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Smart Labs Final Report
Summer 2021

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Abstract

The Smart Labs Project at Los Alamos National Laboratory (LANL) is an initiative derived from The University of California, Irvine and is part of the Department of Energy's (DOE) Better Buildings Challenge. These carbon abatement strategies aim to reduce energy consumption of laboratories while also maintaining health and safety requirements. Smart Labs designs incorporate seven key principles which are: digital control systems, demand-based ventilation, low power-density demand-based lighting, exhaust fan discharge velocity optimization, pressure drop optimization, fume hood flow optimization, and commissioning with automated cross-platform fault detection. As the ALDCP Smart Labs team for the summer of 2021, the scope of the project is to determine the energy savings within building 03-1698 (Material Science Laboratory - MSL). Over the past couple of years, the Sustainability Group has been adding Smart Labs upgrades into the MSL building and the summer team would like to understand the impact made for the overall energy consumption/demand and safety for the building, determine the overall return on investment (ROI), and recommend more Smart Labs upgrades that can be added to the MSL building. The goal is to enable the UI FOD (Utilities and Infrastructure Facility Operation Division) to promote more Smart Labs projects in the future and further the reputation LANL and DOE facilities have of being leading examples of developers of high performing buildings.

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Chapter 1. Introduction

The Smart Labs Project at Los Alamos National Laboratory (LANL) is an initiative derived from The University of California, Irvine and is part of the Department of Energy's (DOE) Better Buildings Challenge. The Smart Labs initiative is a program that demonstrates how deep energy efficiency measures can reduce a laboratory's energy usage by more than 50% in newly constructed or retrofitted facilities. There is a growing concern about achieving a global climate solution and energy efficiency is considered as a key first step in this process. There are seven essential Smart Labs components: lowering system pressure drop, demand-based ventilation, digital control systems, fume hood air flow optimization, exhaust fan discharge velocity optimization, demand-based LED lighting with controls, and continuous commissioning with automatic cross platform fault detection.

The Smart Labs Project at LANL has had several different scopes over the years. In 2019, the focus of the project was on one building -- the Center for Integrated Nanotechnologies (CINT). The student team developed a new design for CINT which addressed the seven key elements of a Smart Labs that needed adjustment or were completely missing. The complete design package included updated CAD drawings, line diagrams, schedules, and a life-cycle cost analysis. Rather than focusing on a single building and implementing all of the Smart Labs elements at one location, the Smart Labs team chose a new approach in 2020, breaking down the seven Smart Labs elements and implementing one at multiple LANL facilities. This allowed the project team to identify and solve problems at specific facilities while also implementing new Smart Labs designs. The team identified four different project areas for different locations at LANL; each focused on updating lighting, control systems, ventilation, and providing sustainability upgrades respectively.

This year, in 2021, there is a very different, but critical, project scope. Over the past few years, the sustainability group at LANL has been adding Smart Labs upgrades into building TA03-1698 (Materials Science Laboratory - MSL). The goal as a project team is to enable the UI FOD (Utilities and Infrastructure Facility Operation Division) to promote more Smart Labs projects in the future and further the reputation LANL and DOE facilities have of being leading examples of developers of high performing buildings. This will be done by providing UI FOD with key deliverables that are discussed in the next section.

The final deliverable will include a summary of all of the work that took place in MSL that is related to Smart Labs. Additionally, the energy savings for each of the Smart Labs features will be quantified - in both cost and energy. An overall payback period will then be provided as well as other suggestions for future Smart Labs projects.

Chapter 2. Overview

The Material Science Laboratory is a two-story laboratory consisting of 71,772 square feet. This building underwent Smart Labs upgrades between 2012 and 2020, primarily focused on the laboratory space which accounts for approximately 28,709 square feet of the building. The following upgrades were completed at the laboratory and assessed by the team to evaluate overall energy efficiency. The Smart Labs project focused on various components of the Material Science Laboratory including: variable fan drives of the B and C wings, controls in the B and C wings, an infill project and lighting throughout the building. The team evaluated trends, calculated power and energy consumption, and determined total ROI for the following components in order to evaluate the efficacy of the Smart Labs project.

