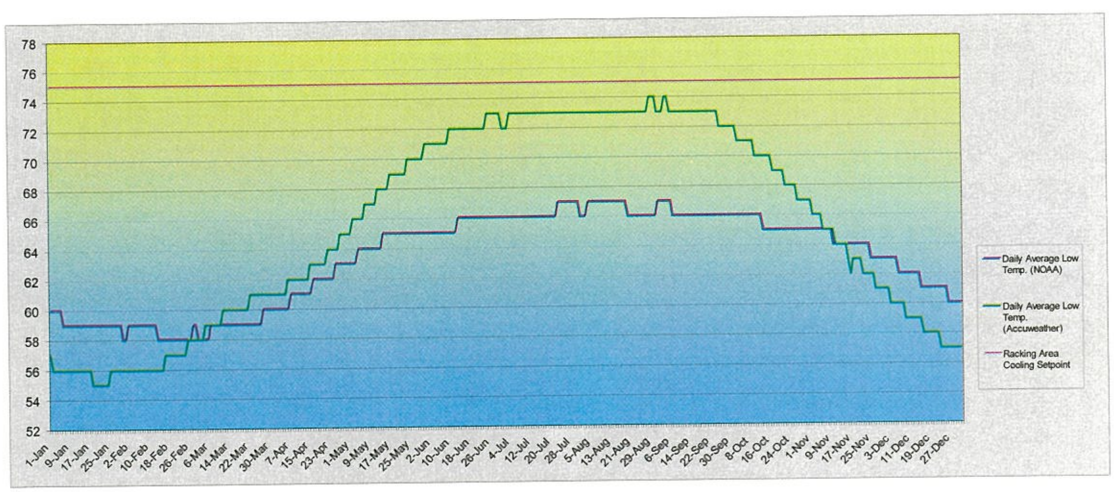

Figure 4: *Year-long Average Low Temperature for the Town of Jayuya, PR*

another AHU at the facility was already storing outside temperature data at half-hour intervals during the last 2 years. Taking advantage of the availability of this reliable and on-site information, the outside temperature values for the most recent full year (2008) were tabulated in a spreadsheet. This yields a model in which to calculate the actual number of hours of economizer cycle operation. The plots for the coldest and hottest months of the year are shown below.

Overall, there were a total of 3,258 hours during the previous year where the outside temperature went below the established setpoint for the area (70°F during daytime and 75°F from 8:00 PM to 6:30 AM). In other words, had the economizer cycle been functioning during 2008, the AHU would have operated with mechanical cooling for 3,258 hours (37.2% of the time).

The number of operating hours, however, is not enough information to calculate the potential energy

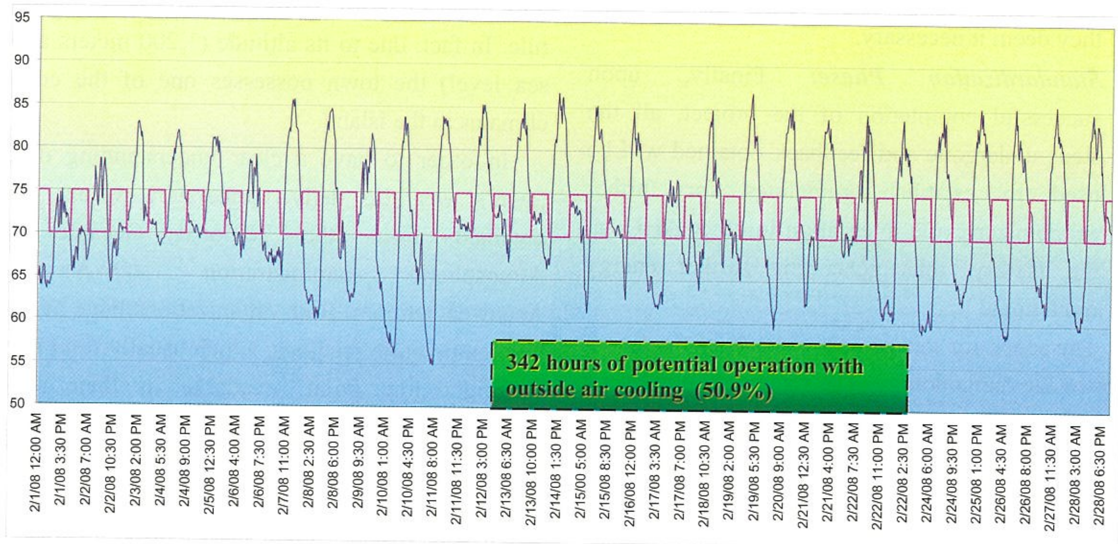

Figure 5: *Facility Outside Air Temp. (°F) and Area Setpoints (°F) during the month of Feb. 2008*

