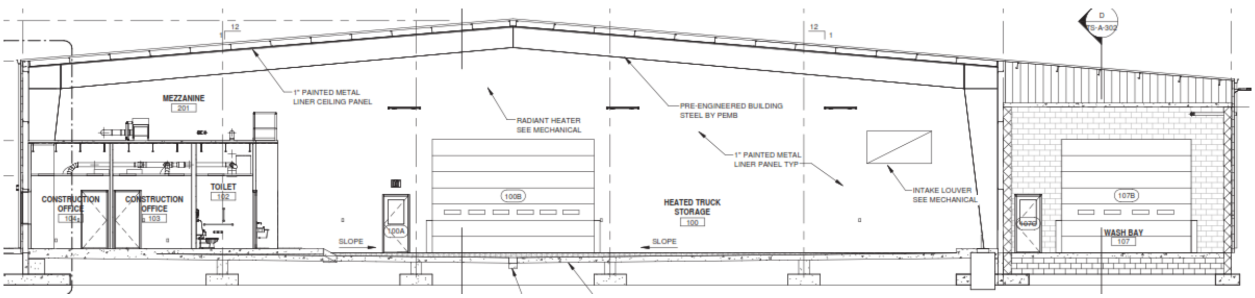
Evaluation of Energy Efficient Options to Heat Ohio Department of Transportation (ODOT) Maintenance Facilities



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16. Abstract

This project was initiated by the ODOT District 2 staff who were looking for more efficient ways to heat and operate their maintenance facilities. This especially applied to the idea of using radiant floor heating as an alternative to today's standard heating systems.

Unfortunately, the research has shown that the financial benefits just aren't enough to justify implementation of many of the recommendations within, especially with the radiant floor system. This is primarily a result of the facilities already performing well, leaving less room for improvement overall.

What can be taken away from this research is a list of targeted recommendations for the Ottawa, Seneca, and Williams Garages, as well as the D2 Headquarters. In addition, a metric for building efficiency has been developed so that buildings throughout District 2 can be prioritized for upgrades. Finally, an interactive tool of best practices and rough savings for a wide variety of measures will allow ODOT staff to help educate themselves and choose the best path forward as facilities are upgraded.

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January, 2018

Prepared in cooperation with the Ohio Department of Transportation
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Executive Summary

This project was initiated by the ODOT District 2 staff who were looking for more efficient ways to heat and operate their maintenance facilities. This especially applied to the idea of using radiant floor heating as an alternative to today's standard heating systems. The Phase I portion of this research was focused on gathering as much background information as possible to determine the state-of-the-art in operating these facilities, as well as the feasibility of implementing these options from a financial standpoint.

Unfortunately, the research has shown that the financial benefits just aren't enough to justify implementation of many of the recommendations that follow, especially with the radiant floor system. This is primarily a result of the facilities already performing well, leaving less room for improvement overall. However, if savings outside of energy are considered, especially related to truck maintenance, radiant floors can become much easier to justify.

One major finding from this study is just how much faster ice could be melted and removed from the underside of the trucks using floor heat instead of ceiling heat. With floor heat, direct radiation will allow the ice to melt more than twice as fast as the convection only heating from the indirect ceiling heat. The result is ice melt in roughly 39% of the time.

Table 1 – Ice Melt Comparison for Radiant Floor vs Standard System

Heat Transfer Source	Radiant Floor Heat	Hanging Heaters
Direct Thermal Radiation (W)	142	0
Air to Ice Convection (W)	91	91
Estimated Worst Case Melt Time	< 2 days	5 days

What can be taken away from this research is a list of targeted recommendations from the buildings that were audited. In addition, a metric for building efficiency has been developed so that buildings throughout District 2 can be prioritized for upgrades. Finally, an interactive tool of best practices and rough savings for a wide variety of measures will allow ODOT staff to help educate themselves and choose the best path forward as facilities are upgraded.

To arrive at these conclusions, a literature search was first performed to investigate best practices at DOT facilities around the country. This, along with tools developed by the University of Dayton, gave insight into a number of potential opportunities to better operate the ODOT maintenance facilities. In addition, interviews were conducted with both local and national cold-weather facilities that use radiant floor systems to gauge the benefits from someone who has firsthand experience. Based on these interviews, the consensus was that these systems are very effective, very comfortable, and easy to operate. Though each person asked felt that there were savings over more traditional systems, none had direct comparisons available to actually quantify the savings. Each person questioned agreed that having someone investigate this more thoroughly would provide a great insight into the true benefits of the system.

Once the literature search was complete, this information was then used as a basis for more in-depth analysis at a representative sample of District 2 facilities. Based on conversations with D2 staff, the Ottawa, Seneca, and Williams Full Service Garages were chosen as the three samples for investigation.

With these three facilities chosen, real-time meters were installed at each to measure gas and electric consumption at 15 second intervals. Walkthroughs were also performed at each building to investigate opportunities for improvement in HVAC, mechanical, and lighting operations. While on-site, surveys were provided to the employees to hear their voice on building comfort and functionality.

Based on these walkthroughs, a number of energy conservations measures were found that could be implemented at various facilities. In order of best to worst payback, these measures include:

- Upgrade to LED lighting
- Replace domestic hot water tank heaters with new condensing style heaters at end of life
- Install solar PV arrays
- Replace old R-22 condensing units with new units operating on R-410a
- Install high volume, low speed fans to help circulate and destratify air in high-bay areas
- Install rapid seal doors on most frequently used overhead doors

Next, the utility histories for the entire District 2 portfolio were analyzed to determine best and worst buildings. Using data analytics developed through the University of Dayton, each building's energy use was disaggregated into heating, cooling, and independent usages. These buildings could then be ranked in terms of most to least efficient, giving the ODOT team a roadmap of which buildings should be upgraded first and which could be saved for later.

The two best facilities are by far the Seneca and Williams facilities. Their energy intensity in all energy categories are far better than the other facilities. These facilities should be looked at as a model for improvement in the other facilities. The two worst facilities in terms of energy effectiveness are the Edison and Lucas facilities, with energy intensities 4-5 times higher than the two model facilities. These facilities would be the first when budgeting for improvements.

Finally, the plans for future buildings were analyzed with the new North Baltimore Outpost as the real-world example for the team to work from. Through expert input with Gresham, Smith and Partners, review and interactions with the JDI Group who is currently designing the new building, and input from the research team based on previous findings, design recommendations were generated for use in future buildings. These recommendations include many specifics related to radiant floor heating systems, as well as other complimentary systems like high-volume, low-speed fans, rapid seal doors, and LED lighting.

Project Background

ODOT is tasked with managing and maintaining a snow and ice fleet of 1,600 trucks in facilities throughout the state. Through this project, ODOT was interested in improving the environment in which ODOT staff maintain ODOTs fleet, improving safety and increasing healthy working environments within the facilities, and increasing fleet capacity maintained in the existing facilities, while also finding cost effective ways to upgrade working conditions within these facilities.

The goal of the project was to lead to improvements that will affect both staff and equipment. The approach included research nationally and internationally of the “state-of-the-art” relative to similar facilities in order to assemble options for improving fleet longevity and capacity, safety, employee health, and facility human comfort and energy efficiency. With “state-of-the-art” options available, an assessment of current conditions could reveal building-by-building gaps regarding the effectiveness of the current facilities in maintaining the fleet; employee health and safety; and facility human comfort and energy effectiveness.

Research Context

The research team has identified the following as the primary research objectives for this project.

Fleet and Maintenance Equipment

- Assess, research, and develop plans for reducing fleet maintenance cycle time and cleaning time
- Continue to properly collect, manage and dispose of vehicle fluid and parts waste. Assess ODOTs existing interior floor drainage collection and oil/water separator systems
- Assess, research, and develop plans to lower stress on undercarriage components
- Assess, research, and develop plans for maintaining equipment used to service fleet (lifting mechanisms, hoists, cranes, etc.)
- Prioritize buildings in terms of opportunities for improved fleet maintenance operations

Employee Safety, Health, and Comfort

- Assess safety in the current facilities, and research and develop plans for improving safety, particularly in regard to the elimination of floor hazards and appropriate ventilation
- Assess human health issues related specifically to mold/mildew and other airborne pathogens, and research and develop plans to mitigate issues related to these health concerns
- Prioritize buildings for improvements in safety & health, and increase the overall comfort of the work environments for the employees

Facility Energy Effectiveness

- Assess energy effectiveness in all ODOT facilities throughout the state; rank facility energy effectiveness
- Prioritize ODOT buildings for energy efficiency improvements
- Research and develop plans for energy effective ways to maintain human comfort in the facility where it is needed
    - Ideally reducing foot print for HVAC system mechanicals
- Evaluate opportunities for reducing the smaller foot print for HVAC system mechanicals
- Develop an economic analysis of potential energy savings for all facilities
- Demonstrate the value of real-time energy measurement in identifying savings opportunities and in continuously commissioning facilities
- Assess, research, and develop a plan for improved servicing and maintenance of HVAC equipment to improve effectiveness and longevity

To accomplish these objectives, a seven-step process was followed as outlined in the table below.

Table 2 – ODOT Maintenance Facilities Included in the Weather Normalized Energy Intensity Analysis

Task 1	Establish “State-of-the-Art” for ODOT Facilities Relative to Fleet Maintenance and Equipment, Employee Safety, Comfort, and Health, and Energy Effectiveness
Task 2	Current Design Evaluation for Future Facilities

Task 3	Facility Walkthrough and Equipment Cataloging at Sample Facilities
Task 4	Survey of ODOT Facility Operators of Maintenance Operations, Employee Safety & Health, and Energy Systems
Task 5	Real-time Utility Monitoring at Sample Facilities
Task 6	Energy Data Analytics to Compare Energy Efficiency of ODOT Facilities [University of Dayton – Energy Informatics Center]
Task 7	Design Analysis of Existing Buildings

Literature Search
The initial literature search effort was completed primarily by the team at the University of Dayton. In general, there was a dearth of reported results in many of the areas seeking input. However, several DOT facilities maintain publicly available environmental, health, and safety documents, as well as maintenance operations process documents. Further, we accessed a recent report that documented benchmarks established by a number of state DOT facilities for assessing operations, productivity, and safety that was particularly useful for our report.

Relative to energy and comfort, the research conducted primarily relied upon best practices in other business domains; namely garages, warehouses, and industrial facilities. The latter drew especially from the nearly 40-year experience that the University of Dayton's Department of Energy sponsored Industrial Assessment Center has in helping manufacturers reduce energy in cost effective ways.

Further, per the request of the ODOT, additional research was conducted to evaluate the energy savings opportunities, as well as the durability, of hydronic floor heating to help inform the design of a new ODOT facility.

Energy Benchmarking
The energy intensity benchmarking study was very effective in identifying the best and worst facilities in terms of energy effectiveness. The following major conclusions can be drawn.

The two best facilities are by far the Seneca and Williams facilities. Their energy intensity in all energy categories are far better than the other facilities. These facilities should be looked at as a model for improvement in the other facilities. The two worst facilities in terms of energy effectiveness are the Edison and Lucas facilities, with energy intensities 4-5 times higher than the two model facilities. Further a number of other facilities (Northwood, Sandusky, and Woods) have very high heating energy intensity relative to the model facilities. These also should be audited to identify the best means to reduce heating energy intensity. Lastly, the Woods and Sandusky facilities should be assessed in terms of their consistent gas energy consumption, which may be used for process heating, vehicle washing, or continued boiler operation during warm weather.

Research Approach

The primary focus of the literature search was to identify other DOTs and use their best practices as a baseline for recommendations in this study. A number of states were investigated with Minnesota having some of the most thorough data available. During these searches, the following segments were independently review for best practices:

- Operations
- Comfort
- Health and Safety
- Energy Use
- Hydronic Floor Heating

For a more personal and qualitative look into the current state of existing buildings, an occupant survey was created and distribute in each building. This survey included questions on building comfort, how conditions change by season, additional devices like fans and space heaters being used, and general feelings about the work environment in each facility. This allowed the research team to understand the viewpoint of the staff that are in the buildings each day when considering recommendations for improvement.

After completing this initial research, the following steps were taken to further the depth of study in a variety of areas.

Energy Benchmarking

In the energy benchmarking effort, we accessed the historical energy consumption data for all NW Ohio ODOT facilities via the EPA Portfolio Manager data. This was arranged by JadeTrack. With this data we were successfully able to determine the energy use intensity for typical weather years for all facilities in the study in all energy categories; namely gas heating, gas water heating or processes, electric lighting and appliances, electric heating or winter increase, and electric cooling. A comparative analysis of the results for all facilities was used to help identify priority buildings for energy efficiency improvements or building de-commissioning.

Real-time Utility Monitoring

In order to get an even more in-depth understanding of energy use, three representative facilities were selected by the ODOT staff to be fitted with real-time utility meters. Utilizing the software platform provided by JadeTrack, interval meters were installed to gather gas and electricity usage data every 15 seconds at the Ottawa, Seneca, and Williams garages.

Design Analysis of Existing Facilities

Based on findings from the energy benchmarking and utility metering, a targeted approach was taken to the facility audits of the three representative facilities. These walkthroughs were used to catalog the lighting, electrical, mechanical, and HVAC systems in order to compare them to today's state-of-the-art and identify areas for improvement and energy savings. In addition, a lighting survey was also performed for the D2 HQ buildings knowing that this can often be one of the best energy savers in any building.

Survey of ODOT Facilities in Order to Assess Operations, Safety, Health, and Comfort
ODOT collaborators on this process indicated that such an assessment would be difficult to obtain. We were encouraged not to pursue this task. Moreover, the research described above relative to these subjects was essential for identifying what should be surveyed.

Design Evaluation for Future Facilities
Utilizing the experience of the industry professionals at Gresham Smith & Partners, designs for future facilities were analyzed for potential improvements. The primary focus of this effort was the potential feasibility and benefits of using radiant floor systems for heat, but other design considerations were assessed as well. A specific focus was into the durability of the microsilica concrete, the main product used in new ODOT facilities, and how it would handle the cycles of heating and cooling associated with radiant floor systems.

The new North Baltimore Outpost, currently in design phase, was used as the real-world example for this part of the analysis. The design architect on the North Baltimore Outpost, The JDI Group, was also consulted during the research.

Research Findings and Conclusions

Based on the various areas of investigation mentioned previously, the following conclusions were made for each.

Operations

A number of state DOT facilities have established performance metrics for operations in maintenance facilities and databases to measure progress relative to the performance. The performance metrics have included: Utilization /Replacement Life Cycle: mileage (for light vehicles) and hours used (for heavy vehicles); Preventative maintenance compliance (hours and/or mileage); Fleet Uptime/Downtime; Replacement life cycle; Day to day operations in every shop; Fleet size compliance; Repair costs; Fuel consumption maintenance compliance; and In-house work versus contracted work. Metrics and processes established in other states can be used as initial targets for ODOT.

Comfort

The research shows the importance of human thermal comfort in terms of employee satisfaction, absenteeism, and retention. It also shows the importance of giving the employees a say in the design of systems leading to improved comfort. Hydronic floor heating, improved dock seals, and high volume fans (ceiling) can be especially helpful in improving thermal comfort.

Health and Safety

A number of state DOT facilities have well-documented safety standards. Moreover, the safety in all facilities is regulated by OSHA. The expectation here is that ODOT certainly has safety standards already in place.

Energy Use

A comprehensive list of energy reduction measures has been presented for any energy consuming element of a DOT maintenance facility. Further, priority energy recommendations established for military facilities are equally valid for ODOT facilities. A number of priorities have been identified throughout this report, though many rely on factors outside of energy consumption to be financially feasible.

Hydronic Floor Heating

The research suggests that hydronic floor heating can reduce heating energy anywhere from 10-50%, while significantly improving human thermal comfort in the winter. There is precedence also for using in garage type facilities. Durability appears to be unquestionable.

Unfortunately, due to the up-front cost of these systems as compared to today’s CoRayVac heaters, it is very hard to justify moving forward with hydronic floor heating based on energy savings alone. With the already low levels of consumption in these garages, there simply isn’t enough energy to save to create a decent payback. With roughly $50,000-$70,000 in added cost, and only $864/year in average energy savings, each facility would need to experience at least $4,136/year in non-utility benefits to make the system a cash-positive alternative over a ten year period.

Recommendations for Implementation of Research Findings

Based upon the research team's understanding of ODOT's expected rate of return for pursuing projects, this project does not appear to meet the requirements and therefore should not be pursued further. That being the case, much of the information provided in this report such as the best practices of other DOT facilities, the rankings of D2's best and worst energy users, the Energy Efficiency Guidebook, and targeted ECMs at the three sample garages and HQ buildings can all be used by ODOT staff moving forward.

If this project were to proceed further, the following methods would be recommended for the next phase of research.

Operations, Health, and Safety

Work with ODOT to develop performance metrics for operations, health, and safety, as well as associated data collection system based on similar systems used in other states. Establish tracking system relative to the performance metrics.

Energy Benchmarking

Strongly recommended is energy benchmarking of ALL ODOT maintenance facilities, however, with additional data factored into the benchmarking in order to account for differences in operation of the facilities. The reality is that the energy consumption in each of the facilities doesn't just depend upon the conditioned floor area and weather. It depends also upon utilization of the facility. We strongly recommend utilizing other data that reflects utility of the facility. With such data, better models for each facility can be developed using data mining multivariate approaches. This type of effort is suggested in Phase II for ALL ODOT facilities.

The additional data could include:

- Number of employees on each shift
- Building setpoints
- Hours of operation
- Overtime hours
- Fleet numbers
- Fleet downtime / uptime
- Winter monthly snowfall
- Monthly salt deployed

and any other factor that contributes to greater energy consumption.

This assessment should be used to prioritize buildings state-wide for on-site energy assessments and subsequent energy reduction action.

Existing Building Upgrades and Tracking

Begin by installing JadeTrack system on the HQ buildings so that all audited facilities can be tracked with live meters. Proceed with recommended ECMs at each building, utilizing the interval data to specifically track and prove the true savings benefits of each upgrade. This will allow for similar upgrades to be confidently made at other facilities with no doubt as to what the savings outcome will be.

North Baltimore Outpost Hydronic Floor Heat

If the Research Department can justify the costs beyond the energy efficiency benefits, installing both the standard CoRayVac heating system and a radiant floor heat system in the same building would provide an excellent opportunity for decisive research on the benefits of each, something that has not been done to this point.

