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Bridging the Gap Between Commissioning Measures and Large Scale Retrofits in Existing Buildings

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ABSTRACT

Most often commissioning of existing buildings seeks to reduce a building’s energy consumption by implementation of operational changes via the existing equipment. In contrast, large scale capital retrofits seek to make major changes to the systems installed in the building to reach the same goal. The purpose of the investigations presented here is to find energy-saving measures which economically fall between the retro-commissioning measures which typically have very short paybacks and the large scale capital retrofits which typically have significantly longer paybacks. Based on a simulation analysis of three previously retro-commissioned university buildings, it was determined that all three are currently consuming more energy than would be expected under ideal operating conditions. The simulation estimated annual savings potential for the three buildings range from 28-44% of whole building energy consumption. A research level assessment of each has been conducted to identify the reasons why the subject buildings are not operating as efficiently as possible and energy saving measures are presented to bring the buildings as close to ideal operation as possible. This work seeks to determine if an on-site assessment can identify commissioning measures that realize a substantial portion of the indicated savings potential or whether it appears that there are reasons that would preclude commissioning measures from achieving significant savings. If it is not practical to implement commissioning measures due to antiquated controls, missing sensors, or other reasons, these investigations identify rapid payback retrofit measures that achieve as much of the projected savings as possible. The analysis indicates that 30-100% of the estimated savings potential can be realized in the three subject buildings with estimated paybacks of less than 3 years.

INTRODUCTION

In the summer of 2010 a proposal was made by the Energy Systems Laboratory (ESL) at Texas A&M University to conduct a research level assessment of three large university buildings. All three buildings have previously undergone retro-commissioning but a simulation analysis of these buildings indicated they are currently using more energy than would be necessary under ideal operation of the existing systems. The purpose of the project is to identify the reasons why the subject buildings are consuming more energy than under ideal conditions and whether retrofits or retro-commissioning measures would be sufficient to reduce this difference. This assessment will entail a detailed investigation of the buildings selected to see if an on-site assessment can identify commissioning measures that would realize a substantial portion of the indicated savings potential or whether it appears that there are reasons that would preclude commissioning measures from achieving significant savings. If it is not practical to implement commissioning measures due to antiquated controls, missing sensors, or other reasons, this investigation will seek to identify rapid payback retrofit measures that will achieve the projected savings. The goal for the retrofits will be to bridge the gap between large scale long payback retrofits and retro-commissioning measures which typically have very short paybacks but generally rely on the existing equipment.

SELECTION OF BUILDINGS

Before the three buildings were selected, an analysis of 16 buildings was performed using the Potential Energy Savings Estimation (PESE) Toolkit developed by the ESL (Liu 2010; Liu et al 2010). The PESE Toolkit utilizes a detailed methodology to estimate the potential for energy savings from commissioning and retrofit measures. This is done using a simplified building energy model based on the Simplified Energy Analysis Procedure (SEAP) developed by Knebel (Knebel 1983). The user must use measured energy consumption and weather data to calibrate the simulation within the tool by modifying the user input building and system information before the savings estimation procedure is completed. Once the simulation is calibrated, the user specifies a maximum and minimum value for the occupied and unoccupied periods for five optimization parameters: exterior zone space temperature, interior zone space temperature, cold duct supply air temperature, hot duct supply air temperature and the outside airflow volume. The user's discretion must be used in determining the values of these optimization parameters based on the building use and other factors. For instance, an unoccupied minimum outside airflow volume of zero might not be appropriate in all lab buildings or hospitals but may be appropriate in office buildings or schools with very regular operating hours. Once the optimization parameters have been entered, the numerical procedure generates and seeks the parameter values which will produce minimum total energy use cost while meeting the indoor thermal comfort requirements. The difference between the calibrated simulation energy consumption and the optimized system energy consumption is the savings potential for that building if the existing systems were operating at their optimum performance level.

For the original 16 buildings, the whole building annual energy savings potential estimates from the PESE toolkit ranged from a low of 6.9% to a maximum of 56.8%. From the original list of buildings, nine were presented to the campus utilities management staff and the three buildings discussed below were chosen from this shorter list based on their savings potential and construction activities planned for some of the buildings not chosen. The initial PESE tool analysis results are outlined below in Table 1.