Variable fan drives were installed on four air handlers within the mechanical room which supply B and C wings of the MSL building. These upgrades were performed from early March to the end of May 2020 costing a total of $228,956.65, with the goal of creating an easily controllable pressure system and reducing the overall energy consumption of the building. Controls were switched from one Building Automation System (BAS) to another. This change is recommended for all buildings across LANL to encourage more stable and predictable changes of flow throughout the lab without sacrificing ease of operation. The overall cost of this component was $733,135.47.

The infill project at the MSL building was upgraded with a new ventilation system in 2014. The demand for ventilation assessment (DVA) report found it necessary to re-engineer the exhaust system, retrofit fume hoods, and reduce and control outdoor air flow in order to reduce annual energy costs and consumption. The current infill project still operates under the old BAS and was not included in the overall upgrades of the building. Lighting upgrades to the MSL building consisted of replacing fluorescent bulbs with LEDs undertaken by contractor NORESCO. Completed in 2012, the project was part of a Lab-wide project for lighting with a budget of $119572.02 allotted to TA03-1698 alone.

Chapter 3. Results/Discussion

The ventilation upgrades completed at the MSL building consisted of the installation of four variable fan drives to air handlers (FEH-1A, 1B, 2A, 2B) located in the mechanical room. VFDs are controllers that convert the sine wave power supplied into variable frequency power which is able to control the speed of the motor and fan blade. In air handlers without VFDs there is a constant volume of air and the pressure is controlled with exhaust gates. Instead of running the fans at 100% all the time, VFDs are able to run the fans at varying percentages of full power in order to regulate the pressure. This drastically decreases the power consumption of the handlers and the overall ventilation system.

To assess the impact of newly installed vfds in MSL buildings, amperage and power usages need to be acquired from a platform called SkySpark, which is a software that automatically records and analyzes building system data. The specific air handler units driven by the vfds are FEH-1A, 1B, 2A, and 2B. However, only 1A and 2B have been the main handler units for the MSL building, while 1B and 2A are reserved as back-up units in case of the main handler's potential malfunctioning.

The amperage data of 1A and 2B are retrieved from SkySpark for the 2019 and 2021 fiscal years, recorded at 12 AM daily. 2020 data was removed as the laboratory-wide shutdown due to the COVID-19 pandemic affected energy consumption. Since most of the buildings in LANL were not in operation, this would not display the actual impact of VFD installation. The amperage data are then converted into a power usage in kW using an equation below:

$$power = amperage \times voltage \times \sqrt{3} \times 0.86$$

Voltage is set to be 480V which is the FEH's standard nominal input, square root of 3 is used to account for the voltage between two-phases in a three-phase system in VFDs, and 0.86 is multiplied as the utilization factor for the time that VFD is in use to the total time that it could be used.