To fully compare the two systems, a number of meters would first be installed to track not only the utilities, but also things like indoor air temperature, humidity, slab temperature, and direct usage by each of the two systems. Alternating usage on a bi-weekly basis throughout an entire heating season, the team could then see the true cost of operating each, and how well they respond to extreme conditions. Things like how long ice is remains on parked trucks, and number of maintenance issues caused by the same could be tracked as well to give a better sense of how each system might affect the life expectancy of the vehicles. Finally, this would allow a real-world durability test for the radiant floor systems with actual vehicles loaded with salt and ice being driven over them throughout the winter.

The results of this study would be a definitive answer to weather future ODOT buildings should be designed as they are today, or with radiant floor heating in all of the bays instead.

Prior to the full-scale study, a simple validation test for hydronic heating and the effect on ice melt time could be quickly and easily performed. The ability of such heating to provide a comfortable thermal environment is certain. Energy savings in the range of 10-50% has been documented. But, one significant other impact in the DOT application is the potential benefit of floor radiant heating on melting ice formed/collected on the undercarriage of the plow trucks. Rather than integrating a hydronic floor into an entire new facility, a realistic experimental simulation should be constructed.

It is feasible to utilized rubberized snow melting mats as temperature controlled surfaces (See: https://heattrak.com/). These mats could be configured beneath one truck bay over the winter. A temperature controller could be used to maintain a constant mat temperature (~ 80^{o}F) over the course of a month in the winter season. The impact of the mat on snow melt from the undercarriage could be assessed by comparing snow melts for trucks without the heated floor mats to that with.

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Appendix I – Literature Review and Analysis

Literature Review Overview

Investigate best practices, case studies, and available publications that can help establish "State-of-the-Art" practices for ODOT facilities relative to fleet maintenance and equipment, employee safety, comfort, and health, and energy effectiveness.

All appropriate literature and subsequent analysis is detailed in the sections below.

Fleet and Equipment Maintenance and Operations

Summary of State DOT Fleet and Equipment Maintenance and Operations Plans

A number of state Department of Transportation facilities host their Fleet and Equipment Maintenance and Operations processes and reporting on-line. The table below documents those DOTs which have done so. Ideally the best practices from these could be extracted; however, the Minnesota strategy is by far the most comprehensive. A summary of this report will follow.

Table 3 – Links to State DOT Fleet and Equipment Maintenance and Operations Processes and Reporting

State (Year)	Fleet and Equipment Maintenance and Operations Process URL
Texas (2003)	Maintenance Management and Safety Guide, https://www.dot.state.tx.us/PTN/documents/mgmtguide.pdf
Minnesota (2016)	Maintenance and Fleet Management, http://www.dot.state.mn.us/maintenance/pdf/manual/ch4.pdf
Montana (2017)	Montana DOT Equipment Vehicle Management System, https://ops.fhwa.dot.gov/publications/fhwahop12046/rwm18_montana1.htm

Of these by far the Minnesota plan offers the most relevance for the Ohio DOT. The plan documents processes and reporting relative to facilities and operations management comprehensively. The report is organized into the sections identified in the table below. Minnesota also maintains the most comprehensive Highway Systems Operations plan[1].

Table 4 – Overview of Minnesota's DOT Facilities and Equipment Maintenance and Operations Plan

Topics Included	Description
Roles and Responsibilities	Identifies the primary responsibilities associated with: • oversight of maintenance functions, • coordination of maintenance functions, and • customer support for the eight MnDOT Districts. State, district, and facilities level responsibilities are documented.

[1] Minnesota DOT, Highway Systems Operations Plan 2012-2015, http://www.dot.state.mn.us/maintenance/hsop/

Operations Performance Measures	Documents the performance measures associated with operations at all levels. The following are the performance measures: 1. Equipment Utilization Rate Tandem and Single Axle Plow Trucks 8,000 miles/yr. Cars, Pickups & Medium Duty Vehicles 12,000 miles/yr. Loaders, Articulated 250 hours/yr. Skid Loaders & Wheel Type Backhoes 125 hours/yr 2. Units Within or Out -of -Life Cycle MnDOT's M5 Equipment Management Information System is used to provide average life-cycle cost information, including running repair costs of parts, labor, downtime, etc 3. Fleet Size Measures The Operations Performance Measure of Fleet Size does not have a goal or target per se. Instead, it is comparing the number of units, perhaps by class, of one District or Office compared to a similar District or Office. It can be used in comparing the number of units per mile or per unit of work performed from one organization to another. 4. Scheduled vs. Unscheduled Vehicle Maintenance Scheduled maintenance is planned component repair or replacement, often triggered by preventive maintenance inspections, Pre-trip and Post-trip inspections, regular oil changes and grease jobs, etc., all of which are scheduled maintenance activities themselves. Unscheduled maintenance is work that results from breakdowns or surprise failures, often triggering road calls and usually causing expensive downtime of labor crews. This measure is intended to compare the portion of the work done in repair shops that is considered preventive maintenance, inspection or modification as opposed to reactionary, operator reported or breakdown maintenance or repair. When a vehicle is down, not available for service, the organization has lost the use of that item which results in less efficient operations. When this down time is unscheduled maintenance an entire crew and job could be idled.
Equipment Management System	Describes use of the M5, Equipment Management System from Asset Works. This tracks every aspect of the fleet, including evaluating a need, budgeting, acquisition, in-service, maintenance schedules, repair history, fuel, lifecycle and disposal. In addition, M5 tracks work flow in the mechanical shops and work order costing including labor, parts, and commercial charges. MnDOT's motor pool locations can use M5 for tracking motor pool units.

Life Cycle Cost Analysis	Life Cycle Costing calculates ownership and operating costs throughout the working life of the units. Includes the valuation of costs associated with things like availability, service, resale value, downtime or rental costs for replacing units "down" for service. Typically, as a unit ages, average maintenance costs go up but investment costs decrease.
Equipment Operations Standard	Defines vehicle operator's responsibilities such as license requirements, minimum age limitations, driving under the influence, insurance coverage when using personal vehicles, seat belt use requirements, using headlights all times, personal liability for traffic violations and fines, etc.
Preventative Maintenance and Inspection	Documents: • Daily operators inspections • Responsibilities operators to adhere to the schedule of lubrication and service of equipment as recommended by manufacturer's lubrication and service instructions. • Winter pre- and post-inspection of all winter equipment • Operator routine inspection responsibilities and schedules • Repair shop preventative maintenance for all vehicle types • Manufacturer service and warranty timelines • Annual commercial vehicle requirements
Repair Shop Operations	Documents: • Requirements for documenting all shop work of any nature, including field service calls and annual Inspections. • Research requests for equipment additions or upgrades
Acquisition of Equipment	Documents: • Justification requirements for new acquisitions • Equipment procurement processes • Justification for modifications/improvements to existing equipment • Justification for renting/leasing equipment • Sharing and partnership responsibilities for equipment
End-of-Life Considerations	Documents: • Processes for managing the end-of-life of equipment, through trade-ins, sales, and disposal.

Best Practices Performance Metrics

A number of state Department of Transportation facilities have documented their best practices relative to Facilities and Equipment Maintenance and Operations performance metrics.

Documenting these is important; as these performance metrics identify what each state considers to be most important. Table 1.1.2 identifies the performance metrics which have been used and which of the states reporting metrics utilize. This information was collected by CalTrans in a 2012 study[2]. Clear from this table is that Pennsylvania and Virginia have the most comprehensive set of maintenance and fleet operations measurable performance metrics.

Table 5 – Performance metrics for facilities and equipment maintenance and operations

Performance Metric	**States**				
	IL	NY	NC	PA	VA
Utilization /Replacement Life Cycle: mileage (for light vehicles) and hours used (for heavy vehicles)	✓	✓	✓	✓	✓
Preventative maintenance compliance (hours and/or mileage)	✓	✓	✓	✓	✓
Fleet Uptime/Downtime	✓	✓	✓	✓	✓
Replacement life cycle		✓	✓	✓	✓
Day to day operations in every shop				✓	✓
Fleet size compliance				✓	
Fuel consumption maintenance compliance				✓	
Repair costs				✓	✓
In-house work versus contracted work					✓

Safety and Health Considerations

Clearly DOT facilities are subject to OSHA safety requirements. This report won't document these processes and requirements[3]. Most state DOT documents on safety (if not all) focus on road safety. We weren't able to access safety documentation from any DOT facility. However, the next sections, dealing with human comfort energy efficiency address environmental safety through maintenance of moisture in a facility (and thus fall hazards and mold contamination) and air quality. Safe operation relative to equipment maintenance and operation, etc… was deemed beyond the scope of our effort.

[2] Caltrans Division of Research and Innovation Produced by CTC & Associates LLC Fleet Equipment Asset Management Performance Measures, December 28, 2012, http://www.dot.ca.gov/newtech/researchreports/preliminary_investigations/docs/fleet_equipment_performance_measures_preliminary_investigation.pdf

[3] OSHA, Process Safety and Management, https://www.osha.gov/Publications/osha3132.html

Employee Comfort and Productivity

The Importance of a Positive Work Environment for Employees

In this section, we address the importance of human comfort in the workplace and the means to achieve it. We start with a broad picture of human comfort.

A 2015 article in the Harvard Business Review emphasized the importance of positive workplace environments on employee productivity[4]. The American Psychological Association estimates (http://www.apa.org/news/press/releases/stress/2014/stress-report.pdf) that more than $500 billion is siphoned off from the U.S. economy because of workplace stress, and 550 million workdays are lost each year due to stress on the job. Sixty percent to 80% of workplace accidents are attributed to stress, and it's estimated (http://www.stress.org/americas-1-health-problem/) that more than 80% of doctor visits are due to stress. Workplace stress has been linked to health problems ranging from metabolic syndrome to cardiovascular disease and mortality.

Second is the cost of disengagement. Engagement in work — which is associated with feeling valued, secure, supported, and respected — is generally negatively associated with a high-stress, cut-throat culture. Disengaged workers had 37% higher absenteeism, 49% more accidents, and 60% more errors and defects. In organizations with low employee engagement scores, they experienced 18% lower productivity, 16% lower profitability, 37% lower job growth, and 65% lower share price over time. Importantly, businesses with highly engaged employees enjoyed 100% more job applications.

Lack of loyalty is a third cost. Disengagement leads to an increase of almost 50% in voluntary turnover. People go on the job market, decline promotions, or resign. And the turnover costs associated with recruiting, training, lowered productivity, lost expertise, and so forth, are significant. The Center for American Progress estimates that replacing a single employee costs approximately 20% of that employee's salary.

A 2003 Gallup poll showed that engagement predicted wellbeing above and beyond anything else. [5] Employees prefer workplace wellbeing to material benefits. Wellbeing comes from one place, and one place only — a positive culture. Thermal comfort is an important element in this culture. If the thermal comfort environment has been previously poor, improvements can be seen very positively by employees.

Key Environmental Factors for Improving Productivity

Informing the possibility of improving productivity in DOT maintenance facilities through environmental factors are numerous productivity studies in manufacturing. The top comfort factors that affect worker productivity include thermal comfort and heat stress, trunk posture, back pain, noise levels, air quality, perceived health risk and safety, lighting, and fire safety and prevention. Managing these factors positively affects worker productivity, health, and safety.

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[4] E. Seppala & K. Cameron, "Proof That Positive Work Cultures Are More Productive," DECEMBER 01, 2015, https://hbr.org/2015/12/proof-that-positive-work-cultures-are-more-productive

[5] T. Tritch, "Engagement Drives Results at New Century," Gallup Management Journal, 2003, https://www.nova.edu/ie/ice/forms/engagement_drives_results.pdf

A recent Manufacturing News article identifies 3 factors that can improve employee perception of the environment, and thus productivity; namely, lighting, thermal comfort, and established safe working conditions[6].

Lighting

Proper and sufficient lighting is essential when it comes to increasing productivity and/or efficiency. If a section or the entire facility isn't lit properly, this can not only cause employees to spend more time locating tools or components they need for their job, it can be an extreme safety hazard.

A simple way to see if a facility is properly illuminated would be to walk the shop floor and ask employees for their input. Ask if they ever have trouble with lighting or if any areas in particular aren't as bright as they should be. Having employees contribute to a comfortable work environment will only help management reach their goal. It gives employees a voice. Once lighting issues are discovered, the next step will be to find a practical solution. It may not require an entirely new lighting system, it could be as simple as moving a shelving unit a couple of inches to eliminate a shadow. A small, inexpensive lighting fixture could be necessary but ensuring that employees are safe, productive, and working efficiently, will far outweigh the cost.

Heating/Cooling

Working in a hot environment can cause the workforce to become exhausted faster. Sweat can drip in eyes, employees might need to walk outside for some air, all of this time adds up to a loss in productivity and a major hit to the efficiency of a manufacturing operation. On the other hand if a facility is too cold, employees won't be as dexterous as they would be in ideal operating temperatures.

NASA conducted a study that showed worker productivity falls significantly for every degree over an optimum temperature of about 72 degrees. For example, if the temperature hits 85 degrees, productivity drops by 18% and accuracy a staggering 40% [7].

It can be particularly difficult to maintain a level temperature in a manufacturing facility. High ceilings mean the heat rises and machines working around the clock create a lot of excess heat. Industrial fans can play a huge part in ensuring air circulates around the shop. This can be the difference between a facility that experiences extreme temperature ranges and one that is comfortable for all of its employees.

Safety & Health

The best way to make sure your workforce is comfortable is to ensure they stay safe and healthy. Injuries, severe, or even the not so severe, can disrupt a large portion of the workday. A strong focus on safety training can have a major impact on the moral of the employees. An employee that feels as though their well-being is important to the company will be more inclined to follow the safety procedure. This will lead to fewer accidents and injuries, and in turn, boost productivity and efficiency.

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[6] Manufacturing News, 3 Ways to Boost Manufacturing Productivity, https://mfgtalkradio.com/3-easy-ways-to-boost-manufacturing-efficiency-and-productivity-the-manufacturing-workforce/

[7]NASAN, "A Compendium of Human Responses to the Aerospace Environment," NASA CR-1205-1

Not only is a strong focus on safety essential, it will be important to ensure any tools, components, or equipment is located in such a way as to avoid unnecessary stress on the back when an employee needs to move or use them. If a heavy box of components is too low to the ground, an employee that lifts wrong, or has a bad back to begin with, can over-exert themselves causing serious harm. Also, a heavy box on a high, hard to reach shelf, is just asking for a serious injury to occur. Go back to the floor, ask employees where they run into issues. The more a manufacturer includes their workforce in the decision-making, the better chance they will have of creating a comfortable facility for their employees to work in.

Managing Thermal Comfort While Minimizing Energy Consumption in Cold Seasons

The DOT facilities evaluated in this study generally utilized overhead radiant heating. Generally, this type of heating enhances thermal comfort, while also permitting maintenance of the space temperature lower than with a forced air heating system. But, there is another option, radiant floor heating. This will be examined in more detail in a following section.

Uponor, a developer of these systems, suggests this technology for high-ceiling commercial structures. DOT facilities would generally fall into this category. Capitalizing on the large mass of the concrete slab, a radiant system will absorb, store and re-radiate heat evenly and efficiently right at the floor level where people work. Just as importantly, this heat will not quickly escape to the outdoors when exterior doors are opened. Instead, the warmth remains indoors, because the floor mass maintains temperature during these times, maximizing comfort for the occupants and energy savings for the building owner. A number of case studies have demonstrated significant energy savings owing primarily to a possible reduction in facility air temperature, from 3-10 degrees below that which would be maintained with a forced air convection heating system. Radiant heat systems have a proven record of reduced energy usage relative to other forms of heating, both in residential and commercial / industrial buildings. The savings result from several factors such as the ability to sustain comfort at lower indoor air temperatures, reduced air temperature stratification, non-pressurization of rooms (which leads to higher rates of air leakage), and the ability to operate with lower water temperatures. Savings vary from one building to the next. Although some projects have shown savings in excess of 50%, a more conservative estimate is 10 to 20% in savings[8].

The comfort benefit of this type of heating is certain. With proper scheduling, workers can start the day in the shop in a warm, comfortable environment. Even with overhead doors open, the space can remain comfortable. The temperature comes back to the set point within minutes after the doors are closed. Another benefit is that the entire facility area can be used. There is no need for supply and return ducts and vents. Further, this type of heating is inherently quiet. It can deliver heat without noise. The gas or oil burner on the boiler is often the only component that makes any detectable noise, and it is usually located in the mechanical room away from the occupied spaces. It is also a clean system. One of the biggest complaints associated with forced air heating is its tendency to distribute dust, odors and germs throughout a facility. In contrast, radiant flooring heating creates very gentle (imperceptible) room air circulation. Many people who suffer from allergies have found that radiant heat doesn’t aggravate the symptoms the way a

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[8] High Cord Heating Systems, “ Benefits of Radiant Floor Heating Systems,” http://www.radiantheatproducts.com/Benefits_of_Radiant_Flooring.php

forced air system often does. Lastly, it is durable. A concrete slab type radiant floor heating system is nearly as indestructible as the slab itself. It's the ideal way to heat garage facilities and industrial buildings, or other buildings with high interior traffic.

Managing Thermal Comfort While Minimizing Energy Consumption and Mold Formation with High Volume Fans

In terms of employee comfort, it's important to understand that the sensation of feeling comfortable is not dependent on air temperature alone. Human thermal comfort takes into account numerous environmental factors including temperature, thermal radiation, humidity, and air speed as defined by ASHRAE Standard 55-2010, along with personal factors including activity level and clothing type. Studies have shown that improved occupant comfort leads to increased productivity, with worker productivity decreasing as temperatures rise above 77 F.
In warmer months, operating between 60% and 100% of maximum speed, 6- to 24-ft-diameter fans improve comfort with either an evaporative cooling effect or the added effect of heat transfer—when skin temperature is warmer than air temperature. Although fans do not lower the air temperature in a space, the perceived cooling effect can make a person feel up to 10 degrees cooler.