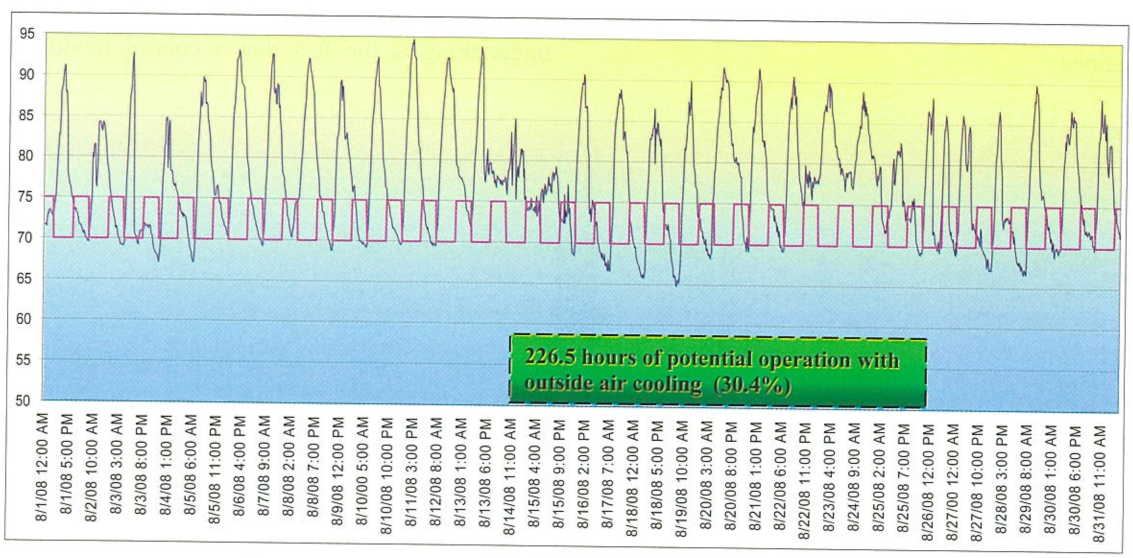

Figure 6: *Facility Outside Air Temp. (°F) and Area Setpoints (°F) during the month of Aug. 2008*

savings derived from the system's integration. Additional data concerning both the location's weather and the AHU itself were obtained, as shown in the tables below.

Table 1: *Facility Atmospheric Properties*

Altitude	1,200 m (3,937 ft)
Precipitation range	2.4 in. (Jan.) – 10.5 in. (Oct.)
Density of moist air	1.2 kg/m^3
Specific heat of moist air	1.01 J/g°C

Table 2: *AHU Characteristics*

Unit Size	60 Tons
Volumetric flow rate	24,000 CFM (11.2367 m^3/s)
Blower motor voltage	230/400 V
Blower motor current	49.6 A
Motor rotational speed	1,745 rpm
Avg. chilled water inlet temp.	44.5 °F
Avg. chilled water outlet temp.	56 .2°F

The energy interactions present in a typical AHU can be categorized into three types: the heat load generated by the occupancy inside the conditioned zone (people, machinery, etc.) which gets cooled by air going through the unit's cooling coils, the cool air losses during its trajectory through ducts due to weak insulation and length, and the electrical energy consumed by the blower's motor. For the purposes of this project, the last two types are neglected. As for the first type, the removal of heat from the return air is in fact not reflected as a power load on the AHU itself, but on the chiller unit that supplies cold water to it.