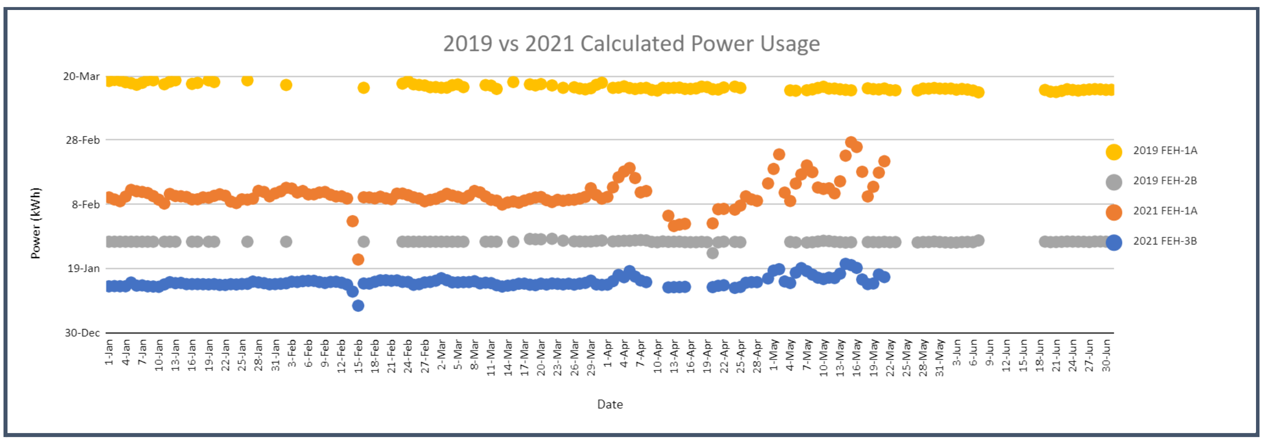


Figure 1: Comparison of 2019 and 2021 Calculated Power Consumptions

From summing the data and calculating average power consumption for FEH-1A and 2B from before and after the upgrades, the average decrease in power consumption for FEH-1A was found to be 56% and a 54.1% decrease in power consumption for FEH-2B.

The amperage and power consumption calculations were then used to determine the annual cost savings for the upgrades. In 2019, average hourly cost of operation was \$8.94, and in 2021, average hourly cost dropped down to \$5.06. At an energy cost of \$0.086/kWh, the cost of operation in 2019 and 2021 were \$78,350.50 and \$44,358.17 respectively. This results in a combined savings of \$33,992.33 per year after the upgrade. The total cost of the project was \$228,956.65 with a payback period of 6.74 years.

2021 Hourly Avg.	$5.06
2021Yearly Cost	$44,358.17
2019 Hourly Avg.	$8.94
2019 Yearly Cost	$78,350.50
Yearly Savings - %	43.4
Yearly Savings - $	$33,992.33
ROI Period (yrs)	6.735538576

Figure 2: Comparison of 2019 and 2021 Cost and Savings

The lighting upgrades done to the MSL building in 2012 consisted of replacing all fluorescent lights with LED ones to ensure longer bulb lifetimes and a significant decrease in energy usage. To analyze these upgrades and determine the total savings investigation was broken down into three main areas: the cost of the upgrades, the energy savings from replacing each bulb, and the total maintenance cost reduction. Through communication with LANL employees who were familiar with the lighting upgrades, two documents were obtained that provided essential data to begin the analysis.

The first document was a detailed energy survey that was done on all the buildings at LANL that underwent lighting upgrades. This document provided the total cost of the lighting upgrades broken down into expenses for each task. However, the survey did not provide a breakdown of cost for each individual building involved in the upgrade. To find the best estimate for the specific cost of the lighting upgrades for the MSL building, the square footage of all the buildings involved in the upgrades was used and calculated a cost per square foot, then multiplied that by the total square footage of the MSL to get the total cost for the upgrades as shown in the figure below. The upgrades totalled $119,572.02.

TOTAL PROJECT COSTS		MSL PROJECT COSTS	LIGHT ONLY
Survey & Proposal	367,487	14,013.60	14,013.60
CPM	258,221	9,846.89	9,846.89
Lighing Materials	655,787	18,136.55	18,136.55
Controls Materials	90,389	6,789.30	0.00
Lighting Labor	1,473,631	57,215.95	57,215.95
Controls Labor	206,500	17,675.00	0.00
Waste Disposal	115,628	4,409.31	4,409.31
Contingency	132,267	5,043.82	5,043.82
Other	285,992	10,905.90	10,905.90
Total	3,585,902	144,036.32	119,572.02

Figure 3: Lighting Upgrades Cost Table

After obtaining the cost of the upgrades, the 2012 As-Built Report provided the information on wattage savings for each bulb. This document included an extensive list that contained every bulb, the quantity of each bulb, and the wattage associated with them. The wattage of each bulb was summed together to find the total wattage required to light the buildings with the new bulbs and then subtracted from the total wattage of all of the old bulbs. This gave an overall energy savings of 41.5 kW every hour. Multiplying that number by the operating hours and days for MSL and applying the energy to cost conversion rate of $0.086 per kWh gave the total yearly monetary savings from energy consumption, which came out to $14,856.34/yr.