In the winter months, operating at 10% to 30% of the maximum speed, large-diameter, low-speed fans successfully destratify tall spaces, mixing the warm air at the ceiling level with the cooler air at the occupant level, creating a more uniform temperature.
The addition of air movement offers multiple benefits that improve the well-being of occupants and, in some cases, of products and machinery as well, by aiding in the following:

- Reducing heat stress on employees
- Reducing condensation to preserve product integrity
- Improving indoor environmental quality (IEQ), when mold or toxic fumes are airborne
- Providing year-round comfort

Condensation within a shop space can prove detrimental to employee safety (e.g., forklifts on wet concrete) and negatively affect product integrity. Dehumidification systems (air conditioning) can decrease moisture content of the air, while heating systems help increase air or surface temperatures to help reduce moisture buildup.
The downside however, is that large spaces are often impractical, or at the very least expensive to heat and cool. Air movement, on the other hand, does not depend on any external conditions to be effective.

Properly designed large-diameter fans with airfoils and winglets disturb the thin film of stagnant air on the metal surface, which in turn dramatically reduces the likelihood of condensation. This is highly beneficial in areas of high humidity where moisture buildup can result in mold and mildew.

Where condensation is a concern, the temperature of a concrete slab will trail the air temperature by about a month. For example, as April's air warms to 70 F, the concrete is still stuck at roughly 50 F, from the month before. This warm, moist air sits on the cold slab and deposits moisture as it cools.

Given the vastness of most facilities, the steady, even air movement from large-diameter, low-speed fans helps move the stagnant warm air off the cold surface before it has a chance to cool down enough to leave puddles. Fans with additional blade-ending fins can help direct the fan's airflow toward the floor, maximizing the fan's coverage area.

Facility Energy Effectiveness

In 2014, the U.S. Department of Transportation in response to President Obama's Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic Performance* developed a statement on Sustainable Operations and Management that established strategic goals for the DOT relative to environmental sustainability[9]. This statement encouraged consideration of the values of sustainability, stewardship, and resource conservation into all policies, programs, operations, investments, and research.

The following specific goals were established:

- Achieve greenhouse gas emissions reduction targets;
- Reduce energy intensity in buildings and fuel consumption in vehicles;
- Increase use of renewable energy and alternative fuels;
- Improve water use efficiency and management;
- Incorporate high performance, sustainable building and location efficiency guiding principles into the siting, design, construction, operation, management, maintenance, and deconstruction of buildings;
- Minimize waste, prevent pollution, and maximize reuse and recycling of remaining waste;
- Reduce the amount of toxic and hazardous chemicals and materials acquired, used, and disposed of;
- Promote sound environmental stewardship of electronic equipment and data centers;
- Advance sustainable acquisition by promoting green purchasing practices with responsible vendors;
- Evaluate operations and undertake actions to enhance climate change preparedness and resilience;
- Continuously improve environmental performance through formal implementation of environmental management systems; and
- Implement this policy through a comprehensive Strategic Sustainability Performance Plan.

The Department of Transportation's 2016 Strategic Sustainability Performance Plan presents the current priorities in all operations to achieve these goals[10]. The Energy Independence and Security Act of 2007 requires each agency to reduce energy intensity in buildings by 2.5 percent annual through 2025, relative to a FY 2015 baseline. The priorities identified for 2017 include the following strategies:

- Make energy efficiency investments in agency buildings
- Install and monitor energy meters and sub-meters

[9] https://energy.gov/nepa/downloads/eo-13514-federal-leadership-environmental-energy-and-economic-performance-2009

[10] U.S. Dept. of Transportation, 2016 Strategic Sustainability Performance Plan, https://www.transportation.gov/sites/dot.gov/files/2016%20DOT%20SSPP%20Final_Complete_Sept_2016.pdf

- Collect and utilize building and facility energy use data to improve building energy management and performance, as enabled by utilizing an Energy Management System to execute, monitor, and track sustainability efforts
- Ensure the monthly energy consumption of all builds above 5,000 gross square feet is entered into the EPA Energy Star Portfolio Manager energy management tool in order to track longitudinal performance
- Reduce on-site fossil-fuel and grid-supplied electricity consumption by installing more efficient boilers, generators, furnaces, etc. and/or use renewable fuels
- Incorporate green building specifications into all new construction, modernization, and major renovation processes
- Include in every construction contract all applicable sustainable acquisition requirements for recycled, biobased, energy efficient, and environmentally preferable products
- Develop and deploy energy and sustainability training for all facility and energy managers
- Utilize performance based contracts to achieve green buildings

Remarkably as of 2015, only 2.0% of the DOT buildings had achieved the energy reduction initially targeted in 2007 for 2015.

Surprisingly, there is very little guidance on specific energy reduction measures to achieve the priority goals defined by the DOT. The following addresses energy efficiency efforts in related buildings; namely, automotive shops, maintenance facilities, and warehouses. It also addresses general energy reduction initiatives in industry having relevance to DOT facilities. The last subsection in this section addresses specific energy reduction measures in manufacturing identified by the University of Dayton Department of Energy Industrial Assessment Center since its establishment in 1980, with continuous DOE funding since then.

Automotive, Truck, and Bus Shops

Energy efficiency strategies in automobile, truck, and bus maintenance facilities provide certain parallels to opportunities in DOT facilities. A 2006 report by the National Automobile Dealers Association, “A Dealer Guide to ENERGY STAR® Putting Energy into Profits,” offers still relevant input. At the time of the report, automotive repair shops had an average energy use intensity of 110 kBTU/sf as compared to an office building energy use intensity of 93 kBTU/sf. Interestingly, as will be reported later, the average annual weather normalized energy use intensity of the NW Ohio DOT facilities was 117 kBTU/sf. Thus, use of this building sector seems relevant. Moreover, the recommendations available in this report still has relevance, except perhaps relative to lighting, which has advanced markedly since 2006.
This report documents certain low cost energy reduction measures, for respectively new construction/major renovation and simple upgrade. Clearly all of these energy reduction measures remain relevant today.

Table 6 - Energy efficient measures for automotive repair shops

Energy Reduction Measure	New Construction/Major Renovation	Simple Upgrade to Existing Facilities
Insulation	✔	
Electrical receptacle seals	✔	✔
High-efficiency heating and cooling equipment	✔	✔
Cool roofing	✔	✔
Multiple pane, low-e windows w/inert gas fill	✔	✔
Regular HVAC maintenance and tune-ups	✔	✔
Install energy efficient lighting	✔	✔
Photocells for exterior lights	✔	✔
Occupancy controlled lighting for all storage, conference rooms, and restrooms	✔	✔
Automatic door closers on exterior bays	✔	✔
Low flow faucets in restrooms	✔	✔

Nagle Energy Solutions (NES) announced its garage-ventilation control system is capturing a 96% reduction in the energy consumed by a sizeable mechanical ventilation system installed recently at the City & County of San Francisco's Sutter Stockton Garage[11].

The garage demand-control ventilation (DCV) system shaves more than 770,000 kilowatt-hours (kWh) a year from Sutter Stockton's baseline energy consumption, providing an operational cost savings of $116,000 a year, not including future utility rate increases.

Since commissioning the DCV system at Sutter Stockton, real-time data logging shows it is limiting the energy consumed (measured in kilowatts) by five, new Huntair Fanwall motor units

[11] California's Local Government Energy Efficiency Portal, "Garage Ventilation System Achieves 96% Energy Savings," Sep., 2017, http://eecoordinator.info/garage-ventilation-system-achieves-96-energy-savings/

and nine, new stand-alone garage-fan motors providing fresh air in to the garage — and possessing a combined 150 horsepower (HP) running 24/7 — to just 4% of their total full-load capacity.

The NES System also slashes — by 96% —utility fees that otherwise would be incurred running Sutter Stockton's mechanical ventilation system 8,760 hours per year (24/7) with no means of motor control in place. Doing so would consume in excess of 800,000 kWh annually, which at the garage's utility rate of $0.15/kWh, amounts to $10,000 a month or $120,000 a year in electric utility fees.

Military Equipment Maintenance Facilities

A 2012 Department of Energy National Renewable Energy Laboratory report on low energy equipment maintenance facilities also offers energy reduction guidance of relevance to DOT facilities[12]. This report documents a deep energy reduction project for a military equipment maintenance facility. The reported retrofit project was able to achieve 40%–63% site energy savings compared to a baseline building model, and 51%–76% source energy savings compared to Commercial Buildings Energy Consumption Survey 2003 (EIA 2008) data for a similar building type. Recommended energy efficiency measures include use of passive house insulation standards (R-40 to R-60 for walls, R-60 to R-90 for roofs, and R-30 to 50 for slabs), demand control ventilation strategies in the maintenance repair bays, radiant floor heating, transpired solar collectors, reduced lighting power densities, daylighting, and lighting control strategies.

Warehouse Facilities

The relevance of energy effectiveness strategies for warehouse facilities to DOT facilities is also certain. The garage doors are a major source of air infiltration. A 2014 Environmental Defense Fund report, documents top priority, high priority, and long-term opportunities for energy reduction. The table below document the short-term savings opportunities. The tables below document these opportunities. The paybacks noted remain relevant for ODOT facilities.

Table 7 - Energy efficient measures for warehouses (top priority)

Top Priorities		
Measure	**Description**	**Payback time (years)**
Participate in Demand Response Programs	In a demand response program, a facility agrees to reduce non-essential energy use during peak demand periods, and the utility pays the company for its participation. The utility is typically required to give advanced notice of peak periods. Contact your local facility to determine availability of a demand response program and whether your facility's energy footprint is	Immediate

[12] Department of Energy National Renewable Energy Laboratories, "Extremely Low-Energy Design for Army Buildings: Tactical Equipment Maintenance Facility," 2012, https://www.nrel.gov/docs/fy12osti/53810.pdf.

	covered.	
Shut-off exhaust fans in unoccupied areas	Exhaust fans can be shut off when warehouse spaces are unoccupied for extended periods of time. Incorporate fan shut off as a part of warehouse closing procedures wherever appropriate.	Immediate
Implement regular HVAC maintenance and tune-ups (contracted)	Regular maintenance of heating, ventilation, cooling and refrigeration systems - including changing filters regularly - improves air quality and avoids wasted energy.	<1 year
Seal air gaps	One of the greatest sources of energy loss for heated or refrigerated warehouse spaces is air infiltration through gaps. Regularly checking and repairing gaps in seals is a quick energy saver	<1 year
Switch Exit Signs to LEDs	Exit sign lights should be upgraded to LEDs in facilities with lease terms of greater than one year. Incandescent and fluorescent exit sign lights use significantly more energy than LEDs and need to be replaced on a more frequent basis. Many utilities offer rebates for upgrades to LED exit signs.	<1 year
Adjust temperature programming and zone controls	Do an assessment of temperatures and ventilation settings for occupied/unoccupied zones and periods, including office space. Schedule regular periodic checks of settings and controls.	1-1.5 years
Docking door insulation	Dock doors should be regularly inspected to ensure gaps are sealed, especially during loading/unloading operations. Doors should be closed and adequately insulated and sealed when outdoor air temperatures conflict with desired indoor temperatures	1-2 years
Install occupancy sensors	Spaces such as aisles that are illuminated but infrequently used can waste energy and money. Occupancy sensors turn off or dim lighting when spaces are unoccupied, significantly reducing energy costs. Occupancy sensors are best used with fluorescent or LED lighting rather than metal halides as metal halides require a several minute delay when starting up. If you are considering use of occupancy sensors, consider upgrading your lighting at the same time.	< 2 years

Table 8 - Energy efficient measures for warehouses (high priority)

High Priorities		
Measure	**Description**	**Payback time (years)**
Delamp in conjunction with biannual lamp cleaning	ILight fixtures often use more lamps than are required for recommended lighting levels. When lights are upgraded from T12 to T8, delamping can be implemented to save energy (fixtures with bulbs removed do not consume energy). At the same time, lighting performance can be improved by cleaning the bulbs on a biannual basis. Lighting improvements can in some cases lead to improved work production and quality as well. Prior to delamping, consider storage of lamps removed and reinstallation costs when the lease term ends. Cleaning, removal and installation generally can be done by on-hand warehouse staff if lifts are available.	< 1 year
Install HVAC control technology/energy information systems	HVAC control technology coordinates HVAC units to reduce spikes in energy demand and consequently reduce demand fees from utilities. Additional HVAC control can reduce maintenance costs on HVAC units. In climatized warehouses, HVAC control technology can manage peak demand fees and reduce demand on individual HVAC units.	0.5-2 years
Upgrade to coldstorage door upgrades and insulation	Refrigerated areas lose energy when doors open to allow forklifts to come and go. Insulated cold-storage doors that open and close quickly and better sealing around loading dock doors will improve efficiency. Air curtains or strip curtains that activate when doors are opened can be used in tandem with refrigerated area doors or to further increase efficiency.	1.5+ years
Install ceiling "destratification" fans	For air conditioned and heated spaces, ceiling fans save energy by improving air circulation, allowing the temperature setting to be lowered by as much as 4.5^0 F and reducing cooling costs by 15-35%.	1-2 years
Slow evaporator fans	Full-speed operation of evaporator fans isn't always necessary. Controllers to slow evaporator fans can reduce energy use significantly.	1-2 years
Install LED lighting	LED lighting is now cost effective. All lighting with consistent use should be considered for upgrade.	1-2 years

	Rebates likely will be available.	
Install task lighting	Installing task lighting in narrow aisles or where workers are located reduces the need for ceiling lighting, proving more delamping opportunities	1-2 years
Section warehouse space into temperature zones	Over cooling or heating warehouse space that is not partitioned according to temperature zone can significantly increase energy use. Warehouse interior construction can be altered to allow for targeted different temperature zones. Sectioning should be considered when temperature requirements are significantly different for warehouse stock or when warehouse reconfiguration is already being considered.	> 2 years
Upgrade to energy efficient vending machines	Vending machines use a significant amount of energy (approximately 3,000kWh/yr per machine) because they are left on all of the time. Upgrading to a vendor who supplies Energy Star-certified vending machines or installing energy saving devices such as Vending Misers can reduce energy use by more than 50%. Include Energy-Star requirements in your next vending machine RFP or ask your current vendor if they can upgrade the equipment. Vending Misers can be installed easily by facility staff.	2-3 years (or immediate when initiating new vending contract)

Table 9 - Energy efficient measures for warehouses (long-term)

Long-term opportunities		
Measure	**Description**	**Payback time (years)**
Utilize beam radiant heaters	Reflector-focused gas or electric radiant heaters (in circumstances where only small employee areas require heat), can dramatically reduce energy costs by allowing the ambient facility temperature to be reduced without loss in employee comfort	2 years
Install economizer controls/free cooling	For climatized warehouses, air-side economizers use a damper to control intake of outside air. When outside air is cooler than return air, the damper adjusts to maximize air intake. When outside air is warmer than return air, the damper reduces outside air intake to the minimum required by building codes, reducing the need for mechanical heating or cooling. Airside economizers	> 2 years

	are best used in cool climates to take advantage of regional temperatures.	
Install cool roofing	Cool roofs are made from material that reflect the sun's energy and consequently reduces the heat transferred to the building below. This reduces cooling costs. Cool roofs should be considered on climatized warehouses if roofs are scheduled for replacement/repair and in longterm leased warehouses with high cooling costs.	> 2 years (when roof upgrades are due.)

Manufacturing

The final sector which can inform energy reduction opportunities in DOT is manufacturing. Additionally, a 2014 National Association of Manufacturers report, “Efficiency and Innovation in Manufacturing Energy use,” provides general guidelines for reducing manufacturing energy use. Additionally, provides specific case studies from leading U.S. manufacturers who have innovated institution wide energy reduction practices. A 2013 article highlights what the author considered to be the top five opportunities for low cost energy savings[13]. These included the following recommendations.

1. **Peak Energy Demand Identification**: Peak demand charges can often equal 30 percent of an industrial organization’s monthly utility bill. Peak demand charges are typically calculated over the 15-minute interval when the organization uses the greatest amount of energy in a given billing period. Peak demand is impossible to determine simply by looking at a utility bill. But with real-time visibility of energy usage, demand peaks become obvious, including irregular peaks caused by intermittent use of high-voltage mechanical systems, improperly programmed building management systems, or other mechanical system failures. Many industrial businesses have regularly scheduled production shifts with relatively predictable demand curves. Industrial businesses can work with vendors to ensure high-energy-demand activity necessary to meet production demands don’t coincide with incidental loads that can be shifted or eliminated.

2. **Weekend Energy Use:** Many industrial businesses have regular production shut downs (weekends, off shift periods, scheduled maintenance windows) that should see substantial reductions in energy demands. Without visibility into shutdown levels that data and analytics make possible, it’s hard to determine if optimal savings are being achieved.

3. **Weeknight Set-Backs:** Looking at the amount of energy used during off-shift periods is another area where savings can be achieved, thanks to the availability of granular energy demand trend information. For instance, data can highlight shallow drops in energy demand, which potentially indicate few pieces of equipment shutting down during off

[13] McDougall, D., 2013, “The Top Five Energy Efficiency Measures for Industrial Businesses,” Sustainable Plant, http://www.sustainableplant.com/2013/03/the-top-five-energy-efficiency-measures-for-industrial-businesses/

periods. Industrial businesses can use new technologies to compare energy use over time to see how setback sequences change. Having access to historical demand data to create a relative performance benchmark is a key consideration when contemplating an energy efficiency strategy.

4. **Start-Up Spikes:** Start-up spikes result when voltage jumps because multiple mechanical systems are turned on simultaneously. But by gradually ramping up mechanical equipment in a staged manner, excessive energy charges can be avoided without compromising production output.

5. **Compressed Air Systems:** Compressed air is used in many industrial processes. Given the large electrical demands needed for air compression motors, up to 20 percent of total electrical use in certain industries can come from air compression systems. This makes these systems prime targets for energy efficiency measures.

Additionally, a 2014 National Association of Manufacturers report, "Efficiency and Innovation In U.S. Manufacturing Energy Use," offers general guidelines for reducing manufacturing energy use. Additionally, provides specific case studies from leading U.S. manufacturers who have innovated institution wide energy reduction practices[14].

This report especially recommends use of an energy audit in order to baseline current energy use by category, thus, enabling establishment of energy goals. These generally start where the biggest improvements can be made with minimal cost. With the goals defined an energy management plan, will then:

- identify the investments needed to reach the goals;
- establish a blueprint and strategy for goal attainment;
- start early, if only with small efforts; • maintain regular contributions over time;
- and keep track of earnings.