Table 1: PESE Toolkit energy savings potential estimates for three subject buildings

Bldg.	%Elec.	%CHW	%HHW	%Total
1	4.8	47.7	85.8	28.6
2	-0.6	52.2	98.4	44.0
3	-1.9	54.8	99.3	35.8

BUILDING DESCRIPTIONS & OPERATIONS

All three of the subject buildings are located on a major university campus with a central utility plant that supplies hot water (HHW) and chilled water (CHW) to the buildings for heating and cooling. All three buildings are multiple use buildings with two consisting mostly of research laboratories and the third consisting of classrooms and teaching laboratories. A detailed description of each building is below.

Building #1

Building 1 was constructed in 1967 and is home to many biological research laboratories and some offices. The building has five floors (including basement) for a total area of 96,000 square feet. It is generally occupied on weekdays from 8:00 AM to 5:00 PM, but also has some occupancy on weekends. The CHW system consists of two variable speed 25 hp pumps and the HHW system consists of one variable speed 7.5 hp pump. Two small (1/3 hp) booster pumps provide CHW and HHW to a special piece of equipment on the first floor. The heating, ventilating, and air-conditioning (HVAC) system in the building consists of 4 air handling units (AHU's) and two fan coil units (FCU's). The two large main AHU's are dual duct variable air volume (DDVAV) units which serve the majority of the building via a full direct digital control (DDC) system. Both of these units have a damper in the hot duct which modulates to control the static pressure in this duct separate from the cold duct. The third AHU is also DDVAV with DDC controls and serves half of the first floor. The fourth AHU is a constant speed outside air (OA) unit with DDC controls which pretreats the OA for the first floor AHU. All of the terminal boxes in the building have DDC controls. The total maximum design supply flow for the building is 155,800 CFM with a design maximum of 31,240 CFM of OA. The maximum total exhaust flow for the building is 65,680 CFM from 38 exhaust fans. The two FCU's are dedicated units conditioning small sensitive lab areas that were not a part of the original construction. The FCU airflows are not included the totals given above.

Building #2

Building 2 was constructed in 1975 and is home to classrooms (large and small), teaching science laboratories and some offices. The building has five floors (including basement) for a total area of 104,949 square feet. It is generally occupied on weekdays from 8:00 AM to 9:00 PM, but also has some occupancy on weekends. The CHW system consists of two variable speed 50 hp pumps and the HHW system consists of two variable speed 25 hp pumps. The HVAC system in the building consists of 12 AHU's: 6 single duct constant air volume (SDCAV) units, 4 single duct variable air volume (SDVAV) units, 1 constant speed dedicated outside air unit, and one heating only make-up air unit serving the fourth floor laboratories. Each floor has its own VAV unit which respectively serves the majority of the first and second floors and all of the third and fourth floors. Four of the CAV units serve two large lecture halls (two per room) at the south end of the building and the two remaining CAV units serve the basement. All of the AHUs in the building have DDC controls with the exception of AHU 7. The terminal boxes on floors 1-3 have local pneumatic control and the terminal boxes on the fourth floor are controlled by the DDC system. The total design maximum supply flow in the building is 155,800 CFM with a maximum of 31,240 CFM of outside air. The total design exhaust flow for the building from 65 exhaust fans is 67,200 CFM.

Building #3
Building 3 was constructed in 1950 and is home to research laboratories, offices and a single large lecture hall. The building has three floors and a penthouse which is connected to a rooftop greenhouse for a total area of 53,800 square feet. It is generally occupied on weekdays from 8:00 AM to 5:00 PM, but also has some occupancy on weekends. The CHW system consists of two pumps with a 25 hp variable speed pump that serves the building and a 3 hp constant speed pump that serves only the rooftop greenhouse. The HHW system consists of a single constant speed 7.5 hp pump with a building bypass valve and return valve which control supply to the building. The HVAC system in the building consists of four AHU's: one SDVAV unit per floor and one SDCAV unit serving the lecture hall. Additionally, the greenhouse has six locally, pneumatically controlled FCU's. The building controls system was upgraded in late 2010 so that all of the AHU's and terminal boxes have DDC control. The terminal boxes throughout are series fan powered boxes with hot water reheat. The total design maximum supply flow in the building (not including the SDCAV unit) is 67,500 CFM with a maximum of 17,500 CFM of outside air. The building has 27 exhaust fans located on the roof.