It is clear that the lighting upgrades done at the MSL building drives energy savings. However, consideration on the effect labor cost in terms of maintenance also needed to be evaluated. Using the bottom-up approach, the labor cost to change one bulb (whether fluorescent or LED) was $13.33. This was derived from the assumption that it takes about 8 minutes to change one bulb and the hourly wage for a LANL maintenance worker is $100. Furthermore, the total annual cost (including labor and material cost) for replacing a fluorescent bulb and LED bulb was calculated. Assuming the average price of 1 fluorescent panel is $40 and that of an LED panel is $100 while also taking into account the average lifespan of a fluorescent bulb and LED bulb is 8250 hours and 50,000 hours respectively, the total annual replacement cost of a single fluorescent bulb is $26.89 and that of an LED bulb is $9.07. Using these numbers and multiplying them with the total number of fluorescent and LED bulbs that were present in the MSL building before and after the project, the annual maintenance savings for the MSL building turned out to be $19,892.52.

Summing up the yearly energy and maintenance savings gave a total of $34,748.87 saved each year from the lighting upgrades. As a final step, ROI and payback period analysis was conducted and found the payback period for the lighting upgrades alone to be 3.44 years. Since the upgrades were completed in 2012, the lighting project had already paid for itself in savings by 2016, and these upgrades gave the best returns out of all of the Smart Labs upgrades done to the MSL.

MSL Building	
Project Cost (Materials + Installation)	$119,572.02
Energy Savings (Annually)	$14,856.34
Maintenance Savings (Annually)	$19,892.53

Totals	
Cost	$119,572.02
Annual Savings	$34,748.87
Payback Period	3.44

Figure 4: Lighting Upgrades Savings Table

The analysis of the control upgrades done to the MSL required a more qualitative approach, since it was difficult to find solid numerical evidence of energy savings. Meetings with SMEs and independent research have shown that the control upgrades were helpful to improve the MSL in other ways such as ease-of-use and maintenance savings. The cost of the control upgrades was significantly harder to determine than the cost of the VFD and lighting upgrades because there were many different controls upgraded in the Lab. Two cost codes provided by the SMEs gave a good idea of the total cost of the upgrades, but there was still a possibility that more cost codes exist for the controls upgrades, so the numbers may not be exact. As seen in the figure below, the cost of the upgrades was $733,135.47.

Fiscal Year		
2014	2015	Grand Total
	620.57	620.57
1,870.55	49,746.11	51,616.66
	496.67	496.67
	266.24	266.24
	7,251.77	7,251.77
	175.47	175.47
	3,246.15	3,246.15
	1,570.38	1,570.38
	123.75	123.75
1,538.06	25,310.59	26,848.65
	1,121.71	1,121.71
3,408.61	89,929.41	93,338.02

2015	2016	2017	Grand Total
	225.63	274.01	499.64
278.83	5,696.55	1,853.75	7,829.13
	468,750.37	18,682.60	487,432.97
278.83	**474,672.55**	**20,810.36**	**495,761.74**
	618.83	144.13	762.96
1,495.50	30,714.27	20,434.47	52,644.24
	87,905.61	2,722.90	90,628.51
1,495.50	**119,238.71**	**23,301.50**	**144,035.71**
1,774.33	593,911.26	44,111.86	639,797.45
1,774.33	593,911.26	44,111.86	639,797.45