Energy plan details, in terms of assessing energy and in involving employees in the process includes the following recommendations.

- Conduct an energy audit to determine how much energy is being consumed at your location; break down the results by category of energy use if possible (e.g., heating, cooling, pumps and fans, lighting, receptacle loads, etc.).
- Establish goals for the overall energy consumption of the building or renovated area. These goals should be broken down by category of energy use. Inform employees of these goals.
- Organize electrical services to permit sub-metering of energy use by category: cooling, pumping, fans and heating, plug loads, etc.
- Collect and analyze sub-metered energy data on a regular basis; compare results to goals for each category.
- Consider alternative heating sources such as ground-source heat pumps, geothermal heat

[14] National Association of Manufacturers, 2014, "Efficiency and Innovation In U.S. Manufacturing Energy Use," https://energy.gov/sites/prod/files/2014/05/f15/energy-nam.pdf

pumps, solar or other renewable energy sources.
- Provide employees/occupants with information on how they use energy and what they can do to reduce their energy use.

Relative to heating, ventilation and air conditioning, the report suggests the following as top priority measures:

- Address leaks and poor insulation in HVAC ductwork.
- Develop operating manuals for all equipment including design intent, set points, setback and setup schedules, on/off time schedules, special features and requirements, etc.
- Develop maintenance manuals for all HVAC equipment with schedules and frequency of service required.
- Ensure heating and cooling are on different schedules and that it is not possible to have the two operating coincidentally.
- As the occupancy schedule changes, ensure time schedules for ventilation fans, purge cycles, heating and cooling are changed to match building occupancy.
- Provide preventative maintenance checks annually to ensure all HVAC systems are operating properly; make any necessary repairs.
- Carry out an annual calibration and check the function of all building automation systems to verify operation and performance.
- Specify single bulb and fluorescent, mercury-free fixtures to replace incandescent ones at the end of their useful life; use the most energy efficient lamps and ballasts available for replacements.
- Consider group relamping. Common lamps, especially incandescent and fluorescent lamps, lose 20 percent to 30 percent of their light output over their service life.
- Replace all the lamps in a lighting system at once. This will save labor, keep illumination high, and avoid stressing any ballasts with dying lamps. It is useful to keep a record of the type of bulbs used and when they are replaced. This allows for long-term monitoring of the efficiency and life span of different types of lighting in different areas.
- Ballasts - standard choke ballasts can be replaced by high frequency electronic ballasts. Electronic ballasts are highly recommended for use with low-voltage tungsten-halogen lamps, high-efficacy argon-krypton filled fluorescent tubes, metal-halide and high pressure sodium lamps. Electronic ballasts offer the following advantages:
    - 20 to 30% energy reduction compared with conventional ballast
    - 50% longer service life of lamps
    - Absence of flicker (ballast operates lamp at a frequency between 22 and 70 kHz)
    - Silent operation

One final set of recommendations is offered for computer equipment.

- Enable energy saving options on computers, monitors, printers, photocopiers, etc.
- Turn all equipment off when not in use (both day and night); this will also increase equipment lifetime.
- Batch copy jobs rather than doing single copies.
- Buy printers and photocopiers that can do double sided printing or reduce page size to fit two pages on one side.
- Ensure that printer and toner cartridges can be returned and recycled by the

manufacturers.

- Choose equipment based on its efficiency and operating costs over time; only buy office equipment that has the Energy Star or Environmental Choice, EcoLabel. Ensure that the
- Energy Star program is initiated when equipment is first installed.

Research on Hydronic Floor Heating of ODOT Full-Service Facilities

Based on research, radiant floor heating can be installed in microsilica concrete slabs with no adverse effects. When microsilica concrete is being cured, it can reach temperatures of up to 160 °F during the curing process without adverse effects. Since radiant heating temperatures are no more than 125 °F it will not affect the performance of the microsilica concrete. Since there are no effects, there is no required thickness needed between the coils and the microsilica concrete as compared to a standard grade slab install.

Typical spacing is 16” from center to center at 1-4” depth. The closer the radiant tubing is to the surface of the slab, the more energy efficient the system is. Radiant floor heating has been successfully installed and used in a heavy vehicle garage and maintenance facility in New Richland, MN not to mention numerous other manufacturing and maintenance facilities. Not only has the system installed in Minnesota been durable and been able to withstand salt runoff from when the vehicles come in during winter but it has saved thousands of dollars a year in energy costs. Since the slab has a large thermal mass, when overhead garage doors are opened and closed, the garage will maintain a comfortable temperature. Since the tubing is spread out evenly throughout the entire slab, there is a constant temperature throughout the building instead of having warm spots by the supply vents and colder spots away from the supply vents. Since warm air rises, compared to an overhead radiant tube heater, the efficiency will be greater since the warm air will be at ground level instead of overhead and wasting all that energy. Energy savings from radiant floor heating range from 20-30% compared to traditional HVAC system. Although energy savings is one perk, air quality is another factor to consider. Since there is no ductwork required, dealing with dust buildup in ducts and having to clean them out periodically is no longer an issue. Dust will not be blown around the facilities due to the supply vents of a traditional HVAC system creating poor air quality.

Efficacy of Heated Floors on Melting Ice on Undercarriages of Trucks

Ice build-up on the undercarriages of the plow trucks poses serious maintenance concerns. Ice build-up can cause corrosion issues that diminish the life of numerous components, particularly the wiring harnesses.

Ceiling level radiant heating, useful from an energy efficiency stand-point because it enables some reduction in ambient temperature, is counterproductive for helping to melt the ice built up on the trucks. The lower ambient temperature (~65^{0}F) actually slows the convective heat transfer to the ice.

Hydronic floor heating offers a means to radiatively add heat to the ice on undercarriage of the trucks as shown in the figurebelow. The question is how much.

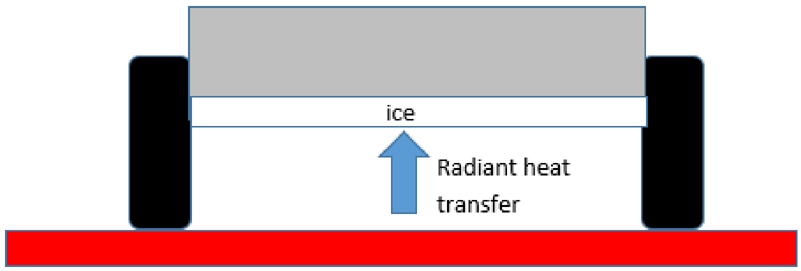


Figure 1 – Radiant Floor Heating Impact on Undercarriage Ice Melt

Assumed in the following analysis are the following: (1) the floor temperature is assumed to be a constant 80^{o}F; (2) the undercarriage temperature is assumed to be equal to the freezing temperature of water, e.g., 32^{o}F; (3) the emissivity of the floor is assumed to be 1 (ideally the surface would be as black as possible; (4) the emissivity of the ice because of its roughness and collection of dirt and other particles is assumed to be 1; (5) the airflow beneath the truck is somewhat constrained, and thus a convection heat transfer coefficient of 5 W/m^2-K is reasonable.

With these assumptions, the following analysis seeks to calculate and compare the heat transfer to the ice via thermal radiation exchange between the floor and the ice and convection. The following table summarizes equations used to calculate heat transfer for the two mechanisms; namely from thermal radiation between the floor and the ice and via convection.

Table 10 – Equations Used to Estimate the Heat Transfer to the Ice

Thermal radiation	Convection
$\sigma(T_{floor}^4 - T_{ice}^4)$	$h\ (T_{amb}\text{-}T_{ice})$

The next table summarizes the rate of heat transfer to the ice. Interestingly, the heat transfer to the ice is more than 155% of that from convection alone. The ice melt time consequently will be approximately 39% of what it is currently. Thus, a 5-day melt time could be reduced to 2 days. This could be reduced further by increasing the floor temperature. For example, if the floor temperature was increased to 85^{o}F, the 5-day melt time could become 1.8 days.

Table 11 – Contributions of Heat Transfer to the Ice

Thermal radiation (W)	Convection (W)
142	91

Appendix II - Energy Efficiency Guidebook

Energy Efficiency Guidebook – A Comprehensive Path to a More Efficient Facility

As part of the effort to identify efficiency opportunities in the ODOT facilities, the research team has compiled the below in summary of the University of Dayton Industrial Assessment Center (IAC) Energy Efficiency Guidebook (EEG). The EEG is a culmination of over 30 years of energy audits in the manufacturing sector. These best practices have been compiled into an Excel document with easy to use navigation and includes calculators to estimate savings for each of the best practices. EEG has been modified to include the information pertinent to ODOT facilities. The EEG will be shared with ODOT staff to utilize in future analysis.

Shared below are the best practices for a maintenance facility broken down by system category.

Utilities

Rate Structure

Understanding the electrical rate structure in terms of service, energy, demand and power factor charges helps manage electrical costs. In addition, some utilities offer lower rates for companies who can reduce electrical demand during the utilities peak demand periods.

Billing Errors

Billing errors can be identified by calculating energy costs using the electrical rate structure and comparing calculated and comparing calculated and billed costs.

Meter Consolidation

Facilities served by multiple meters typically have higher electricity costs than facilities served by a single meter. The cost savings from consolidating meters typically come from: eliminating service charges for multiple meters, pushing more energy use and/or demand into blocks with lower unit costs, and from non-coincident demand.

Purchasing Transformer

Utilities generally have different rates depending on whether the utility or the customer owns and maintains the transformer. When the customer owns and maintains the transformer, it is called "primary service". When the utility owns and maintains the transformer, it is called "secondary service". Many rate structures offer lower electricity rates for primary service, since the customer must purchase and maintain the transformer. In many cases, it is advantageous for a customer to purchase the transformer when the average monthly demand exceeds about 1,000 kVA.

Power Factor Correction

Devices which generate large amounts of reactive power in relation to actual power consumed have low power factors. Such devices include under-loaded motors and devices which convert AC power to DC power such as DC drives, welding machines and induction furnaces. Many utilities have explicit or implicit charges for low power factor. In addition, low power factor increases the line current, and hence losses, in transformers and the electrical distribution system. Correcting power factor by right-sizing oversized motors or adding capacitors to the electrical systems can reduce or eliminate these costs.

Demand Saving Potential

In manufacturing facilities, demand costs typically make up about 50% of the total electricity costs. Thus, reductions in peak demand can significantly reduce electricity costs even when total electricity use remains the same. Three general methods of reducing peak demand are:

- Rescheduling operation of electrical equipment in order to reduce peak demand. Sometimes this can be done by moving operations from first shift, when the peak demand typically occurs, to second or third shift.
- Using control equipment that ensures that equipment does not run simultaneously.
- Using control systems to strategically shed loads to keep the peak demand within a specified range.

Lighting

Recommended Lighting

The Illuminating Engineering Society of North America (IESNA) publishes recommended lighting levels for various tasks and spaces. IESNA recommended lighting levels for some common spaces are shown in the following table (IESNA Handbook, 9th Edition).

In general, recommended lighting levels increase as the size and contrast of the visual task decrease. Thus, the recommended lighting level will be near the lower level of the ranges shown in the table below when the visual task is large in size and/or high contrast. Conversely, the recommended lighting level will be near the upper level of the ranges when the visual task is small in size and/or low contrast. For example, we generally recommend 15 fc for warehouses with large bulk items and 25 fc for warehouses with hand-stocked items. Similarly, we recommend 30 fc for general manufacturing and up to 50 fc for manufacturing tasks requiring visual precision.

Light Quality

Our eyes evolved to see in natural sunlight. Thus, we distinguish colors best in sunlight. Light from electric lamps is generated at lower temperatures than sunlight and reduces our ability to distinguish between colors. Color Rendering Index (CRI) describes the effect of a light source on the color appearance of an object. CRI varies between 0 and 100. Approximate CRIs of various types of lighting are shown in the following table.

Some tasks, such as inspection and painting, clearly require high-quality light. In addition, most people prefer to work and live in light that is as close to sunlight as possible; thus, the CRI of a light source should always be a consideration when selecting lights. For example, many people report seeing better under fluorescent lights with a CRI of 85 than under high-pressure sodium lights with a CRI of 22, even though the measured illuminance level under the high-pressure sodium lights is higher. Thus, using a light source with a higher CRI but lower light output (lumens) is generally better and more energy-efficient.

Glare

Glare is uncomfortably high illuminance. Glare can be problematic with large windows with direct sunlight and with direct high-intensity artificial lighting, especially with a dark background. For this reason, windows are often equipped with some type of shading, luminaries are often designed to diffuse light and ceilings are painted a light color.

Turn off Blocked Lights and Lights in Unoccupied Areas

Blocked fixtures do not provide useful light to the work area, therefore disconnecting them would decrease energy consumption without changing lighting levels.

Use Motion Sensors to Turn off Lights in Seldom Used Areas Such as Warehouses

Motion sensors turn lights on when a space is occupied and turn lights off several minutes after the space is unoccupied. Most occupancy sensors use infrared sensors to detect body heat in motion. They could be used to turn off lights in unoccupied time to reduce energy consumption.

Turn off Unnecessary Lights near Windows or Skylights

Windows or skylights can provide natural light to the facility. Lights around them would be providing unnecessary light during daytime and can be turned off to reduce electricity consumption and achieve cost savings.

Use Photo Sensors to Turn on/off Outdoor Lights
Photo sensors measure light levels and control lights based on the difference between the measured light level and a set point. In outdoor applications, photo sensors turn lights off during the day and on during night.

Determine Required Light Level and Disconnect Lights in Over Lit Areas
There are recommended lighting levels for different facilities areas. For areas over lit, unnecessary lights can be disconnected to reduce electricity consumption.

Replace Colored Glass and Fiberglass with Corrugated Polycarbonate, and Turn off Unnecessary Lights
Corrugated polycarbonate costs same as fiberglass and has higher transmissivity with good impact strength and long-term weather durability. Natural light can be utilized with corrugated polycarbonate and electric lights around the window area can be turned off.

Add Windows or Skylights, and Turn off Unnecessary Lights
Adding windows or skylights can help utilizing more natural light during daytime, thus reduces lighting energy consumption. Also, natural daylight has good light quality with a high Color Rendering Index.

Clean Dirty Lenses and Replace Yellowed Lenses
Dirty lenses and degraded lenses have low transmissivity and they block part of lighting. These fixtures cannot provide as much illuminance as fixtures with clean lenses so that more lights are required to get certain lighting level.

Add Reflectors to Fluorescent Strip Lights
Reflectors push light downward onto the work plane rather than allowing it to escape upward onto the ceiling. Thus, unnecessary lights can be disconnected while providing about the same lighting levels as current.

Add Task Lighting over Critical Areas and Decrease General Lighting
Some tasks, such as inspection and painting, clearly require high-quality light and high lighting level. Task lighting can be installed for these areas and thus general lighting in facility are unnecessary to provide high lighting level.

Paint Ceilings and Walls Lighter Color
Light color ceilings and walls have high reflectivity, which makes coefficient of utilization larger, thus less lighting is required in the facility.

Replace Incandescent and Halogen Lights with Compact Fluorescent Lights
The lighting efficiency of incandescent and Halogen lights is generally low since most of the energy is released as infrared radiation rather than visible light. Compact fluorescent lights, comparing to incandescent lights, use about 30% as much energy and last about seven times longer.

Replace Fluorescent Lights with LED Equivalents

Compared to T12, T8, and even T5 fluorescent lights, LED lights are energy efficient with lower wattage and lower ballast/driver factor when providing similar lighting level. Also, LEDs have good lumen maintenance over life and their Color Rendering Index is better than T12 and sometimes even T8. Many old fluorescent fixtures can be utilized via a retrofit to successfully house LED equivalents.

Replace HID Lights with HBF Lights

HID lights including metal halides and high pressure sodium lights are less energy efficient than high bay fluorescent fixtures, and their Color Rendering Index are not as good. Also, high bay fluorescent don't have a restrike time, which means they can be turned on and off instantly, while HID lamps take about 3 minutes to start-up when cold and about 25 minutes when warm.

Motors

Reduce Run-Time and Peak Electrical Demand

Turn off motors whenever possible. Run motors during off-peak periods to reduce peak electrical demand.

Improve the Efficiency of Motor Drive Trains

Use cogged V-belts instead of regular V-belts. Cogged V-belts last longer and improve system efficiency by 2% to 4% over regular V-belts. As a result, they save energy while reducing maintenance and replacement costs. For large motors with high duty factors, consider using synchronous belt drives. Synchronous belt drives have efficiencies of over 98%, last four times as long as V-belts, and do not require re-tensioning.

Right-size Oversized Motors

Motor efficiency and power factor degrades quickly when motors are less than 25% loaded. Because of this efficiency penalty, it may be cost effective to replace a severely oversized/under-loaded motor with a properly-sized motor.

Replace Failed Motors with Energy-Efficient Motors

It is generally cost-effective to replace failed 100-hp and smaller motors with energy efficient motors. Rewind motors generally lose about 1% of their original efficiency. Purchasing energy-efficient motors instead of rewinding old motors generally pays back in about 3 years depending on motor size and hours of operation.

Fluid Flow

Decrease Elevation Head

The total pressure difference through the piping system includes elevation pressure difference. In some applications, it may be possible to reduce the elevation pressure difference by increasing the height of the fluid in the supply tank or reducing the height of the fluid in the outlet tank. Doing so reduces the total system pressure difference and pump energy use.

In Intermittent Operations, Run Pump/Fan Slower and Longer

In some pumping applications, pumps may operate at a relative high flow rate for part of the time and then be turned off until needed again. Because friction losses are proportional to the square of flow, it is more energy-efficient to pump a lower volume flow rate for a longer period of time.

Increase Pipe/Duct Diameter

Friction head loss in internal flow is strongly related to the diameter of the pipe/duct. Small pipes/ducts dramatically increase the velocity of the fluid and friction pressure loss. The friction pressure loss through pipes/ducts is inversely proportional to the fifth power of the diameter, which means that doubling the pipe/duct diameter reduces friction pressure loss by about 97%.

Use Smoother Pipe/Duct

Use of the smoothest pipe/duct possible for a given application reduces pipe friction losses. The progression from smoothest to roughest pipe is: plastic, copper, steel, concrete.