CURRENT BUILDING OPERATION

As a part of this analysis, a detailed onsite investigation of the current system operation as well as an analysis of the controls programming (where relevant) was conducted. The findings for each building are discussed below.

Building #1
When the whole building cooling load is low, the CHW system flow is controlled by the building control valve. Once the whole building cooling load increases so that more flow is required, the first CHW pump is commanded on followed by the second pump when the load increases further. The pumps are operated based on a differential pressure setpoint which is reset based on the maximum position of the valves on the four AHU's. During the observation period, both pumps were found to be operating at or near full speed during all site visits. Trend data from the controls system confirmed this observation at other times of the day. The HHW pump differential pressure setpoint is also reset based on the valve position of the AHU's.

Both of the main AHU's have outdoor air temperature (OAT) based static pressure setpoint resets for the hot ducts. The cold duct static pressure setpoints for both AHU's are reset based on the demand as determined by the total of the flowrates measured at all of the terminal boxes. The cold duct and hot duct temperature setpoints for all of the AHU's (except the OA unit) have OAT based resets. The OA unit has a constant discharge temperature setpoint of 60°F. Due to difficulties maintaining room setpoints in the building during cooling season, the cold duct static pressure setpoints for the two main AHU's have been manually set to artificially high constant values of 4.5 and 5.25 inWG, causing the fans to run at or near full speed at most times. Similarly the cold duct discharge temperature setpoint for one of the main units has been manually set to a constant value of 50°F. Neither of the main AHU's is able to meet the discharge setpoint during the cooling season. Both of the main AHU's have pretreat coils which at the time of the investigation were being retrofitted so that they can precool and preheat the OA. Both pretreat coils were dirty and the outside air dampers were not connected to the controls system (i.e. they were in one position at all times).

Building #2
Both the CHW and HHW pumping systems have dynamic differential pressure resets based on AHU and terminal box valve positions. At the time of the investigation, one of the CHW pumps was not operating due to an electrical problem which caused the other pump to operate above 60% speed during unoccupied hours and above 90% speed during occupied hours. The HHW pumps were operating as intended.

The 4th floor makeup AHU has an OA dew point (OADP) temperature based unoccupied period shutdown control with a constant 65°F discharge setpoint at all times of operation. The dedicated OA AHU has a dynamic discharge temperature reset schedule based on CHW valve position of the AHU's it serves with a limit based on the OADP temperature intended to control humidity. The main AHU's for the first and second floors have both discharge static pressure and temperature resets and are shutdown at night. The CAV AHUs serving the lecture halls are couple controlled with discharge temperature resets based on the return temperature. The AHU for the 3rd floor has both a discharge pressure and temperature reset. The AHU for the fourth floor has a nighttime shutdown schedule and discharge static pressure and temperature resets based on the terminal box valve and damper positions. One of the basement CAV units is not connected to the controls system. The other is controlled based on the temperature of the two zones it serves. The HHW valve is controlled based on the temperature in one zone and the CHW valve based on the temperature in the other zone which has a flow control damper in its supply duct. At the time of the investigation, the 4th floor makeup AHU and one of the CAV AHUs serving the basement were not operating. The reason for the makeup unit to be off at the disconnect was not discovered but a maintenance issue is the likely cause given past problems with the unit. Due to the large number of exhaust fans serving the 4th floor and the unit not operating, the fourth floor was found to be negatively pressured relative to the stairwells and the ambient. The basement CAV that is turned off serves a storage room and is only operated when needed. Numerous instances of simultaneous heating and cooling were also found. The operating basement AHU was found to have a fully open HHW valve while the CHW valve was about 60% open. For this AHU, the heating coil is located before the cooling coil so humidity control does not account for this operating condition. The pneumatic tubing which operates the CHW valves for three of the four lecture hall AHU's was found disconnected from the actuators. As a result the normally open valves are supplying full cooling when the units operate. In an effort to control the room temperature, the HHW valves are also open to increase the supply the temperature. Also, thirteen of the exhaust fans were not running at the time of the investigation for a variety of reasons including mechanical issues.