The heat transfer occurring at the cooling coils can be modeled as a simple heat transfer function:

$$Q = V\rho_0 C_P (T_R - T_S) \qquad (1)$$

where V is the volumetric flow rate, ρ_0 is the density of moist infiltrated air, C_P is specific heat of the infiltrated air, and T_R and T_S are the return air wet bulb and supply air dry bulb temperatures in Celsius, respectively.

A few assumptions have been made for calculating the potential energy savings. Since the AHU fan motor operates continuously, the volumetric flow rate inside the unit is considered to be constant. Also, the moist air density does not account for the site's altitude. Taking these assumptions into consideration, the heat transfer equation becomes:

$$Q = \left(11.237\, {m^3}/{s}\right)\left(1.2\, {kg}/{m^3}\right)\left(1{,}010\, {J}/{kg°C}\right)(\Delta T) \qquad (2)$$

Ideally, there would have been historical temperature data available for the conditioned area, just as was the case with the outside temperature. However, neither supply temperature nor return temperature values were being recorded. To account for this, average daily values from a 3-day period were used for the entire year. This evidently has an impact on the reliability of the model, since there are some daily variations more marked than others throughout the various seasons of the year. However, it is an alternative in the absence of recorded data.

To model the heat transfer in the AHU when the economizer cycle is in operation, the return air temperature values are simply substituted. For time intervals when the outdoor temperature is found to be lower than the setpoint, Equation (1) becomes:

$$Q = V\rho_0 C_P (T_O - T_S) \qquad (3)$$

where T_O represents the outdoor air temperature.

The monthly energy consumption estimates for both the AHU with and without the economizer cycle are listed in Table 3 and Table 4. The tables also list the monthly costs for each case. Due to the highly fluctuation of oil prices, the actual kWh rates charged by the local power company during the previous year were used, instead of an average value for all months. Overall, the integration of an economizer cycle would result in an annual consumption of 694,439.66 kW versus 859,493.49kW with the current system. This represents a 19.2% of energy savings and translates into a $ 33,960.00 annual cost reduction.

***Table 3:** Energy Costs (AHU Only)*

Month	Consumption (kWh)	$/kWh	Monthly Costs
January 2008	55,787.78	0.261	$ 14,560.61
February 2008	73,943.57	0.196	$ 14,492.94
March 2008	74,823.84	0.180	$ 13,468.29
April 2008	76,144.25	0.193	$ 14,695.84
May 2008	77,904.80	0.196	$ 15,269.34
June 2008	60,409.21	0.240	$ 14,498.21
July 2008	60,739.31	0.261	$ 15,852.96
August 2008	81,866.02	0.230	$ 18,829.18
September 2008	81,311.45	0.230	$ 18,701.63
October 2008	80,756.88	0.221	$ 17,847.27
November 2008	78,785.07	0.160	$ 12,605.61
December 2008	57,021.32	0.170	$ 9,693.62

***Table 4:** Energy Costs (Proposed Economizer-integrated AHU)*

Month	Consumption (kWh)	$/kWh	Monthly Costs
January 2008	40,253.20	0.261	$ 10,506.08
February 2008	52,561.23	0.196	$ 10,302.00
March 2008	54,780.63	0.180	$ 9,860.51
April 2008	58,109.73	0.193	$ 11,215.18
May 2008	62,548.53	0.196	$ 12,259.51
June 2008	51,905.04	0.240	$ 12,457.21
July 2008	52,737.32	0.261	$ 13,764.44
August 2008	72,535.82	0.230	$ 16,683.24
September 2008	71,137.60	0.230	$ 16,361.65
October 2008	69,739.38	0.221	$ 15,412.40
November 2008	64,767.92	0.160	$ 10,362.87
December 2008	43,363.28	0.170	$ 7,371.76

SYSTEM DESIGN

The basic functioning of the current AHU system is represented in Figure 7 as a Piping and Instrumentation Diagram (P&ID). As the cycle begins, warm air flows through the cooling coils in the AHU, which then uses a blower to circulate the cooled air through an 8-meter-long air duct and into the room. Once inside, the air becomes warmer due to the occupants and heating sources in the room. Some of the air leaves the open space into the adjacent areas, while the rest returns to the AHU and the process is repeated. The room temperature is maintained by a two-way control valve (PV 101) which regulates the flow of chilled water through the coils. This valve serves as the actuator of the system and is controlled by the unit control module, which in turn, receives its input from a return temperature sensor (TT 103).