Use Low Head-Loss Fittings

The use of low-pressure drop fittings can significantly reduce friction head loss. The use of fully-open gate valves instead of globe valves reduces the friction head loss through the valve by 98%. Similarly, the use of swing type check valves instead of butterfly valves reduces the friction head loss through the valve by 33%.

Reduce Pipe/Duct Length and Turns

Reducing pipe/duct length and turns can reduce friction pressure loss and hence reduce required pump/fan head.

Reduce Entrance/Exit Head Loss

Reducing entrance/exit head loss can reduce total pressure loss, thus the system would call for less pump/fan head to provide required pressure.

For Fixed Flow, Control Flow by Trimming Pump Impellor or Slowing Fan

If the required flow is constant and less than the design flow, cost effective alternatives are to trim a pump impellor or slow a fan.

For Variable Flow, Control Flow with VFD

The most energy efficient method of varying flow is by controlling pump/fan speed. If the required flow varies over time, speed control is best facilitated by an electronic variable frequency drive (VFD) which can continuously and smoothly adjust pump/fan speed as needed.

In VFD Applications, Reduce Static Pressure Requirement during Off-Peak

Total pressure difference consists of static pressure difference, velocity pressure difference, elevation pressure difference and friction pressure difference. Total pressure difference is proportional to the energy required to move an incompressible fluid through pipes or ducts. Reducing static pressure requirement can reduce energy consumed by the system.

Use High Efficiency Pumps/Fans, Drives, Motors

Energy converting systems like pumps/fans, drives and motors all have an efficiency of converting energy into required power. Pumps/fans, drives and motors with high efficiency have less energy loss when working than old standard systems.

Compressed Air

Reduce Compressed Air Demand

Discontinue uses of compressed air that could be accomplished by more energy efficient means. Utilize sensors to control solenoid valves to match compressed air consumption to process demand. Reduce compressed air flow by using Venturi nozzles when compressed air is required in blow-off applications.

Fix Leaks

Most compressed air systems lose about 20% of compressed air to leaks. Using an ultrasonic leak detector is the most reliable method of locating leaks in a compressed air system. A bi-weekly preventative maintenance program to identify and fix compressed air leaks ensures minimal compressed air lost to leaks.

Reduce Excess Pressure Loss in Distribution System and Lower Compressed Air Pressure Setting to Lowest Possible Level

Few compressed air tools require above 90 psig, and the pressure drop through the compressed air distribution system should be 10 psig or less. Compressing air to the lowest possible pressure reduces compressed air lost to leaks, air compressor energy use and energy cost.

Install Sufficient Compressed Air Storage

Adding primary receiver capacity to store compressed air dampens pressure swings when using load/unload compressors, and enables load/unload compressors with auto-shutoff to shut off more frequently. Adding secondary receiver capacity upstream of processes requiring large intermittent air demands stabilizes air pressure for other pneumatic equipment upstream of the secondary receiver. The secondary receiver will provide air to the intermittent process, while the needle valve will cause the receiver tank to recharge slowly between the intermittent loads.

Use Refrigerated Dryers Instead of Desiccant Dryers When Possible

Refrigerated and desiccant air dryers reduce the dew point temperatures of compressed air to about 35 F and -35 F respectively. In most cases, compressed air at a dew point temperature of 35 F is sufficiently dry. Unheated desiccant dryers use about 15% of the total compressed air for blow down, which is about 4 times more energy than refrigerated dryers. Thus, use refrigerated dryers instead of desiccant dryers whenever possible.

Use Efficient Compressed Air Output Control

The compressed air output of air compressors is controlled to meet the demand using five primary types of control methods, as shown below. These methods are described below in order of least energy efficient to most energy efficient. Use the most energy-efficient type of control possible for the trim compressor.

Blow Off

Centrifugal compressors sometimes use blow off control to blow off compressed air to ambient when demand for compressed air decreases. This is the least energy efficient method of control, since compressor power stays constant as compressed air demand falls.

Modulation

In modulation mode, the compressor's inlet butterfly valve modulates between fully open and fully closed to meet facility compressed air demand. When the inlet air valve is fully open the compressor's power draw is 100% of full load power; when the inlet air valve is fully closed the compressor's power draw is about 70% of full load power. This mode of operation is generally inefficient at part load compared to load/unload control mode.

Load/Unload

In load/unload mode, the compressor "loads" and begins to add compressed air to the system when the system pressure falls to the lower activation pressure. The compressor continues to run and add compressed air to the system until the system pressure reaches the upper activation pressure. It then runs "unloaded" until the system pressure drops to the lower activation pressure. When running unloaded, it is not adding compressed air to the system. Load/unload control is more energy efficient at part load than modulating control. However, most rotary screw compressors still draw 50% to 60% of full load power while running unloaded. Thus, it is important to run compressors in load/unload mode with auto shutoff capabilities enabled, so that the compressor shuts off after running unloaded for 10 minutes.

Variable Speed

The most efficient way to control a rotary screw air compressor at part load is with a variable frequency drive (VFD). A VFD slows down or speeds up the motor in order to meet facility air demand. A VFD compressor draws about 10% of its full load power when it is not producing compressed air. Thus a VFD can achieve the constant pressure output of modulation mode with maximum energy savings at low loads.

On/Off

Reciprocating compressors turn off when not compressing air. This is the most energy efficient method of control.

Capacity and Power

The fraction compressed air capacity (FC) is related to the fraction of full load power (FP) draw by the following equation, where FP_0 is the fraction power at zero capacity:

$$FP = FP_0 + (1 - FP_0) \times FC$$

Stage Compressors Using Pressure Settings or Automatic Sequencer

When multiple air compressors are required to meet facility demand, the compressors should be staged so that base load compressors run fully loaded, and trim compressors operate only when needed. Staging can be accomplished by setting the activation pressures of the trim compressor(s) a few psi below the activation pressures of the base load compressor, or by installing a controller.

Compress Outdoor Air

It takes less energy to compress cold air than hot air. The average year round air temperature in Ohio is about 50 F, which is significantly cooler than typical facility indoor air temperature. Thus, compressing outdoor air instead of indoor air reduces air compressor energy use and cost.

Install Ducts to Vent Hot Air into the Facility during Winter Months

In air-cooled compressors, installing ducts to vent hot air into the facility during winter months will offset heating costs by making use of useful heat that is otherwise wasted. The ductwork should be installed so that the hot air can easily be directed into the facility in the winter and outside in the summer. A simple schematic is shown in the figure below.

Steam

Reduce Steam Demand

Steam demand can be reduced by proper control and by reducing losses from process equipment by adding insulation. In open tanks, the total heat loss is the sum of heat loss through convection, radiation and evaporation. These losses can be significantly reduced by adding a cover or floats to the tank.

Fix Steam Traps

Steam traps are automatic valves that discharge condensate from a steam line without discharging steam. If the trap fails open, steam escapes into the condensate return pipe without being utilized in the process. If it fails closed, condensate fills the heat exchanger and chokes-off heat to process. Fixing failed steam traps is usually highly cost-effective.

Insulate Pipes and Tanks

Uninsulated steam pipes, condensate return pipes, condensate return tanks, and deaerator tanks lose heat to the surrounding by convection and radiation. Insulating uninsulated surfaces reduces steam use and reduces the risk of burns.

Preheat Boiler Feed-water Using Exhaust Air

An economizer is a heat exchanger that preheats feed-water to the boiler using heat from the exhaust gasses. Economizers are most cost effective in process boilers that operate all year.

Reduce Steam Pressure to Minimum Required By Process

Generating steam at unnecessarily high pressures decreases boiler efficiency, increases heat loss from steam pipes and increases flash loss. Reducing boiler pressure to match the highest required process temperature decreases these losses. Moreover, reducing steam pressure to match the local required process temperature reduces flash loss. Thus, always produce and supply steam at the minimum pressure required to meet the process temperature requirement.

Install Automatic Blow-Down Controls

Blow down is the practice of expelling steam to reduce contaminant build ups. Blow down can occur from the surface and/or bottom of the boiler. Typical blowdown rates range from 4% to 8% of boiler feed-water. Blowdown may be manual or automatic. Manual blowdown relies on intuition or periodic testing to determine when the concentration of contaminants is high enough to warrant blowdown. Manual blow down virtually always results in excess blow down that wastes energy or insufficient blow down that creates excess scale on heat transfer surfaces and reduces efficiency. Automatic blow down controls monitor the conductivity of the water in the boiler and open the blowdown valve as needed to maintain the conductivity within a specified range. Optimizing the quantity of blow down using automatic controls reduces energy, water and water treatment costs.

Run Boiler in Modulation Mode

Most boilers are designed for peak load, but operate at part load most of the time. Modulating burners typically have a minimum firing rate of 25% to 33% of maximum output. If steam demand is less than the minimum firing rate, the boiler cycles on and off. Each time a boiler cycles on and off, it purges natural gas from inside the boiler by blowing the combustion air fan. Installing a burner with a smaller minimum firing rate can eliminate the on/off cycling and reduce fuel use.

Adjust Fuel/Air Ratio

Most boilers use linkages that connect natural gas supply valves with combustion air inlet dampers. Unfortunately, the linkages do not function perfectly, and the air/fuel ratio is seldom held constant over the firing range. The linkages should be regularly adjusted to maintain no more than 10% excess air at some point in the firing range.

Install O_2 Trim

Most boilers use linkages that connect natural gas supply valves with combustion air inlet dampers. Unfortunately, the linkages do not function perfectly, and the air/fuel ratio is seldom held constant over the firing range. O_2 trim combustion controls regulate combustion intake air to maintain 10% excess air across the entire firing range. O_2 trim combustion controls are most cost-effective for boilers that operate all year long.

HVAC

Decrease Unnecessary Ventilation and Balance Facility Airflow

Ventilation rates in industrial facilities are frequently 6 to 8 air changes per hour compared to an average infiltration rate of less than 1 air change per hour for residences. At high ventilation rates, most of the space heating or cooling energy added/removed from the space is simply to heat or cool the ventilation air. Thus, reducing unnecessary ventilation yields large heating and cooling savings.

Insulate Uninsulated Walls and Roofs

Heating loads are directly related to the thermal resistance of the envelope of the building. Installing insulation to un-insulated walls and windows reduces heating loads and heating energy consumption.

Reset Temperature Set-point During Unoccupied Hours

Lowering interior set-point temperatures during unoccupied periods during the heating season lowers heating loads. Similarly, increasing interior set-point temperatures during unoccupied periods during the cooling season lowers cooling loads. Small reductions in set-point temperature can significantly reduce heating and cooling energy use, because the heating and cooling loads are proportional to difference between indoor and outdoor air temperature.

Heat with Makeup Air Units Only During Occupied Hours

The energy required to heat outdoor air to a reasonable discharge temperature is much greater than the energy required to heat inside air to a reasonable discharge temperature. Thus, use internal air rotation, unit-heaters or fan-coil units for heating rather than makeup air units whenever possible.

Deliver Heat Effectively

Heating systems should deliver heat where it is needed. Heat added near the ceiling can easily be swept out without delivering any warmth to the occupants. For this reason, gas-fired IR heaters, which warm the floor and equipment, are often cost effective. In general, we assume that the effective efficiency of IR heaters is 25% better than space heaters. Alternately, large volume fans mounted at the ceiling can be used to force the warm air down and mix with the cooler air, reducing the stack effect. Reducing the stack effect also reduces infiltration into the building through the envelope, increasing occupant comfort and decreasing heating energy use.

Utilize Airside Economizers to Cool Facility

Economizers vary the amount of outside air supplied to the conditioned space in order to reduce cooling energy consumption and costs. Economizers are highly effective on air conditioners that provide cooling all year round, since during fall, spring and winter the air is generally cool enough that no additional cooling is needed.

Convert Constant-Air-Volume to Variable-Air-Volume Systems

Constant-Air-Volume Reheat (CAV-RH) systems first cool supply air to about 55 F to remove excess humidity, then heat the air to the temperature required to keep the conditioned space at the set-point temperature. CAV-RH systems achieve the necessary humidity control, but do so at the expense of excess energy consumption since the air is first cooled then reheated. Variable-Air-Volume (VAV) systems achieve the required humidity control without reheating the air. VAV systems cool air to 55 F to remove excess humidity; however the volume of air supplied to the zone is varied to meet the set-point of the conditioned space. Thus, VAV control eliminates reheat, reduces cooling and fan energy consumption.

Reclaim Heat from Air Compressors and Processes to Heat Facility

The heat which is being rejected outdoors by processes could be redirected to heat the facility during the heating season.

Renewable Energy

Benefits and Incentives

Renewable energy systems generate electricity or thermal energy without the use of fossil fuels and therefore do not emit CO_2 or other pollutants. Significant financial incentives are now available that make installing renewable energy systems especially attractive to business owners. These incentives come from the State of Ohio, the U.S. Government and Ohio utilities.

Wind Power Systems

Wind turbines convert the kinetic energy of the wind into electricity, which is consumed by the facility or fed into the electrical power grid. The electricity generated on site offsets a portion of the electricity consumed by the facility, lowering electricity costs. Furthermore, if the net amount produced by the wind turbine is greater than the amount consumed by the facility, electricity is fed into the electrical power grid and sold to the utility. To ensure proper maintenance and operation, wind turbines require professional service. Additionally, the large size and height of wind turbines may present zoning and permitting challenges.

Photovoltaic Systems

Photovoltaic (PV) solar collectors convert sunlight directly to electricity with no moving parts, long life-times and little-to-no maintenance. The electricity generated on site offsets a portion of the electricity consumed by the facility, lowering electricity costs. Furthermore, if the net amount produced by the PV system is greater than the amount consumed by the facility, electricity is fed into the electrical power grid and sold to the utility. PV systems generally require very little maintenance and are very reliable. PV collectors can be mounted on a roof or on grade and require a large area to produce significant amounts of electricity. Mounting location and orientation to the sun is important to maximize the PV output. Minimizing shading is also an important concern, because even only partial shading of a panel severely lowers the power output.

Solar Thermal Systems

Solar thermal (ST) systems absorb solar radiation to heat a circulating fluid, commonly water. ST systems consist of solar collectors, a pump to circulate a heat absorbing fluid, a water storage tank with heat exchangers and a system controller. ST technologies can be used for water heating, space heating, space cooling and process heat generation. ST systems are generally roof mounted, but may be mounted on grade if there is not sufficient roof area. Unlike PV systems ST systems are not affected as strongly by partial shading, however proper orientation is still important.

Appendix III - Equipment Overview

D2 Headquarters

The District 2 HQ Garage, like other HQ garages, is used primarily for major maintenance and repairs. Though vehicles and equipment aren't typically stored in theses garages, they do see consistent usage from equipment needing maintenance.

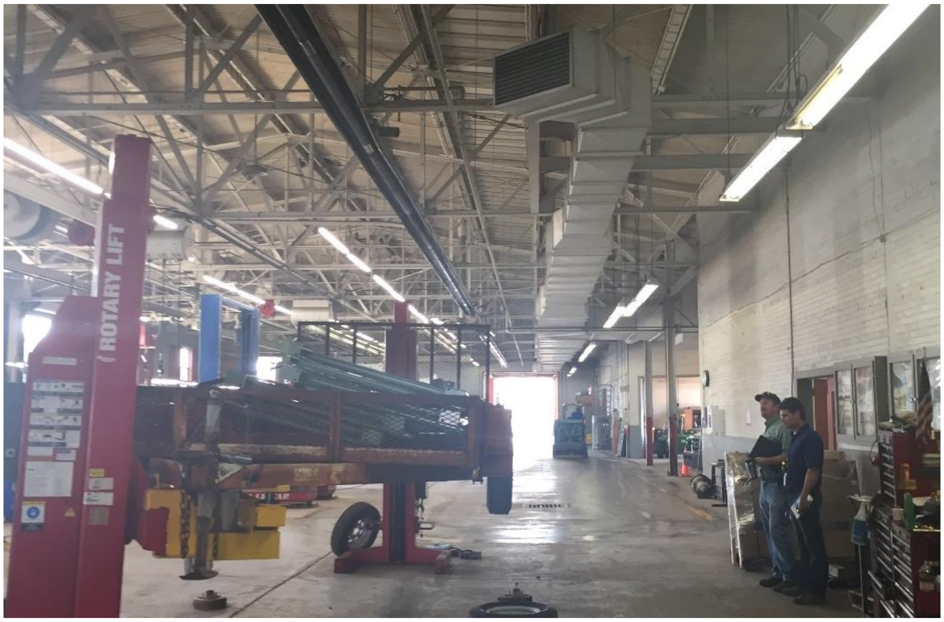


Figure 2 – HQ Garage Maintenance Bay

HVAC

Heating is supplied to the maintenance areas using hanging radiant tube heaters (CoRayVac) and a few hanging fan coils near the entrances. There is no cooling in this area. Domestic hot water is all point of use with small individual heaters in each area.

The remaining office and storage areas are served by a combination of residential style split systems and hot water baseboard heat served by a 1200 MBH Bryan hot water boiler from 187. The Bryan boiler and one of the condensing units are well past their expected life and in need of replacement. The condensing unit is still operating on R-22 refrigerant which is currently being phased out of use in the united states and will become more and more expensive in coming years.

The west side of the HQ Office building is served by four Weil-McClain condensing hot water boilers with unit ventilators in the offices served by an outdoor condensing unit. The east wing is served by two packaged rooftop units supplying VAV boxes in each space with both heating and cooling.