Building #3

The CHW system has an OA temperature based differential pressure reset. The constant flow HHW system has an OA temperature based return temperature reset. The CHW and HHW systems were found to be operating as intended.

The first floor AHU has OA temperature based static pressure and discharge temperature resets as well as a constant preheat coil temperature setpoint. Each floor has a building pressure sensor which is programmed to maintain a neutral building pressure by modulating the return air damper. The first floor AHU also has a shutdown schedule for unoccupied hours. The second floor AHU has the same control settings as the first floor unit with the exception of the building pressure setpoint which is negative for this floor. The third floor AHU preheat coil temperature setpoint varies according to the discharge temperature setpoint. All other control settings for this unit are the same as for the second floor AHU. The lecture hall AHU CHW coil is controlled to maintain the room temperature setpoint. The HHW coil maintains a room setpoint which is equal to the room temperature setpoint minus 2°F. When the unit is operating the OA damper is fully open. This DDC controls for this unit were not operating correctly and the unit was not physically accessible; therefore, no further information regarding its operation is available beyond spot measurements taken in the room. At the time of the investigation, none of the AHU's were being shutdown during the unoccupied hours as programmed. One did not shutdown at all, and the others shutdown for a matter of minutes every night. The OA flow into the building was found to be restricted due to very dirty bird screens at the OA intake louvers. On one AHU, a hole had been cut in the bird screen which greatly increased the OA flow. A preheat valve was found to be leaking by on one AHU causing unnecessary simultaneous heating and cooling. The belt on one of the supply fans was slipping intermittently causing strong fluctuations in the supply static pressure and airflow.

ANALYSIS AND ENERGY MODELLING

Prior to simulating the buildings in an energy analysis program, an analysis of the measured energy consumption data available was conducted to determine the validity of the data. This assessment was performed using the energy balance method (Shao, 2005; Shao and Claridge, 2005; Baltazar et al, 2007). The energy balance is based on the first law of thermodynamics applied to each building as a whole. The energy balance is defined as the sum of the energy inputs into the building (HHW and electricity) minus the energy removed from the building (CHW). For all three buildings, the energy balance results indicated only a small handful of data points from each building were found to contain invalid data. Following the energy balance analysis, each building was simulated to assist in the assessment of energy conservation measures and the subsequent savings estimates presented below. These efforts for each building are discussed below.

Building #1

Following the initial energy balance data analysis discussed above, the energy balance method was then used to estimate the amount of outside air brought into the building. Using the slope of the energy balance plot and estimated building envelope characteristics the outside airflow was estimated to be 31,000 CFM. This estimate is much larger than the measured total outside airflow of 21,600 CFM. This is in part due to the fact that the energy balance will also account for outside air introduced through infiltration since the additional load due to infiltration air which is not exhausted from the space will eventually be met by the HVAC system through the conditioning of the return air.

An energy simulation was done using the DOE2.1E simulation program. This simulation was calibrated (see calibration statistics in Table 2) to daily energy consumption data and weather data from July 2009 to June 2010. In the calibrated DOE2.1E simulation, the outside airflow was estimated to be 33,783 CFM. Considering the number of assumptions made in building and calibrating the simulation, this outside airflow rate should be regarded as nothing more than a gross approximation; however, it is worth noting the similarity between this estimate and the estimate of 31,000 CFM obtained from the energy balance analysis.

Table 2: Calibration statistics for building 1 energy simulation in DOE2.1E

Energy Source	**MBE (MMBtu/h)**	**RMSE (MMBtu/h)**	**CV-RMSE (%)**
CHW	-0.169	0.190	13.3
HHW	-0.065	0.100	7.0

Building #2

Using the same energy balance based method as described for building 1, the outside airflow for building 2 was estimated to be 23,200 CFM which is larger than the measured total outside airflow of 18,100 CFM.

An energy simulation was done using the DOE2.1E simulation program. This simulation was calibrated (see calibration statistics in Table 3) to daily energy consumption data and weather data from June 2009 to May 2010. In the calibrated DOE2.1E simulation, the outside airflow was estimated to be 25,000 CFM which is again similar to the energy balance estimate of 23,200 CFM.