As can be seen in the diagram, the current configuration lacks a return air damper. Also, the outdoor air damper is completely closed. The unit has in fact 2 outdoor air dampers with different dimensions, the bigger of which is currently out of service since it has been covered with insulation.

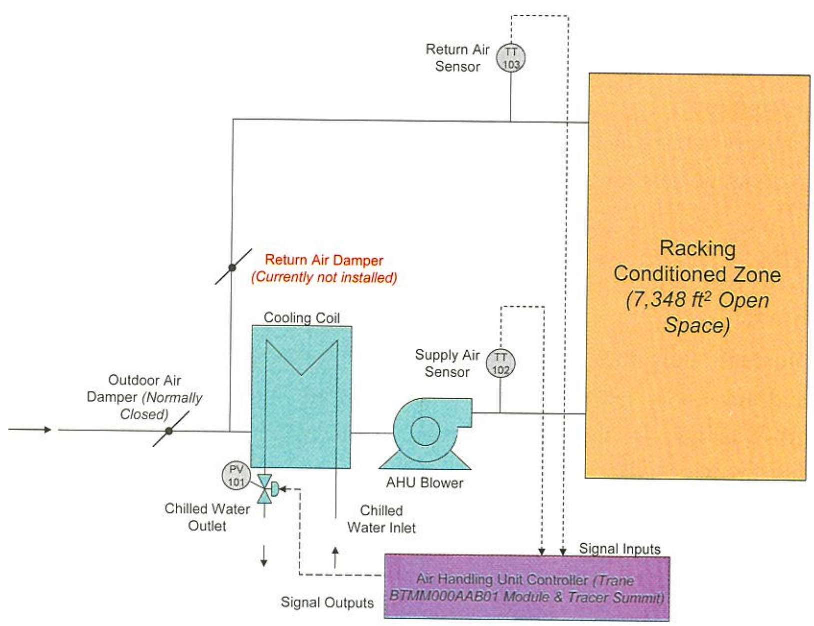

***Figure 7:** Current AHU P&ID*

The new design illustrated in Figure 8 makes use of the existing out of service outside air damper and installs a return air damper. An exhaust damper is also added to remove warm return air from the system when the economizer cycle becomes active. Whereas before a damper had to be manually opened or closed, all three dampers in the new design would now be modulated by actuators. The control module receives an input from an outdoor air temperature sensor (TT 104) in order to know when to activate the economizer cycle. Finally, a humidity sensor is added for monitoring purposes.

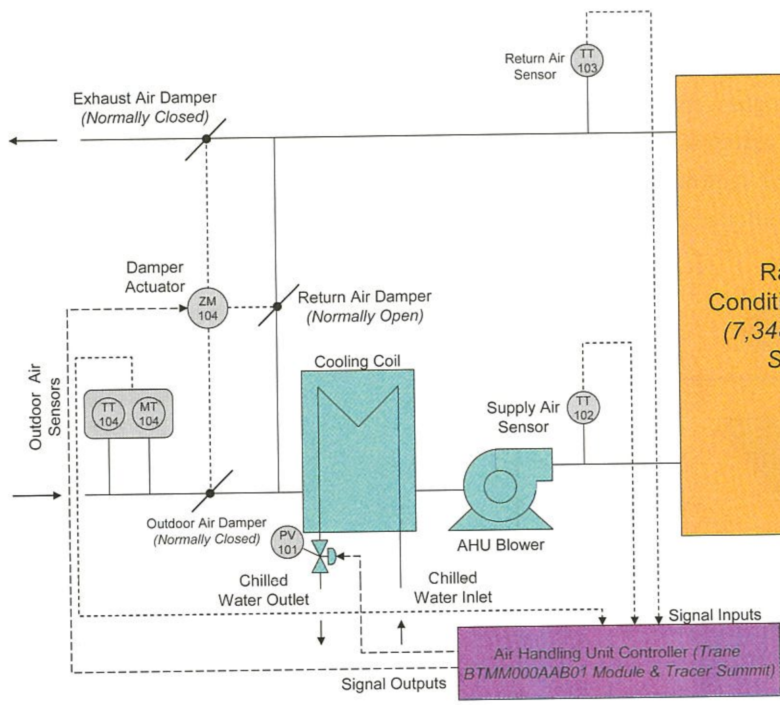

Figure 8: *Economizer-integrated AHU P&ID*

Component Selection

Due to this being a retrofit project, component selection is limited, with the main design considerations focusing on the return air damper and its actuator. The design will make use of the outdoor air damper that already exists in the AHU. The control module and sensors will be purchased as per the recommendations of the AHU's manufacturer.