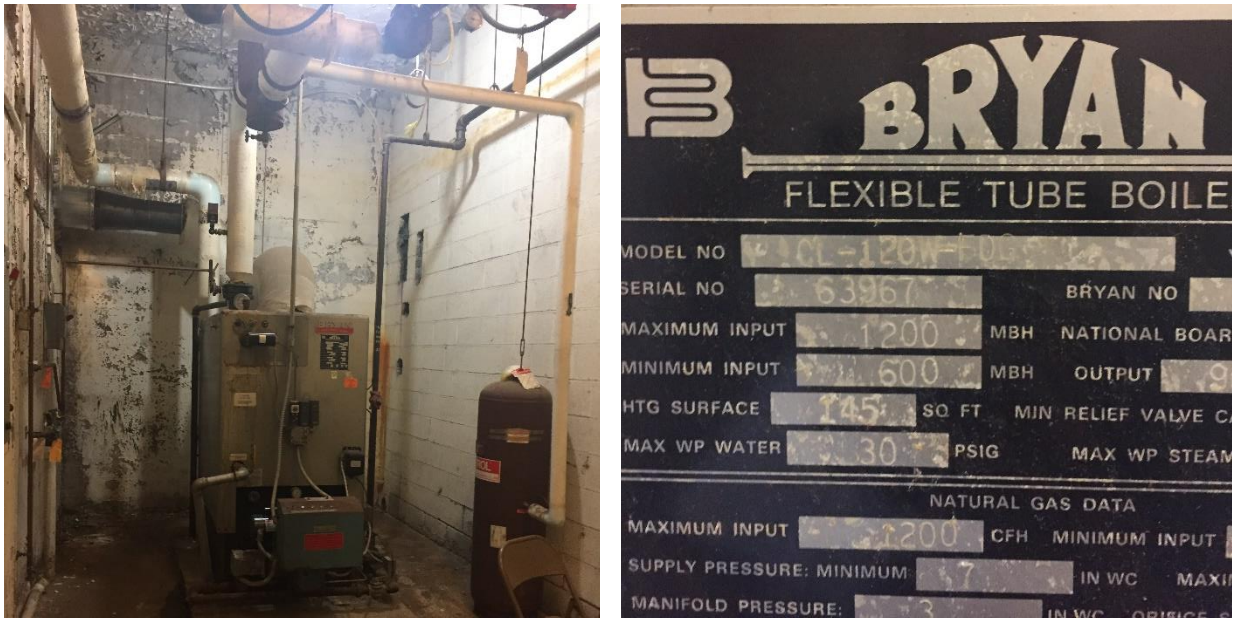


Figure 3 – 1987 Bryan Hot Water Boiler in Garage

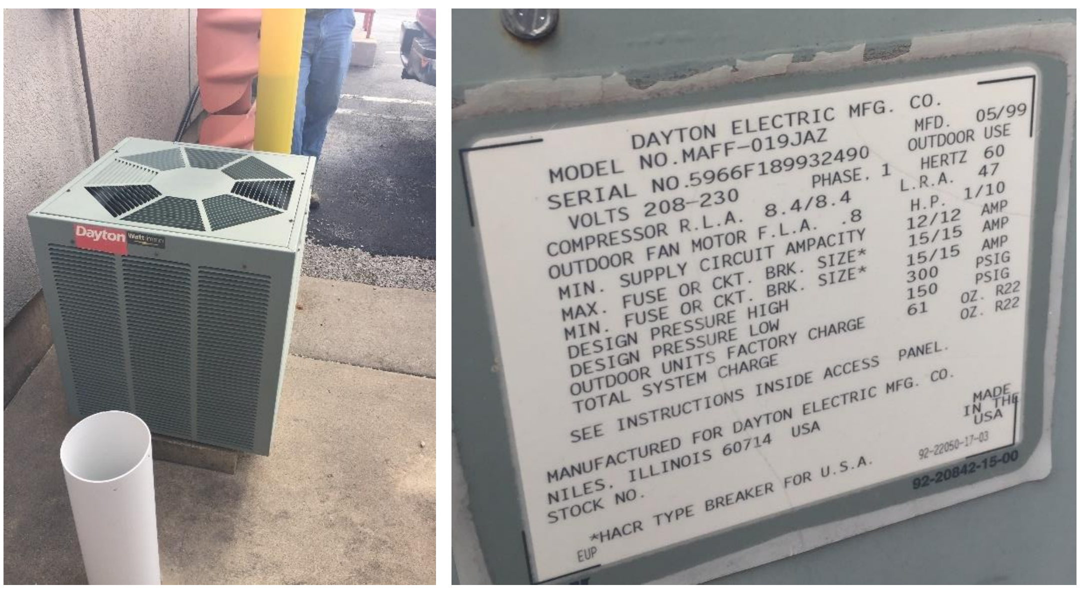


Figure 4 – 1999 Dayton Condensing Unit for Garage Offices

Figure 5 – HQ Office Building Boilers and Condensing Unit

Lighting

Lighting is made up mostly of linear fluorescent fixtures. Though some of the garage offices have been upgraded to LED, most areas in the main office building and maintenance garage are a combination of T12 and T8 tubes.

Seneca Full Service Garage

Like the other full-service garages throughout the state, Seneca is used primarily as a storage facility and launch point for ODOT field staff. Though some minor maintenance is performed in this building, most equipment is sent to HQ for repairs. This garage houses 12 salt trucks and is heavily used during extreme weather in the winter months.

Figure 6 – Seneca Garage Storage Area

Figure 7 – Seneca Garage Maintenance Area

HVAC

Heating is supplied to the maintenance areas using hanging radiant tube heaters (CoRayVac) and some recently added Hercules fans to help destratify the air in the high bay areas. There is no cooling in this area. The offices are served by split systems that are original to the building (1997). Like the HQ garage, the condensing units still run on R-22 refrigerant and should be replaced.

Figure 8 – Seneca Garage 1997 Trane Condensing Unit for Office Split Systems

Domestic hot water is served by a 75-gallon residential-style tank heater, shown below.

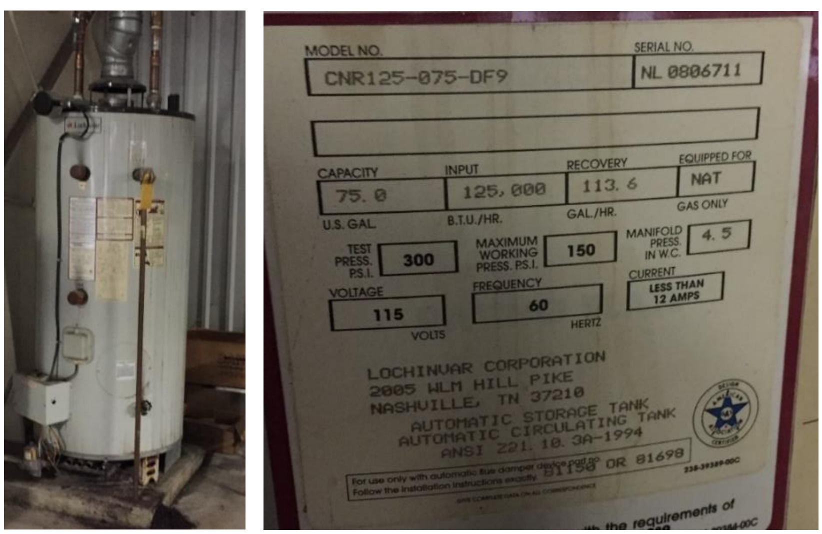


Figure 9 – Seneca Garage DHW Tank Heater

Lighting

Lighting throughout the garage was recently updated to all LED. The lighting is clean and consistent throughout the space.

Williams Full Service Garage

This garage is a perfect mirror to the Seneca Garage, also serving a fleet of 12 trucks. They are the exact same layout and size, simply flipped end for end. The garages were even designed and built by the same teams around 1997. The biggest difference in the two is that Williams has not been converted to LED (still using HID fixtures), and does not have the Hercules fans like Seneca. Because of the similarities between the two, they make for a perfect comparison case to see the benefits of any technology upgrades.

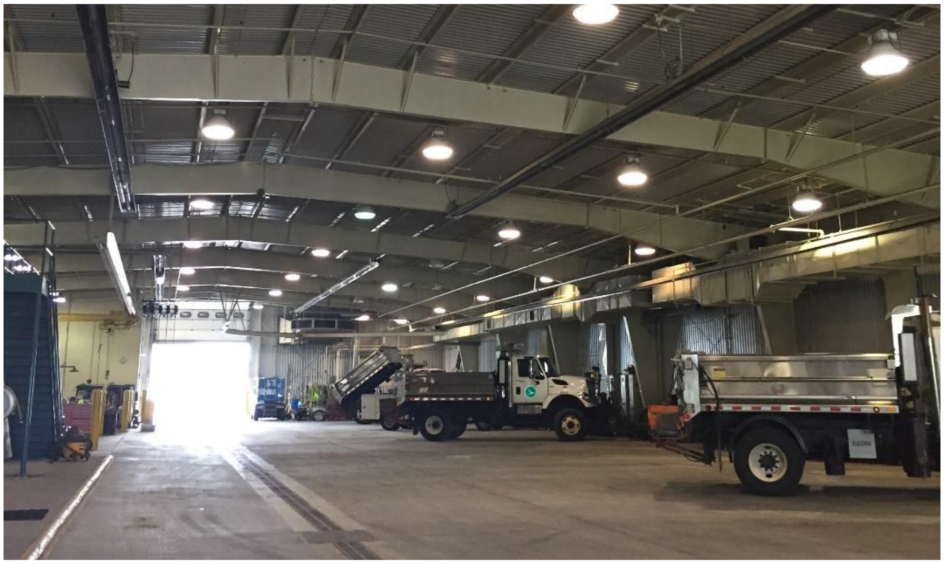


Figure 10 – Williams Garage Storage Area

Figure 11 – Williams Garage Maintenance Area

Ottawa Full Service Garage

Though the Ottawa Garage does not match the layout of the previous two, its main function is very much the same. Primarily a storage facility for 14 trucks, again some minor repair work is done in this building.

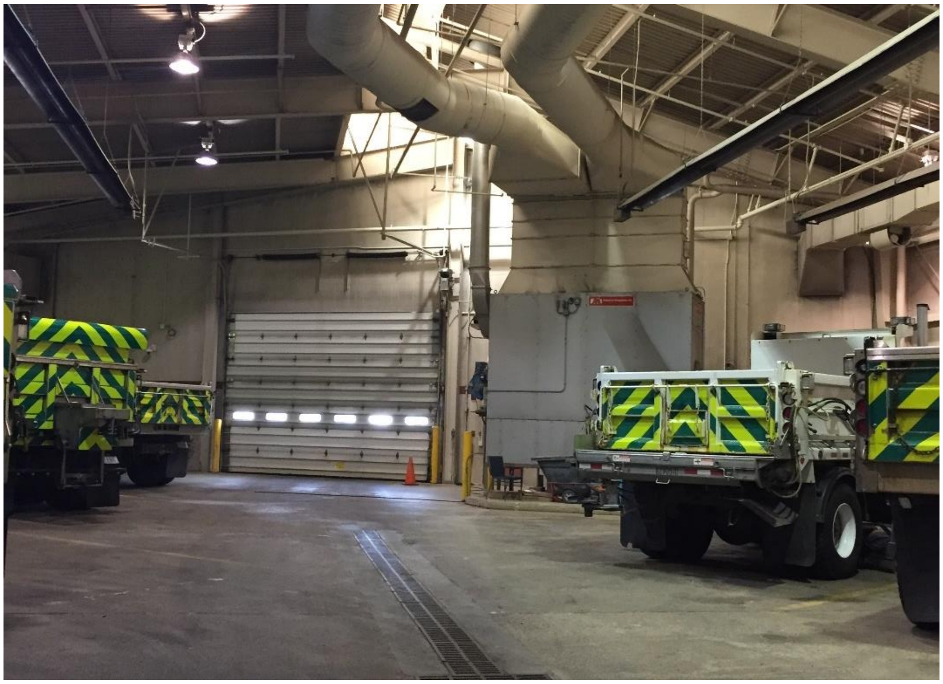


Figure 12 – Ottawa Garage Storage Area

HVAC

Heating is once again supplied to the maintenance areas using hanging radiant tube heaters (CoRayVac). There is no cooling in this area. The offices are served by a multi-duct air handler which is fed by a 400 MBH hot water boiler and Trane condensing unit, both original to the building in 1991. Like the other garages, the condensing units still run on R-22 refrigerant and should be replaced.

Figure 13 – Ottawa Garage Multi-duct AHU

One thing unique about this garage from the others that were investigated is that it has a recently update building automation system from JCI. From discussion with staff, the team is very pleased with the ease of use and functionality of the new system.

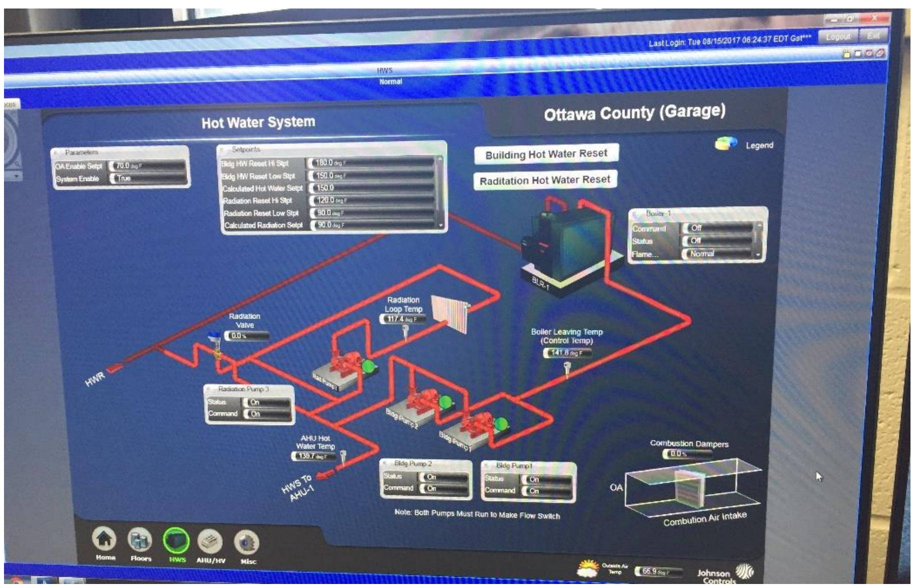


Figure 14 – Ottawa Garage BAS from Johnson Controls

Domestic hot water is again served by a residential-style tank heater.

Lighting

Lighting throughout the garage is mainly HID, with linear fluorescents in the office areas.

Appendix IV - Sample Facilities Baseline

To begin baselining the facilities, we first take a high level look at the historical consumption on an annual basis. This is shown in the table below, along with heating and cooling degree days for the same period to give us a feel of what the weather was like during these times. After looking at this high level, we then dive deeper into interval data using monthly, weekly, or even finer resolution data to get a better understanding of the trends.

ODOT District 2

Annual Utility Summary

Benchmark — **June 2016 - May 2017**

	Facility Name	Facility Size (ft2)	ELECTRIC kWh	kW	Cost	$/kWh	kBtu/ft^2	FUEL MMBtu	Cost	$/MMBtu	kBtu/ft^2	Total Annual Cost	Total kBtu/ft2	Total $/ft2
1	D2 HQ	77,875	209,517	-	$ 26,343	$ 0.126	9.2	1,370	$ 9,698	$ 7.08	17.6	$ 36,042	26.8	$ 0.46
2	Seneca Full Service Facility	36,325	88,160	-	$ 10,654	$ 0.121	8.3	823	$ 6,163	$ 7.48	22.7	$ 16,816	31.0	$ 0.46
3	Williams Full Service Facility	36,325	157,200	-	$ 17,516	$ 0.111	14.8	872	$ 6,192	$ 7.10	24.0	$ 23,708	38.8	$ 0.65
4	Ottawa Full Service Facility	35,200	209,517	-	$ 26,343	$ 0.126	20.3	1,267	$ 8,834	$ 6.97	36.0	$ 35,177	56.3	$ 1.00
Portfolio Totals		**185,725**	**664,394**	**-**	**$ 80,856**	**$ 0.122**	**12.2**	**4,332**	**$ 30,888**	**$ 7.13**	**23.3**	**$ 111,743**	**35.5**	**$ 0.60**

Previous Year — **June 2015 - May 2016**

	Facility Name	Facility Size (ft2)	ELECTRIC kWh	kW	Cost	$/kWh	kBtu/ft^2	FUEL MMBtu	Cost	$/MMBtu	kBtu/ft^2	Total Annual Cost	Total kBtu/ft2	Total $/ft2
1	D2 HQ	77,875	161,454	-	$ 20,388	$ 0.126	7.1	1,269	$ 6,712	$ 5.29	16.3	$ 27,100	23.4	$ 0.35
2	Seneca Full Service Facility	36,325	146,960	-	$ 15,999	$ 0.109	13.8	692	$ 4,061	$ 5.87	19.1	$ 20,060	32.9	$ 0.55
3	Williams Full Service Facility	36,325	173,760	-	$ 17,451	$ 0.100	16.3	799	$ 5,375	$ 6.72	22.0	$ 22,826	38.3	$ 0.63
4	Ottawa Full Service Facility	35,200	161,454	-	$ 20,388	$ 0.126	15.7	1,171	$ 6,078	$ 5.19	33.3	$ 26,466	48.9	$ 0.75
Portfolio Totals		**185,725**	**643,628**	**-**	**$ 74,226**	**$ 0.115**	**11.8**	**3,932**	**$ 22,226**	**$ 5.65**	**21.2**	**$ 96,452**	**33.0**	**$ 0.52**

Degree Days

		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Heating	Benchmark	48	16	10	87	328	604	1,153	1,046	761	880	372	272	**5,577**
	Previous Year	61	37	46	93	382	596	746	1,188	967	679	574	250	**5,619**
	5 Year Average	55	31	39	143	400	739	988	1,247	1,143	848	521	196	**6,350**
Cooling	Benchmark	221	310	295	147	42	9	0	0	2	3	32	62	**1,123**
	Previous Year	153	212	188	155	20	7	0	0	0	3	16	95	**849**
	5 Year Average	201	272	221	119	24	3	0	0	0	8	13	119	**980**

Figure 15 – Annual Utility Summary – Ottawa, Seneca, Williams

Interval Consumption Summaries

Overview of Baseline Data

During the course of this research project historical utility bill data was combined with the data from a real-time metering platform that was installed on several facilities. This system monitors performance and is useful in benchmarking energy consumption. Although the system has yet to experience a winter heating season, and thus offer the opportunity to analyze fuel trends, significant patterns can already be seen in the electrical consumption of these facilities.

The following figure shows several weeks of data for three of the ODOT facilities. The Seneca and Williams facilities are most notable as these buildings are almost identical in construction. LED lights and large fans are notable improvements in the Seneca facility. The figure below shows that Seneca is by far the lowest user of electricity, with Williams significantly higher and Ottawa even higher than that.