Table 3: Calibration statistics for building 2 energy simulation in DOE2.1E

Energy Source	**MBE (MMBtu/h)**	**RMSE (MMBtu/h)**	**CV-RMSE (%)**
CHW	-0.114	0.233	15.3
HHW	0.005	0.113	7.4

Building #3

Using the same energy balance based method as described for building 1, the outside airflow for building 3 was estimated to be 5,800 CFM which is less than the measured total outside airflow of 6,150 CFM. For the case of building 3, due to unavoidable measurement circumstances the measured OA flow values are not considered to be very accurate. However, the similarity to the energy balance results suggests that perhaps they are more accurate than suspected.

In order to allow for more flexibility in the analysis and due to the limited amount of measured data available for calibration in the post-DDC conversion period, the simulation for BSBE was done utilizing the Simplified Energy Analysis Procedure (SEAP), or Modified Bin-Method, for the loads analysis and a spreadsheet calculation for the system analysis in addition to the DOE2.1E simulation discussed below. This simulation was calibrated (see calibration statistics in Table 4) to daily energy consumption data and weather data from October 2010 to December 2010. These dates were chosen in order to analyze the post-DDC conversion consumption data since the pre-DDC conversion data would not be indicative of the building operation at the time of the investigation. In the calibrated SEAP simulation, the outside airflow was estimated to be 8.500 CFM which it is worth noting is similar to the energy balance estimate of 5,800 CFM. The results of the DOE2.1E simulation calibration are not as good as those for the SEAP simulation, however, the DOE2.1E simulation is necessary for gaining accurate estimates of savings associated with HVAC shutdown measures discussed below.

Table 4: Calibration statistics for building 3 energy simulation using SEAP methodology

Energy Source	**MBE (MMBtu/h)**	**RMSE (MMBtu/h)**	**CV-RMSE (%)**
CHW	0.088	0.143	18.8
HHW	-0.141	0.160	21.1

RECOMMENDATIONS

All savings estimates below use an electricity price of $0.113/kWh, and CHW price of $14.582/MMBtu and a HHW price of $18.147/MMBtu. All savings estimates were made using the calibrated DOE2.1E simulation with the TMY3 weather file for College Station, TX unless otherwise noted. The cost estimates were made using data from the 2007 RS Means (RS Means, 2007(a); RS Means 2007(b)) books for electrical and mechanical systems. A number of maintenance items that need to be addressed were identified in each of the buildings visited. These will not be discussed in detail unless they have a strong effect on the energy consumption of the building and subsequent savings estimates.

Building #1

First, observations in the building indicated there is potential to save on lighting energy by adding occupancy based controls to the relevant circuits.

Given the requirements of some of the laboratories in the building, occupancy based lighting controls are not appropriate for the entire building; however, the transiently occupied spaces and many offices are good candidates for occupancy controls. In addition to controlling the lighting, it is recommended that the occupancy sensors be used to control the HVAC system for the space as well. For instance, in labs where it is appropriate the air change per hour (ACH) setting for the space could be reset to 4 ACH during unoccupied periods saving fan power as well as heating and cooling energy.

Given that the energy required to condition the outside air is the main driver of the overall energy consumption of the building, adding the ability to control the amount of outside air brought into the building has the potential to greatly affect the energy consumption of the building. The outside air requirements of the building will be either controlled by the ventilation requirements of ASHRAE Standard 62.1-2007 or the exhaust flow of the various fume hoods and general exhaust fans in the building, whichever is greater. According to the requirements of Standard 62.1-2007, the outside airflow required is approximately 11,000 CFM. This is not much less than the measured flow of 14,940 CFM but is much less than the estimated flow of 30,952 CFM which also includes a large portion of outside air entering through infiltration as discussed above. A detailed measurement of all exhaust airflow has not been conducted. The last detailed survey of the exhaust flows done in 2003 found a maximum exhaust flow of 43,069 CFM. This is still greater than the estimated outside airflow from the energy balance plot. Dedicated unconditioned or minimally conditioned outside air supplies could be added for fume hoods and other exhaust air streams for which this would be appropriate. Simply put, the outside air would be provided on an as needed distributed basis instead of a central supply through the general supply air stream of the AHUs. In the best case scenario, this would reduce the OA intake volume at the AHU to just that required by ASHRAE Std. 62.1-2007.