The new return air damper considered for installation is a 44" x 37" parallel type, since it promotes air mixing better than an opposed blade damper [4]. The damper size takes advantage of the entire area in the return air duct opening, allowing a more precise range of modulation.

The proposed damper actuator for the design is a linear model with an electric motor. This actuator type has the ability to move the damper directly with a crank arm.

Programming

Figure 9 shows a basic flowchart of the proposed programming logic. While the AHU is operating normally, it will continuously sample both the outside temperature *T_out* and compare it to the current setpoint temperature *Setpoint*. As long as the *T_out* is higher than Setpoint, the unit will continue to operate normally. If the opposite is true, then the economizer cycle will be activated.

As for the economizer cycle, once the sub-routine is activated, the flow rate value inside the AHU's plenum is stored and the outside air damper (also referred to as the make-up damper) opens completely. As the outside air damper opens, the return air damper closes by the same ratio, as both are expected to be controlled by one actuator. The outside air damper will then start closing little by little (5% each time) in order to maintain the previous flow rate value stored. This will happen for a maximum of 20 times to avoid a situation where the program is unable to exit the economizer subroutine. A tolerance range of around 10% is taken into account when making the flow rate comparison. After the program ends the economizer subroutine, it won't be reactivated for at least 15 minutes in order to avoid sudden air flow changes that might affect the conditioned area and the AHU.

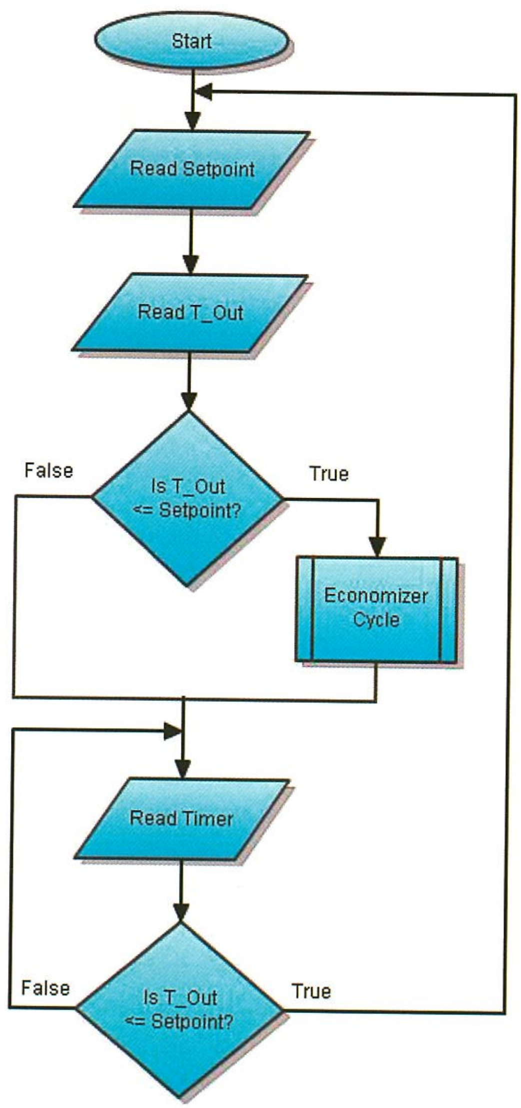

Figure 9: *Control Program Flowchart*

The economizer's programming will be integrated into an exiting control module, which regulates the current control strategy for the AHU, in order to reduce costs and eliminate possible conflicts during programming. Consequently, all programming will be performed by the control module supplier.