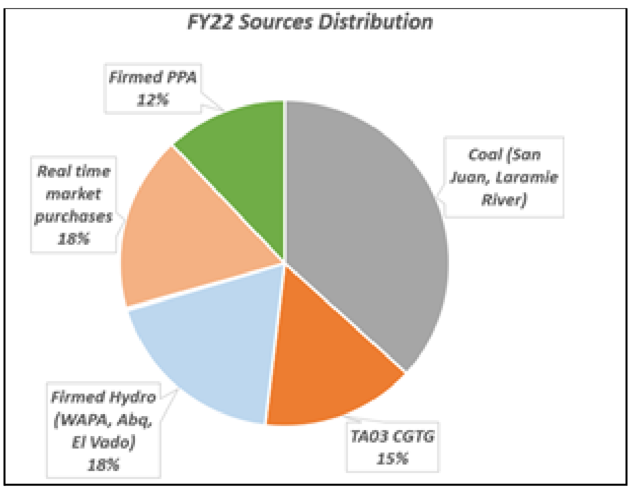
$93,338.02 +$639,797.45 = $733,135.47

Figure 5: Cost Codes for Controls Upgrades

One of the largest benefits from the controls upgrades that the MSL still experiences today is ease-of-use. Before the upgrades, the MSL was run under a proprietary automation system and had a contract with LANL that would allow them to come onsite to troubleshoot, make changes, and update the system as needed. This system worked well for the Lab until the Smart Labs Initiative brought the idea of switching the controls system to a less restrictive automation system. This new system became the new standard for the MSL controls except for in the Infill room, which is still using the proprietary system. This newer system was easier for the engineers and building managers to learn how to use because it was an overall more intuitive system. It provided better visibility of the HVAC system exhaust and fume hood flows. It also allowed for better building pressure maintenance and chiller control.

The ease-of-use benefit led to a reduction of maintenance costs since the upgraded system provides users with a troubleshooting tool to work with instead of requiring a company technician to come onsite to make the fixes. Although there are no numbers on the cost to bring out technicians for the old system, assumption can be made that there was decent savings in terms of maintenance after these upgrades were completed. This also allowed LANL to direct those funds to making their own fixes and adjustments as they saw fit. Updating Windows systems in the MSL with the upgraded BAS did not require outside help since it has backwards compatibility, unlike the older system. Overall, the simplicity of the new automation system, in addition to the time and money savings regarding maintenance made the controls upgrades worthwhile.

The total cost of the Smart Lab upgrades totaled $1,081,673.14. The cost of the ventilation upgrades were $228,965.65, for lighting $119,572.02, and controls were $733,135.47. Yearly savings were found to be $68,741.20 in total with $33,992.33 coming from ventilation and $34,748.87 from lighting upgrades. Savings from controls upgrades were not included in this analysis as the focus of the upgrade focused more on efficiency and ease of use rather than energy savings. This results in a current yearly ROI of 6.36% and a total pay back period of 10.7 years. The amount saved to date is $346,732.16 or equivalent to 4031.77 MWh in saved energy.



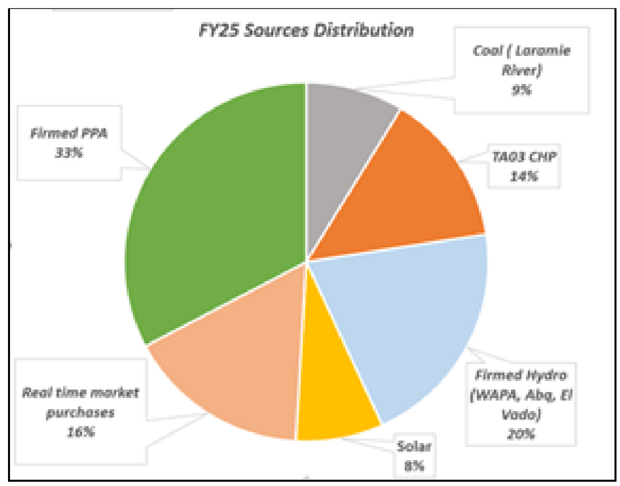


Figure 6: LANL Energy Plan Portfolio

LANL continues to strive towards its goal of using 100% clean energy sources by 2050, and the Smart Labs upgrades served as another step towards reaching that goal by significantly reducing CO_2 emissions caused by the MSL energy usage. The current energy usage of LANL can be broken down into five energy sources from which the laboratory pulls energy, but the Lab is working to diversify their energy sources . The clean energy sources used are solar, wind, and hydroelectric energy. The carbon-emitting sources are steam and coal plants, which account for 52% of the total laboratory power generation. This number was used to determine emissions saved based on energy saved from the Smart Labs upgrades. Of the 4031.77 MWh saved from the upgrades, 2096.52 MWh are those that would have been produced by the San Juan

Generating Station which uses coal to produce energy. Using the EPA Greenhouse Gas Equivalencies Calculator, it was found that through the energy savings at MLS, the equivalent of 1,486 metric tons of CO_2 emissions, or the equivalent of 144.9 metric tons of coal, were spared because of these upgrades.