Resolving the room temperature issues may seem like only a comfort issue, but given the manual control settings described above, the steps taken in an attempt to alleviate these problems are driving the operation of the whole building's HVAC system. Resolving the problems in these spaces would potentially allow for the manually altered setpoints to return to EMCS control where they would be allowed to modulate based on the programming in place. This would potentially save fan and pump energy as well as heating and cooling energy if there are any spaces that are using heating and cooling as a result of the low supply air temperatures and high static pressures. The high electric load in these spaces due to the large amount of electrically driven equipment and high lighting levels in some of the spaces are causing the load in the spaces to exceed the cooling capacity of the HVAC system for the rooms. Presuming that the equipment load cannot be altered due to the needs of the lab occupants, one remaining option is selective delamping. This approach would require detailed coordination with the lab directors and researchers to ensure no labs were adversely affected.

Currently, the discharge temperature for the dedicated OA AHU is set to a constant 60°F. The minimum hot deck temperature of the AHU supplied with OA from this unit is 75°F. The mixed air temperature of the secondary AHU is often below the hot deck setpoint as a result of the low discharge setpoint of the OA unit. This causes the valve of the hot deck coil to open in order to meet the setpoint. This behavior was observed during the peak of the cooling season when little or no demand for heating should be expected. Given that the main HHW pump is controlled in part based on the position of the hot water valves in the building, this often causes the hot water pump to run during peak cooling season as well. Increasing the discharge temperature of the OA unit to 70°F when the hot deck temperature of the secondary unit is at its minimum (75°F) and the ambient humidity is below 65% would reduce heating consumption as well as pump energy consumption. Additionally, the main HHW pump could be commanded off when the outside air temperature is above 85°F which corresponds to the ambient temperature where the secondary unit hot deck setpoint is at its minimum value of 75°F.

Building #2

First, the simultaneous heating and cooling at the lecture halls AHUs should be eliminated. Eliminating this unnecessary heating and cooling load could be accomplished numerous ways. First, simply reconnect the pneumatic control lines to the actuators. This solution is likely not to be a permanent solution given that the lines were likely disconnected to eliminate hot calls in the rooms. Second, replace the pneumatic actuators with electronic actuators which cannot be disconnected as easily. This will likely assure that the EMCS will have full control of the AHU in the long term. Following this installation, the hot conditions in the rooms could be addressed with additional programming language as needed without the simultaneous heating and cooling at all times.

Second, the simultaneous heating and cooling at the basement AHU which is operating should be eliminated. The likely cause for this is the control programming for the AHU. It is recommended that the control programming be modified so that the unit operates as a couple controlled unit with a small deadband similar to the current control used for the lecture hall air handling units. The same room temperature setpoint could be used with the average room temperature determining the discharge temperature of the AHU which is then met using couple controlled coil control valves. The discharge damper for the reception area would modulate to control the flow to the relevant space in order to maintain the space temperature.

Third, add the fourth floor bench hood exhaust fans to the DDC system and implement a nighttime shutdown. Each of the fourth floor labs are served by three exhaust fans: one serving all of the bench hoods and one for each of two fume hoods. This analysis suggests that the bench hood fans could be shut down during unoccupied hours while still meeting the ACH requirement via the fume hood exhaust. While this whole room analysis shows the fume hood fans would be able to meet the basic requirement, in reality if the hoods continue to receive makeup directly from AHU 1, then the amount of air ventilated from the area of the room not near the fume hoods would be greatly diminished as long as AHU 1 is operating. To ensure proper airflow throughout the room, the fume hood makeup ducts could be equipped with dampers which shut when the bench hood exhaust fans are shut off. This would require all of the exhaust air to be taken from the room and help ensure proper ventilation during unoccupied hours.

Observations in the building indicated there is potential to save on lighting energy by adding occupancy based controls to the relevant circuits. Observations indicate that the building occupants do a fairly good job turning off lights at night with the exception of one floor where all of the hallway lights were left on all night. This indicates that there may not be a large opportunity for lighting energy savings during unoccupied hours; however, observations during occupied hours found rooms with lights on for extended periods while the room is not in use. In addition to the lighting energy savings, on the fourth floor where the terminal boxes are already DDC controlled, the occupancy sensors could be used to control the laboratory ventilation system. This would potentially increase the savings over using simple scheduling to control the laboratory ventilation system.