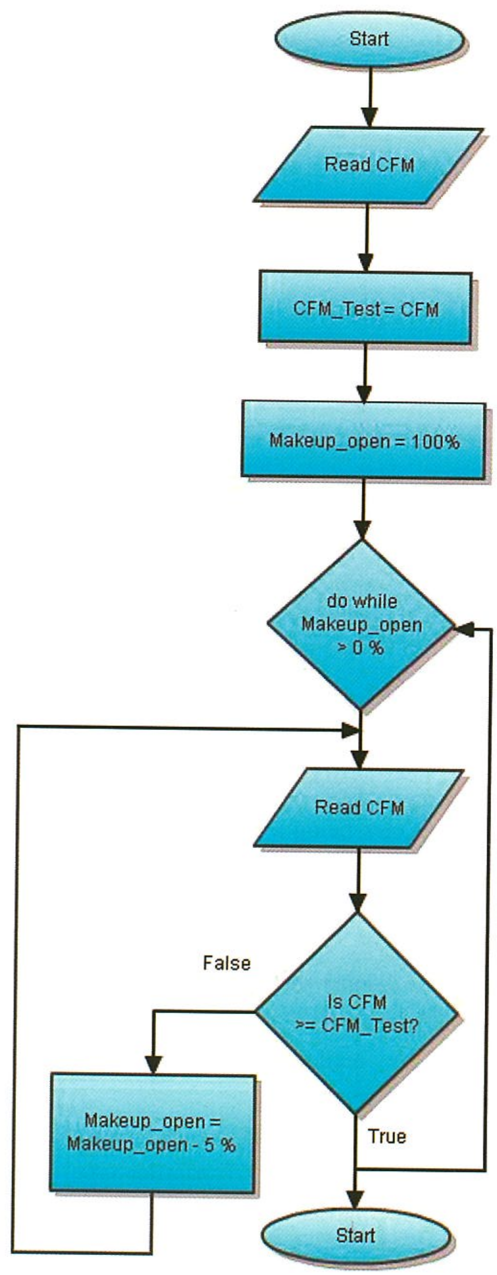

Figure 10: *Economizer Cycle Sub-routine Flowchart*

PROJECT COSTS

The costs of implementation were found to be twice as expensive as originally estimated. However, these costs are still expected to be recouped within the first 3 months of operation.

Table 5: *Economizer Cycle Implementation Costs*

Project Resources	Estimated Cost	Actual Cost
Materials		
Metal Ductwork	$ 500	$ 600
Insulation	$ 150	$ 170
Equipment		
Dampers and actuators	$ 800	$ 960
Control Module	$ 100	$ 350
Enthalpy Sensors	$ 60	$ 290
Communication cable	$ 80	$ 150
Labor		
Installation and performance monitoring	$ 0	$ 0
Programming	$ 0	$ 830
Total	**$ 1,690**	**$ 3,350**

CONCLUSIONS

For this project, an economizer cycle design for an existing AHU was developed. The outdoor climate around the facility was found to be ideal, having temperatures as low 55°F (far lower than the 70°F - 75°F required setpoints). The temperature records throughout one year were examined, which yielded a total of 3,258 hours of potential mechanical cooling. This data was used to calculate the energy load savings corresponding to the chiller unit (165,054 kW or 19.2% per year). The cost savings were substantial, resulting approximately in $ 33,960.00 annually. For the economizer cycle design, additional dampers were procured in order to exhaust hot air from the conditioned zone and to control the flow of return air. The design relies on the outside air temperature and the air flow sensors inside the AHU to activate the economizer cycle.

Currently, the project's status is in the component installation phase. To avoid impact on the production process schedule, the retrofitting of the components is being scheduled to be performed during weekends.

As a final observation, this project underscores the importance that historical data plays when designing an accurate model for a system.

FUTURE WORK

In addition to the installation of the economizer components and verifying that the system operates properly, the following ideas are recommended for future implementation:

- Analyze additional temperature locations through the entire geography of Puerto Rico to determine the areas where economizer integration would be a viable energy savings approach.
- Develop an economizer operation cycle for Clean Room areas which are controlled by additional parameters such as pressure, humidity, and air quality.
- Consider a system design where multiple AHUs supply air to the same conditioned zone.
- Develop a control strategy for AHUs which incorporate heating coils and includes a low temperature limit during the economizer cycle.

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