Chapter 4. Recommendations

One of the main recommendations involves reducing the energy used for ventilation by decreasing the air flow in certain lab spaces according to their risk control band. Risk control banding is a method to assess the hazard level of a laboratory. A lab space with a higher risk band requires more ventilation, and therefore more air changes per hour. Air changes per hour (ACH) is the amount of times the air in a room is completely replaced in one hour. If air is replaced less often, then less energy is used. Since the current risk bands couldn't be found, an assumption was made that the current risk band for each lab is the same as it was as stated in the Demand for Ventilation Assessment (DVA) completed in 2017. The DVA report also provides the recommended ACH according to the risk banding.

In order to determine the energy being used to drive the current ACH in each laboratory, a correlation between the energy and flow for the air handlers - HVA 1,2, and 3 was determined and calculated the resulting energy usage value through an interpolation of the flow for individual lab spaces and. Using the energy, the correlation was then multiplied by the cost of one kWh of energy ($0.086) to get the total cost. The same method to determine the costs according to the flows in the DVA report was utilized.

Following these energy and cost calculations, it was found that the flows according to the DVA report require significantly less energy and money than the current flows being used. If the DVA flows were used instead, about 270,000 kWh and $23,000 would be saved each year. Therefore, it is recommended to use the flows given in the DVA report.

The calculated savings and the return on investment for VFD upgrade has successfully reduced the overall yearly operation cost of MSL building. There are also ongoing plans to further reduce the cost through various Smart Lab features, such as modular chiller installation and an adjustment in the air changes per hour (ACH) in each room. Modular chiller is a small packaged chiller installed outside as part of the HVAC system in the building. The advantage of modular chillers is the decentralization of the chiller unit where it adds an extra layer of redundancy to the overall HVAC system. One of the issues with a traditional single chiller unit in the building is the recovery time period, especially when the system goes down due to malfunctioning, developing a discomfortable environment for building occupants. However, since modular chillers can be operated either jointly or independently with their own dedicated powers, there will always be a consistent cooling capacity. Additionally, the energy efficiency of the modular chiller can reduce the environmental impact caused by the HVAC system by meeting ASHRAE 90.1. ASRAE 90.1 functions as a benchmark for minimum energy performance standard, providing the minimum energy efficiency requirements to design and construct a new HVAC system or retrofit an existing system. Several modular chiller manufacturers install non-ozone-depleting refrigerants to minimize the environmental impact and to ensure that the building is kept safe.

Furthermore, as mentioned in the ACH recommendation section, the current ACH level in each room in the MSL building needs to be adjusted based on their intended purposes and volumes. For instance, many office spaces in the building will not require a high level of air changes compared to the lab spaces that handle various chemicals. Such high level air changes will result in more energy consumption, leading to more VFD usage. There needs to be a thorough study on how each room is utilized and determine its minimum and recommended ACH level which can be achieved through the upgraded controls system dashboard.

More can be done in terms of lighting to drive up savings even with the current savings and efficiency in lightings. One major recommendation is to add the controls to the office spaces of the MSL building on the already existing LED lights. Having lighting controls will help drive down energy consumption by an estimated 20%. Also, other benefits of controls include ease of use when it comes to maintenance and less risk of spreading viruses due to the control being touchless. Some of the controls we want to implement are listed.