Previous investigations as well as measurements taken during the course of this investigation indicate that the large lecture halls at the south end of the first floor and second floor have serious indoor air quality issues related to insufficient ventilation air. The outside airflow measurements for this investigation (given above in Table 5) found the total outside air flow for the first floor lecture hall to be 111 CFM and for the second floor lecture hall to be 406 CFM. The total outside air required for both lecture halls is estimated to be 5,200 CFM in order to meet the ventilation standard. It is recommended to install an additional variable air volume outside air AHU on the roof of the second floor lecture hall to precondition the necessary supply air supplied to the lecture hall AHUs. This unit could utilize the existing ductwork supplying the lecture hall AHUs with outside air. The lecture halls AHU’s could be left to operate as they are currently operated since the new AHU would precondition the outside air and also aid in dehumidification of the supply air when necessary. This measure is not intended to generate energy savings and in fact would increase energy consumption due to the large increase in the volume of outside air that must be conditioned; however, this measure would help increase the indoor air quality and improve occupant comfort.

Based on an analysis of trend data, of the four AHUs that serve the north portion of each floor, only AHU 11 on the third floor is operating all hours of the day. It is recommended that this AHU also be shutdown at night unless this is deemed impossible due to the use of the space. Also, currently the north end of the second floor is vacant but the AHU (AHU 8) still runs during the entire occupied period. It is recommended that this AHU be shut down except for 3 separate 2 hour periods: one in the morning (8-10AM), one in the afternoon (2-4PM) and one in the evening (8-10PM).

Adding the remainder of the building to the DDC control system would allow for reductions in energy consumption as well as increased comfort. DDC control would allow for the minimum flows for all of the boxes to be set properly and controlled based on demand where possible. Additionally, reducing the minimum flows would help alleviate the cold temperature problems in zones where the terminal box is not equipped with a reheat coil. The demand control of the terminal box minimum flows could be accomplished using simple scheduling or more dynamically by connecting the occupancy sensors outlined in another recommendation to the terminal box controls. Rooms such as the smaller first floor lecture halls and class rooms could have their minimum flow rates reduced to zero during unoccupied hours. The laboratories on the second and third floor could have their minimum flows reduced so that only enough air is supplied to makeup for the air exhausted through hoods where applicable. DDC control would also allow for improved control of discharge pressure and temperature setpoints on AHUs 3, 8 and 11. DDC control on AHUs 5, 6, 9 and 10 would allow for a nighttime shutdown of these units as discussed above.

Building #3

First, a demand based static pressure reset should be implemented using the recently installed DDC terminal box controls. This type of reset would sample the damper positions of all the terminal boxes as an indicator of supply air flow demand. Then the static pressure setpoint of the air handler would increase or decrease based on the maximum damper position. This measure should be implemented with a static pressure reset schedule to limit any effects of malfunctioning equipment.

Second, a demand based supply air temperature reset should be implemented for the second and third floor AHUs using the recently installed DDC terminal box controls. This type of reset would sample the reheat valve positions of all the terminal boxes as an indicator of supply air temperature demand. Then the discharge air temperature would increase or decrease based on the minimum reheat valve position. This measure should include a high and a low limit to limit any effects of malfunctioning equipment. This measure may not be appropriate for the first floor due to the high latent loads present on the first floor due to the fish rooms.

Third, the constant volume pumping systems should be retrofitted to variable volume systems. As described above, the HHW pumping system for the building consists of a single 7.5hp constant volume pump providing hot water to the entire building. Converting this system to a variable flow system would reduce the electricity consumption during times when the heating requirement for the building is low. Similarly, the CHW system consists of two pumps: one constant volume and one variable volume. The constant volume pump serves the greenhouse and the variable volume pump the rest of the building. Depending on the piping configuration of the CHW system, the existing VFD pump might be capable of providing CHW to the entire building or a VFD might need to be added to the greenhouse pump to achieve the estimated savings. Since no trend data was available for the CHW system, a rough estimate of the current electricity consumption was done to estimate the savings for this measure.