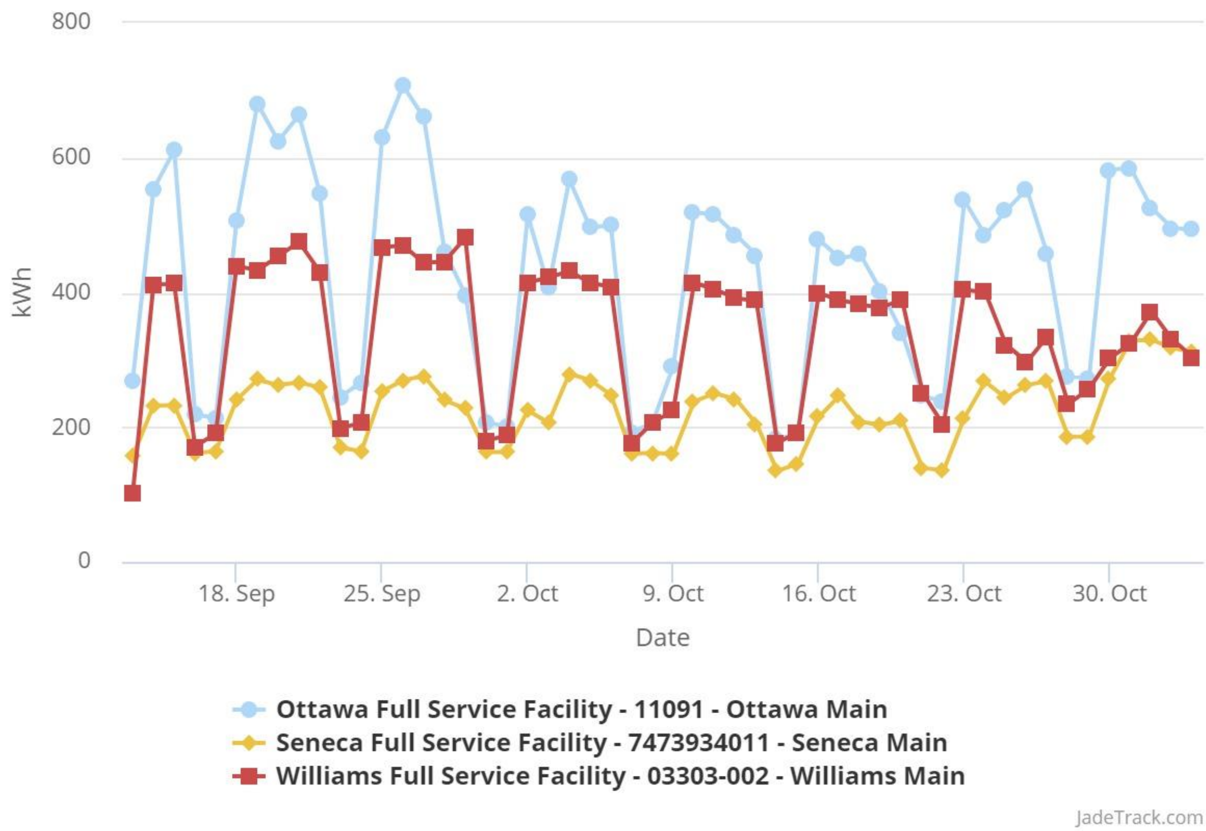


Figure 16 – Real Time Metering Electric Data – Ottawa, Seneca, Williams

This difference in total consumption is also easily viewed on a weekly basis in the JadeTrack metering software as shown in the figure below.

Figure 17 – Weekly Electrical Consumption Using the JadeTrack System

Looking back in the system log, we can see an obvious change at Seneca from February to March of 2016. We estimate this is likely when a significant facility upgrade was made and indicates the level of change one could expect by making similar changes in the other garages.

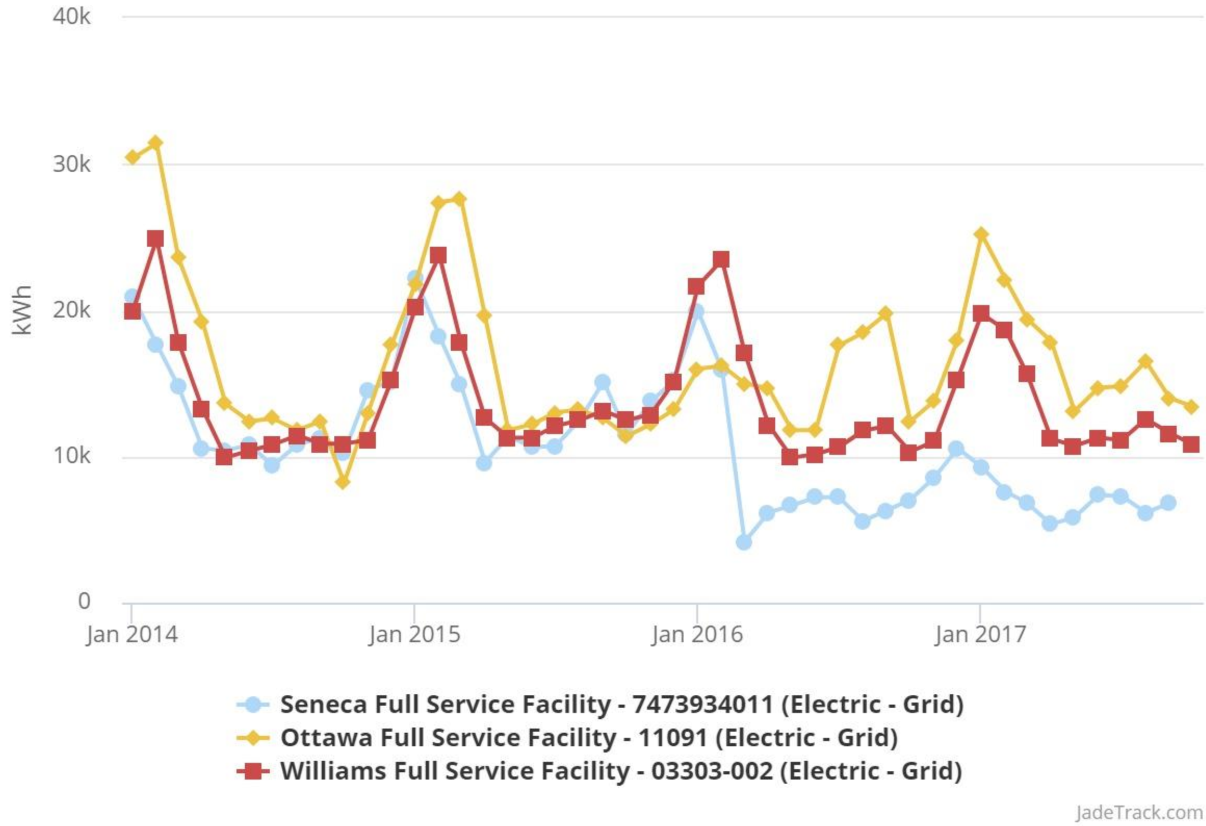


Figure 18 – Monthly Electric Billed kWh 2014-2017

The figure below shows the fuel consumption for a similar time period.

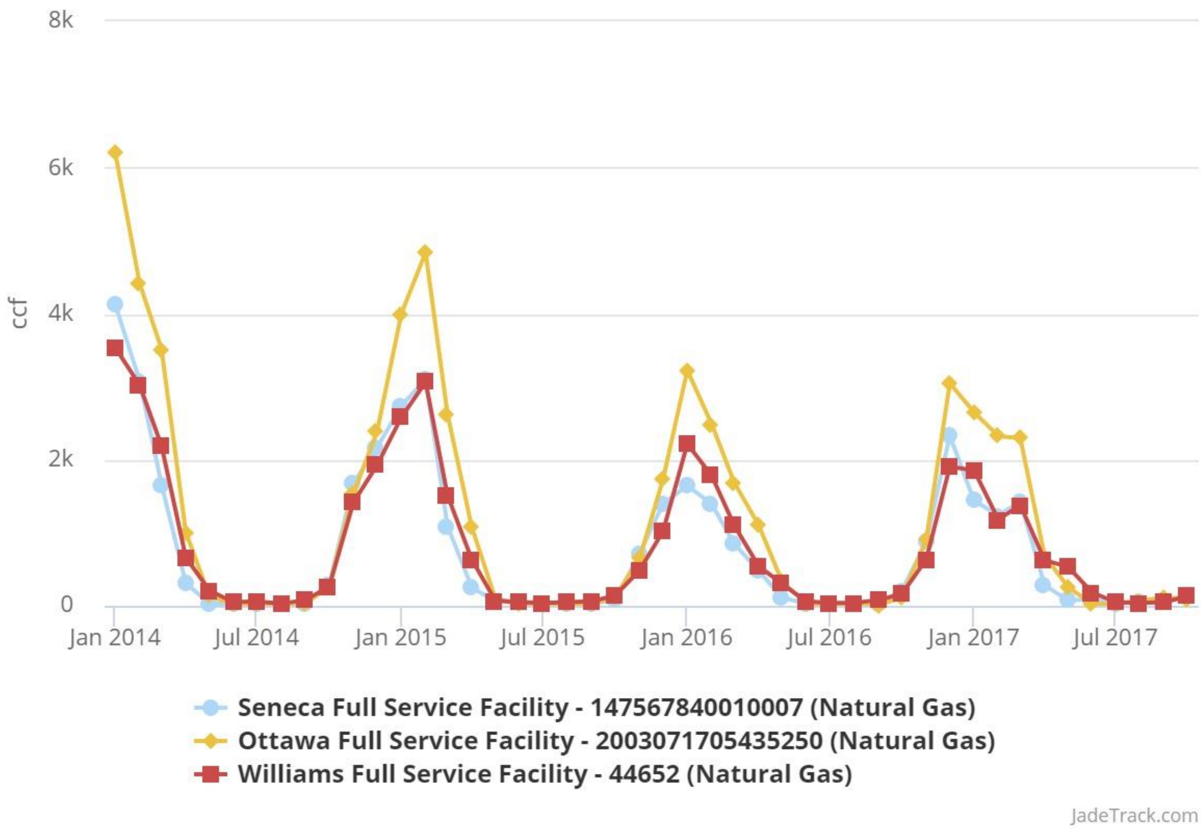


Figure 19 – Monthly Fuel Billed CCF 2014-2017

Using the JadeTrack Platform

One of the most powerful abilities that real time metering grants a facility manager is the ability to take a pulse on a facility at any given time to build an understanding of how that building operates. Below are listed several examples of how the JadeTrack metering system can be used to:

- Get a feel for the "normal" behavior of each building
- Understand where energy is being consumed and where efforts should be targeted
- Discover data pattern changes and anomalies that could indicate a problem or warrant further examination

Seneca Garage

Electric demand moving into heating season -- Seneca is relatively predictable from September to the present. However, in the last week we see that break down. This is an opportunity for investigation.

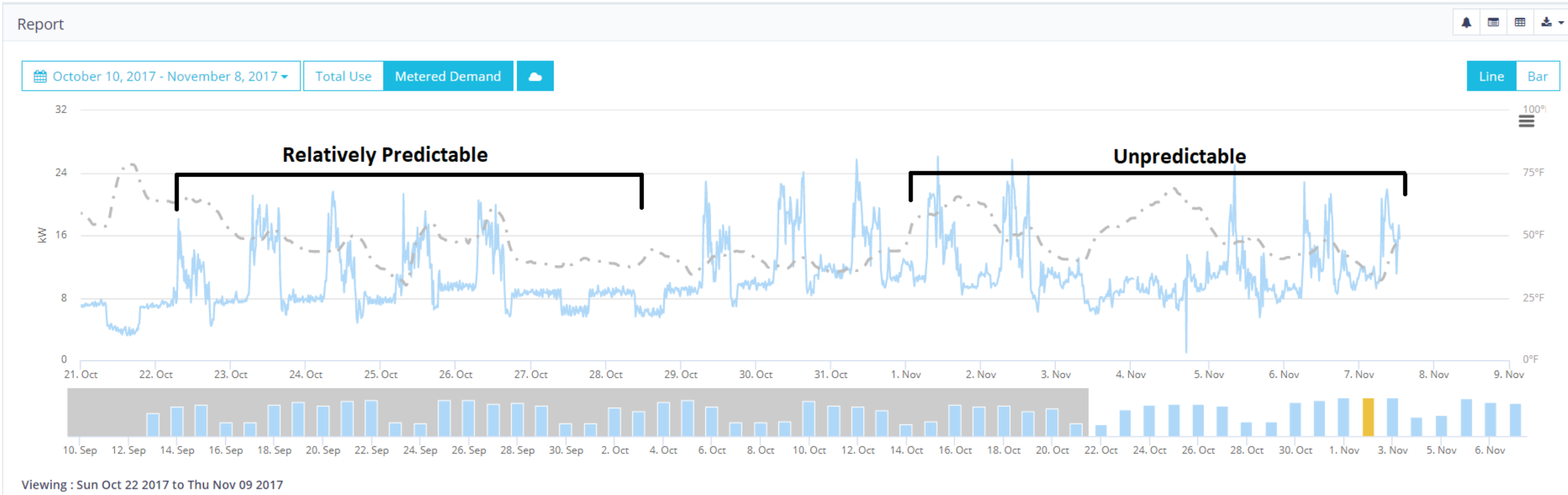


Figure 20 – Daily Electrical Data – Seneca Garage

Williams Garage

Overall a very predictable pattern. By analyzing when the pattern changes we can see that outdoor lighting is a significant portion of load. This same trend is seen at the Seneca and Ottawa garages.

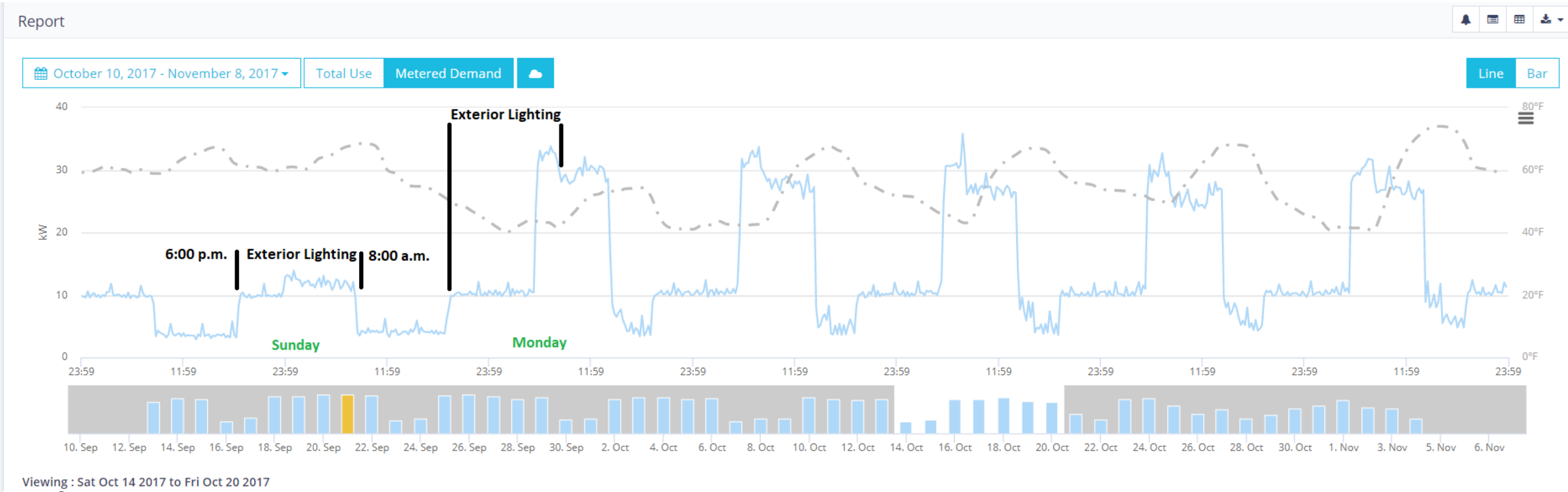


Figure 21 – Daily Electrical Data – Williams Garage

Ottawa Garage

By observing how the "normal behavior" changes from week to week, it can be observed that something changed at Ottawa Garage as the outdoor air temperature falls. Our estimate is that electric heating started to kick in during the colder periods.

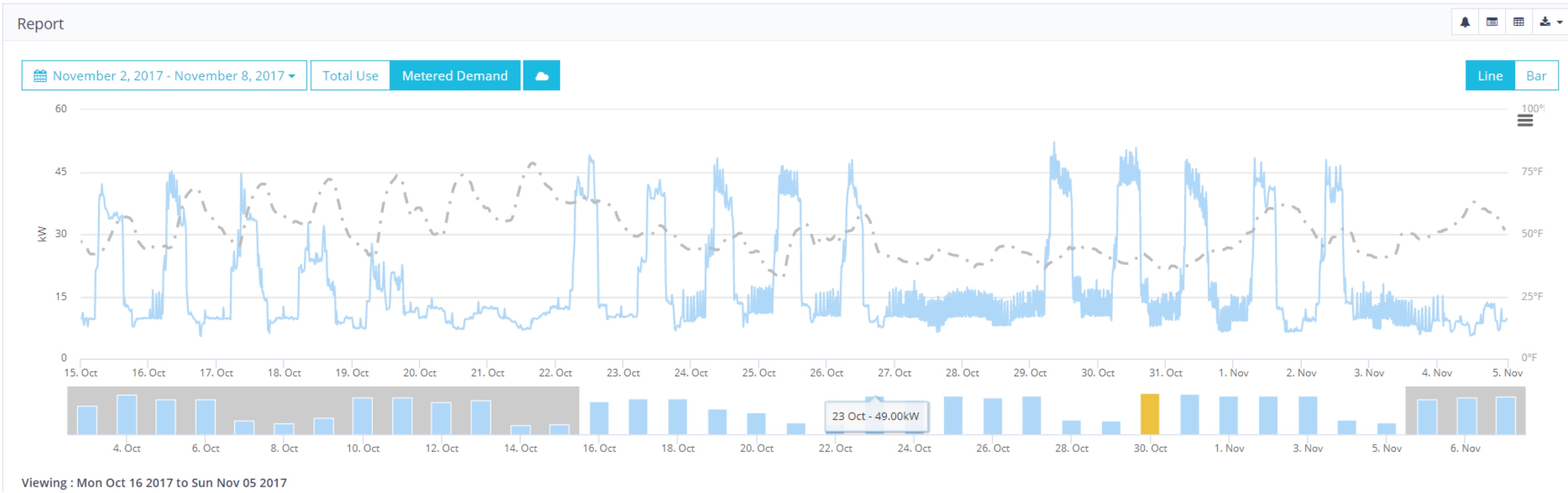


Figure 22 – Daily Electrical Data – Ottawa Garage

Appendix V - Energy Data Analytics to Compare Energy Efficiency of ODOT Facilities

Goals

The goal of this research was to determine the annual weather normalized energy intensity and disaggregate normalized energy intensity (heating, cooling, base load) for all of the DOT maintenance facilities included in the study (NW Ohio). This information can be used to help prioritize future energy reduction actions in this facilities or help to identify the priority facilities for replacement.