High End Trim and Taks Tuning set the maximum light level for each space. For example, the human eye can barely distinguish between a 100 percent light level and an 80 percent light level—but setting lights to 80 percent reduces energy use by about 20 percent. Light- level tuning sets the appropriate target level for each space, which is lower than the high-end trim level. Occupancy sensors can automatically turn off as the result of inactivity. These sensors can reduce lighting/electricity use from 15 to 60 percent, depending on the use and size of the space.

Scheduling automatically dims or turns lights off at certain times of the day. Few buildings operate on 24-hour schedules, and many are empty during the overnight and weekend hours. Astronomical time clocks are preferable to standard time-of-day time clocks because they can automatically adjust lighting based on astronomical events such as sunrise or sunset, ensuring lights are not wasting energy when they don't need to be on. Scheduling can reduce lighting costs by 10 to 35 percent. Finally, daylight harvesting automatically dims electric lights when enough daylight is present. A daylight harvesting system can typically save an additional 10 to 60 percent in lighting electricity costs in buildings with many windows or skylights.

With significant additional benefits that the upgraded controls system can bring compared to the old, it is recommended for the infill room's control be upgraded as well. Since the newer system has become a dominant control system that runs the MSL building, converting the infill room will finalize the control centralization which provides engineers and technicians the capability to oversee every aspect of the building in-house.

Installing a sash position sensor controlled by the BAS system ensures the safety of the Lab workers and potentially reduces the energy consumption by air changes. With many fume hoods located in the MSL building, improper closing or opening of sash can drive the HVAC system to operate even when the fume hood is not in use, and various chemicals are involved in the fume hood, there will always be a safety hazard involved even with extensive lab training. With sash height position sensor installed, there will be a constant monitoring of fume hood operation through BAS, especially whether they are in operation or not based on sash height, and if sash is opened for a long duration of time, an alarm or notification can be sent to inform occupants.

Lastly, there needs to be a periodic update on standards and guidelines regarding the control operation. As new features and upgrades in the control system come up, an outdated standard and guideline may cause an issue such as optimization and inadequate functioning of sensors due to control. Furthermore, additional installation of Smart Labs sensors in near future may require updated standards in order to be utilized at their best capabilities. Thus, a periodic update on standards and guidelines needs to be evaluated more often than before to avoid any issues and to keep up with new upgrades.

Chapter 5. Conclusions

The Smart Labs project team was successful in providing the key deliverables for UI-FOD which consists of a summary of all work that took place in MSL related to Smart Labs, quantification of energy savings of the Smart Labs upgrades, an overall ROI, and other recommendations. This report focuses on various components of Smart Labs upgrades done for the Material Science Laboratory, which includes: variable frequency drives of the B and C wings, controls in the B and C wings, an infill project and lighting throughout the building. The team evaluated trends, calculated power and energy consumption, and determined total ROI for the following components in order to evaluate the efficacy of the Smart Labs project. Although the Smart Labs team was successful in meeting the deliverables, there can still be more work to be completed. These are outlined in the Recommendations section of the report.

The overarching goal of the Smart Labs projects, both past and present, is to provide more stewardship towards upgrading LANL facilities and improving energy efficiency. Without such stewardship through presentations, outreach, and dedicated student teams, further expansion of Smart Labs components to other areas at LANL becomes much more challenging. To truly be a world class laboratory and be the example for other laboratories and facilities, LANL needs to continue to support these Smart Labs upgrades, so that its facilities along with its scientists are also world class. This specifically can be done by allowing UI FOD to implement more Smart Labs features into more laboratories at LANL. The summer team has confidence that these projects are just the beginning for future work necessary to allow LANL to become a leading proponent of Smart Labs technologies.

Chapter 6. Acknowledgements

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Chapter 7. Acronym List/References

Acronyms

ACH - Air Changes per Hour
BAS - Building Automation System
CINT - Center for Integrated Nanotechnologies
DOE - Department of Energy
DVA - Demand for Ventilation Assessment
MSL - Materials Science Laboratory, TA03-1698
LANL - Los Alamos National Laboratory
ROI - Return on Investment
VFD - Variable Frequency Drive
UI FOD - Utilities and Infrastructure Facility Operation Division
SME - Subject Matter Expert

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