Observations in the building indicated there is potential to save on lighting energy by adding occupancy based controls to the relevant circuits. Observations indicate that the building occupants do a fairly good job turning off lights at night with the exception of one floor where all of the hallway lights were left on all night. This indicates that there may not be a large opportunity for lighting energy savings during unoccupied hours; however, observations during occupied hours found rooms with lights on for extended periods while the room is not in use. In addition to the lighting energy savings, the occupancy sensors could be used to control the laboratory ventilation system.

A nighttime AHU shutdown should be implemented where possible. Available trend data and observations indicate that none of the AHU's in the building are shutdown during unoccupied hours. Trend data for the first floor AHU indicates this unit does not shutdown at any time. This may be necessary due to the fish rooms located on the first floor which could cause high humidity levels if the AHU were shutdown for any extended period of time. Trend data for the second and third floor AHUs indicate that these AHU's are shutting down every night around midnight; however, the trend data shows that both units are only off for a matter of minutes. Trend data is not available for the lecture hall unit, but observations made during the nighttime walk through indicate this unit runs continuously or on a schedule similar to that of the second and third floor AHUs. Implementing a nighttime shutdown for these units presents a clear opportunity for energy savings, given that the space requirements would allow for a unit shutdown. As previously mentioned, the first floor fish rooms may not make a shutdown feasible. Similarly, since the penthouse is conditioned by the third floor AHU and houses some plants which are not in the separately conditioned greenhouse, a purely schedule based shutdown of this AHU may not be feasible either. In this case, a time of day based shutdown implemented with a condition that will return the AHU to operation if the space temperature exceeds certain tolerances is recommended. The recommended shutdown would take place from 10PM till 6AM for the second floor, third floor and lecture hall AHUs.

SAVINGS ESTIMATES

Below is an overall description of the estimated savings and costs for implementing the measures outlined above. Following the general description, the measures are broken into non-retrofit and retrofit measures in Table 5 and Table 6.

Building #1

Following analysis of the PESE tool inputs and the outside air requirements of the building, it was expected that the total savings would not be as great as that estimated by the PESE tool because the PESE outside airflow values were lower than required. As the work in the building progressed additional savings opportunities were identified which the PESE toolkit did not consider. The combination of the savings estimated by the PESE tool which was largely the result of reduced outside airflows and the other opportunities identified yielded total results very similar in magnitude to the initial estimates.

If all of the recommendations outlined above were implemented together, the resulting savings is estimated to be $170,000/yr. At a cost of $308,000 the simple payback for the recommendations would be 1.81 years.

Building #2

If all of the recommendations outlined above were implemented together, the resulting savings is estimated to be $173,800/yr. At a cost of $307,500 the simple payback for the recommendations would be 1.77 years.

Building #3

If all of the recommendations outlined above were implemented together, the resulting savings is estimated to be $44,000/yr. At a cost of $58,000 the simple payback for the recommendations would be 1.32 years.

Table 5: Summary of non-retrofit measures

Bldg.	Measure Description	Cost ($)	Savings ($)
1	Delamping	0	9,000
	Control Changes for OA AHU		
2	Elminate Lecture Hall Sim. Htg. & Clg.	0	105,450
	Eliminate Basement Sim. Htg. & Clg.		
	AHU Shutdown		
3	Static Pressure Reset	0	38,000
	Supply Temp. Reset		
	AHU Shutdown		

Table 6: Summary of retrofit measures

Bldg.	Measure Description	Cost ($)	Savings ($)
1	Occupancy Sensors	279,000	163,000
	OA Supply Alteration		
2	4th Floor Exhaust Control	307,500	68,350
	Occupancy Sensors		
	Lecture Hall OA AHU		
	DDC Conversion		
3	Occupancy Sensors	58,000	6,000
	CV to VV Pumping		

CONCLUSIONS

The detailed investigation of each of the subject buildings, including site visits and energy simulations, has shown that a significant portion of the savings potential initially identified is obtainable in all three buildings through the application of conventional retro-commissioning and rapid payback retrofits. The preliminary results of this study of three buildings indicates that given proper analysis, it is possible to realize energy savings beyond conventional retro-commissioning results without requiring large scale capital retrofits in the subject buildings. This analysis includes prescreening subject buildings to determine their savings potential, conducting detailed site visits, and performing energy simulations as needed to determine the savings potential of the identified remedies. Further application of the process is needed to confirm these results, but these initial results suggest it is possible to bridge the energy savings gap using this process.

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