Data Used

The data used in this analysis included:

- Energy consumption data for all fuel types for minimally the past year. This data was accessed through the EPA Portfolio Manager database for the ODOT facilities included in this study.
- Actual weather data (hourly) for the weather station closest to each ODOT NW Ohio facility over the entire historical meter data period obtainable through the National Climatic Data Center (Climate Data Online).
- Building area for each building.

The table below documents the maintenance facilities were included in this analysis.

Table 12 – ODOT Maintenance Facilities Included In the Weather Normalized Energy Intensity Analysis

Building Name	**sq. ft.**
Edison Bridge Outpost Garage	3,763
Fulton Full Service Facility	15,778
Henry Full Service Facility	15,200
Lucas Full Service Facility Old	13,111
Northwood Full Service Facility	21,820
Ottawa Full Service Facility	35,200
Sandusky Full Service Facility	17,897
Seneca Full Service Facility	36,525
Williams Full Service Facility	36,325
Wood Full Service Facility	18,400

Annual Weather Normalized Disaggregated Energy Intensity Methodology

Overview

Here, we describe the methodology utilized to determine the weather normalized energy intensity for all energy categories and for each fuel type. The energy categories include for electrical consumption: base load (appliances, lighting, etc…, anything that is not weather dependent); cooling load (anything that depends upon summer weather conditions); and heating (anything that is dependent upon winter weather conditions). For gas consumption, the energy categories include only base load consumption (generally associated with water heating or any natural gas consuming machinery such as generators) and heating (any gas consumption dependent upon winter weather conditions).

It should be noted that weather dependent energy consumption certainly includes heating and cooling use, but it can also include effects from increased or decreased seasonal energy use. For example, DOT maintenance facilities clearly can have a greater duty cycle during winter months if there is substantial snow fall.

Methodology

The methodology employed is documented in detail elsewhere[15,16]. It effectively employs inverse modeling. Inverse energy modeling for buildings refers to use of actual data for consumption of energy to draw conclusions about the physical properties of the building envelope and equipment. Fundamentally the modeling assumes that the heat loss/gain from a building is linearly dependent upon the difference in temperature between the inside and outside of a building. Thus, heating and cooling energy depends linearly on outdoor temperature, as shown in the figure below, when respectively the outdoor temperature falls below or rises above what is referred to as the heating and cooling balance point temperatures. In creating the inverse energy models, it is assumed that the building envelope does not change seasonally and that energy use can be normalized by floor area of the building. The latter assumption works best for heating and central cooling, the focus of this study, where the interior temperature is maintained fairly constantly throughout each of the facilities analyzed. Note: that this situation may be far from optimal from an energy consumption perspective.

[15] KP Hallinan et al., 2011, *Establishing Building Recommissioning Priorities and Potential Energy Savings from Utility Energy Data*. ASHRAE Transactions 01/2011; 117(2):495; presented at ASHRAE Summer Conference, Montreal, Canada.

[16] KP Hallinan, H Enns, S Ritchey, P Brodrick, N Lammers, N Hanus, M Rembert, & T Rainsberger, 2012, *Energy Information Augmented Community-Based Energy Reduction*. Sustainability, 12/2012; 4(7):1371-1396.

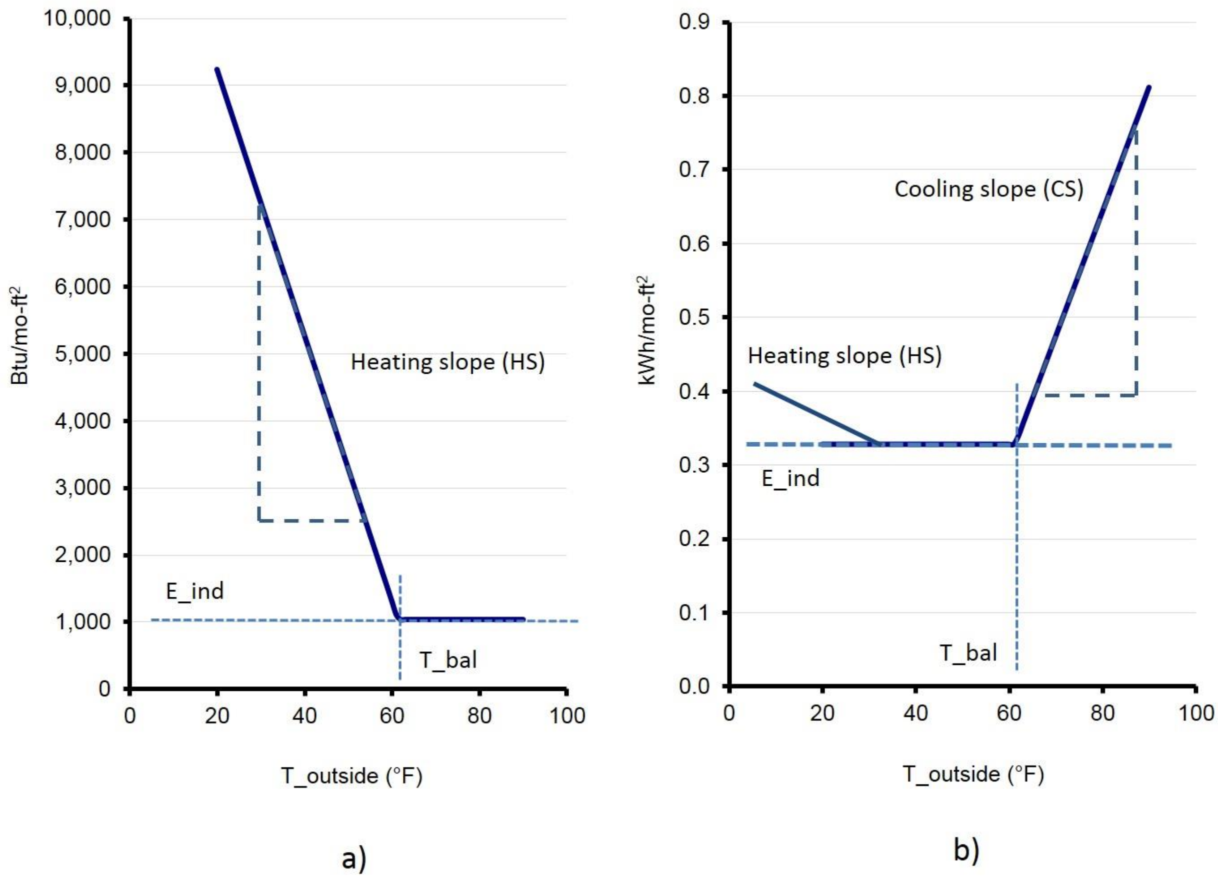


Figure 23 – Weather dependence of energy consumption

To properly benchmark energy use and ultimately establish an approximate energy model for each house, the monthly energy data for each fuel type (if applicable) must be disaggregated into weather-dependent and weather-independent components. To this end, five-parameter and three-parameter regressions of monthly energy versus monthly average temperature during each billing period are employed for electric and gas data, respectively. A swarming genetic algorithm optimization approach was used to do the regressions. Output parameters from the regressions are shown below in the table below. The regression optimization aimed to minimize the R-squared error between predicted actual monthly energy data, subject to an inequality constraint requiring that the annual predicted energy (from the regression) be within 1% of the actual reported energy for each facility.

Table 13 – Regression Fit Parameters

Regression Parameter	Description
CS_e	Cooling slope (kWh/month/^{p}C), electric
HS_e, HS_{ng}	Heating slope (kWh/month/^{p}C), electric and gas
$T_{balc,e}$	Cooling balance point temperature, e.g., outside temperature above which there is cooling
$T_{balh,e}$, $T_{balh,ng}$	Heating balance point temperature, e.g., outside temperature below which there is heating
E_{ind}	Temperature independent energy use (kWh/month)

With regression parameters developed, the annual heating (electric and natural gas) and cooling are estimated. These are weather-normalized so that cooling and heating energy can be compared from year-to-year as the weather changes. A Normalized Annual Consumption (NAC) approach is employed to calculate cooling- and heating-degree hours (CDH and HDH, respectively) from the estimated balance temperatures and typical weather year (TMY3) temperature data, as shown below.

$$CDH_e \text{ [deg.F-hr]} = \sum_{i}^{8760} \left(T_i - T_{balc,e}\right)$$

$$HDH_{e,ng} \text{ [deg.F-hr]} = \sum_{i}^{8760} \left(T_{balh,e,ng} - T_i\right)$$

where the summation is over every hour in the year and T_i is the typical hourly temperature for a specific hour, i , in the year.

The normalized annual electrical cooling intensity (NECI), for the facilities where there is significant cooling energy consumption, is calculated from

$$\text{NECI [kWh/sf/year]} = CS_e \times CDH_e \qquad (1)$$

Similarly, the normalized annual electric heating intensity (NEHI) is given by

$$\text{NEHI [kWh/sf/year]} = HS_e \times HDH_e \qquad (2)$$

Finally, for facilities with natural gas consumption, the normalized heating (NGHI) and baseline energy use can likewise be determined from the estimated HS_{NG}, $E_{ind,NG}$, and $T_{balh,NG}$.

$$\text{NGHI (BTU/sf/year)} = HS_{ng} \times HDH_{ng} \qquad (3)$$

Results

The table below shows the model results for each of the facilities. Included in the results are the Baseline, CS, HS, and balance temperatures for both fuel types for each building. These model parameters are especially useful downstream in measuring savings given new consumption data.

Table 14 – Model results from regression analysis

	Natural Gas				Electric						
FACILITY	Base (ccf/mo)	HS (ccf /mo/degF)	Tbalh (degF)	HDH (hr-degF)	Base (kWh/mo)	CS (kWh/ mo/degF)	Tbalc (degF)	HS (kWh /mo/degF)	Tbalh (degF)	HDH (hr-degF)	CDH (hr-degF)
Edison Bridge Outpost Garage	99	99	99	99	14,580	128	50.0	519	51.9	71,550	12,557
Fulton Full Service Facility	75	153	55.6	104,577	4,834	19	51.4	116	64.9	65,593	1,685
Henry Full Service Facility	99	99	99	99	14,580	128	50.0	519	51.9	71,550	12,557
Lucas Full Service Facility Old	204	110	52.9	91,637	14,580	128	50.0	519	51.9	71,550	12,557
Northwood Full Service Facility	98	145	51.5	85,241		14,580	128.1	50	519.4	52	71,550
Ottawa Full Service Facility	71	113	54.8	100,904	9,355	295	51.4	327	62.5	65,593	26,481
Sandusky Full Service Facility	112	57	57.5	114,841	7,785	20	50.0	231	58.2	71,550	1,994
Seneca Full Service Facility	112	57	57.5	114,841		7,785	20.3	50	230.8	58	71,550
Williams Full Service Facility	155	77	52.6	90,221	10,234	62	50.0	323	55.4	71,550	6,109
Wood Full Service Facility	98	145	51.5	85,241	14,580	128	50.0	519	51.9	71,550	12,557

The table below documents the weather normalized energy consumption intensity for the various energy categories for the study facilities. The buildings with the highest energy intensity in each energy category are conditionally formatted with a red background; those with the lowest energy intensity are likewise conditionally formatted with a green background; and those in the middle are conditionally formatted with a yellow background.

Table 15 – Annual weather normalized energy consumption intensity for gas

		Natural Gas		Electric		
Building Name	**sq. ft.**	Heat Int (kBTU/sf)	Base Int (kBTU/sf)	Cool Int (kBTU/sf)	Heat Int (kBTU/sf)	Base Int (kBTU/sf)
Edison Bridge Outpost Garage	3,763	NA	NA	3.34	16.43	46.50
Fulton Full Service Facility	15,778	138.82	5.67	0.11	1.59	3.68
Henry Full Service Facility	15,200	NA	NA	0.83	4.07	11.51
Lucas Full Service Facility	21,820	63.56	11.21	0.58	2.83	8.02
Northwood Full Service Facility	21,820	77.56	5.42	0.58	2.83	8.02
Ottawa Full Service Facility	35,200	44.33	2.42	0.75	1.82	3.19
Sandusky Full Service Facility	17,897	72.74	9.59	1.48	3.58	6.27
Seneca Full Service Facility	36,525	24.45	3.66	0.05	1.02	2.56
Williams Full Service Facility	36,325	26.11	5.12	0.17	1.26	3.38
Wood Full Service Facility	18,400	85.63	10.84	1.44	3.48	6.10

Poor performance in a specific energy category can help to inform priority action for each building. The table below documents the recommendations for detailed assessment for each building. The Seneca facility is the best of the facilities in all energy categories. It should be viewed as a model for renovation of all of the other facilities.

Table 16 – Priority Actions for Each of the Facilities Included In the Study

Building Name	Priority Actions
Edison Bridge Outpost Garage	The electric energy consumption intensity in all energy categories is very high relative to all other buildings. The base load electric energy intensity is particularly high. It is critical that this facility be analyzed to determine the causes of particularly the high base load and the very high winter season bump in energy consumption intensity.
Fulton Full Service Facility	The heating energy intensity is SUBSTANTIALLY higher than all of the other facilities. When this is the case, the common issue is excessive outdoor air intake. This facility should be examined to investigate the cause of the high heating energy intensity.
Henry Full Service Facility	This facility has a relatively high base load electrical and winter season energy intensity. Again, the causes for these should be investigated.
Lucas Full Service Facility	This facility has an inordinately high heating energy intensity (gas) and base load intensity (gas). No other facility has as high of a base load energy intensity. Both of these situations should be investigated. Likely is a high make-up air condition. The high base load condition either emerges from high hot water loads or even continued operation of heating equipment during the summer season. The electrical base load intensity and the winter season electrical energy intensity bump are relatively high too. These should be investigated.
Northwood Full Service Facility	There are two concerns with this facility. The heating energy (gas) energy intensity is relatively high. Also, the base load electrical energy intensity is relatively high. These should be investigated.
Ottawa Full Service Facility	None of the energy categories for the Ottawa facility are relatively poor compared to the other facilities. However, comparison to the best facility (Seneca), it is obvious that the heating energy intensity is almost double. Further the electric heating intensity bump and the base load electric intensity are higher than the Seneca facility.
Sandusky Full Service Facility	The gas heating and base load energy intensities are relatively poor compared to the other buildings. These should be looked at. Further the electrical energy intensity in all categories is in the middle, but quite higher than the Seneca facility.

Seneca Full Service Facility	This facility is the best of the facilities in all energy categories. It should be viewed as a model for renovation of all of the other facilities.
Williams Full Service Facility	This facility is the second best of all of the facilities. Yet in comparison to the Seneca facility, there is still room for improvement. The base load gas energy intensity is roughly double that of the Seneca facility. The base electric and winter season bump energy intensity are also higher. Again, the Seneca facility can be seen as a model for improvements in this building.
Wood Full Service Facility	The energy intensity characteristics of this facility are almost identical to the Sandusky facility. The recommendations for the Sandusky facility apply equally here.

Recommendations for Future Work

The reality is that the energy consumption in each of the facilities doesn't just depend upon the conditioned floor area and weather. It depends also upon utilization of the facility. We strongly recommend utilizing other data that reflects utility of the facility. With such data, benchmarks can be established for energy consumption as a function of weather and other factors such as:

- Number of employees on each shift
- Overtime hours
- Hours of operation
- Fleet numbers
- Fleet downtime / uptime

and any other factor that contributes to greater energy consumption.

This assessment should be used to prioritize buildings state-wide for on-site energy assessments and subsequent energy reduction action.

Appendix VI - Existing Building Recommendations

Energy Conservation Measure Overview for Existing Buildings

The following table summarizes the investigated energy conservation measures (ECMs) for the Headquarters, Williams Garage, Ottawa Garage, and Seneca Garage.

The numbers are intended to be used as budgetary guidelines for what a turn-key installation would look like utilizing a contractor or energy service company and might not include the program fees for a general contractor to pursue a financed energy savings project. Every measure should go through a thorough design process before implementation to ensure the correct solution is installed in the correct manner.

Table 17 – Energy Conservation Measure Overview

Energy Conservation Measures Organized by System	Annual Electric Savings	Annual Fuel Savings	Annual Operational Savings	Total Annual Savings	Turn-Key Project Price	Utility Rebate	Tax Incentives (Third Party)	Simple Payback (Years)	R.O.I.
Lighting Retrofits - HQ and Garage Replace existing fixtures with LED, install occupancy sensors in key locations, LED exit signs, vending misers, LED fixtures in high bay areas, and new exterior LED fixtures including parking heads, flood lights, wallpacks, and canopies	14,509		1,451	15,960	112,743	7,212	0	6.6	15.1%
Lighting Retrofits - Williams Garage Replace existing fixtures with LED, install occupancy sensors in key locations, LED exit signs, vending misers, LED fixtures in high bay areas, and new exterior LED fixtures including parking heads, flood lights, wallpacks, and canopies	5,761		576	6,337	52,025	3,511	0	7.7	13.1%
Lighting Retrofits - Ottawa Garage Replace existing fixtures with LED, install occupancy sensors in key locations, LED exit signs, vending misers, LED fixtures in high bay areas, and new exterior LED fixtures including parking heads, flood lights, wallpacks, and canopies	7,096		710	7,806	50,580	3,527	0	6.0	16.6%
Install On-Site Generation Array - HQ 150 kW A great way to reduce costs, control a portion of electric costs for an extended period of time, and reduce carbon footprint	19,194			19,194	375,000		183,202	10.0	10.0%
Install On-Site Generation Array - Williams Garage 70 kW A great way to reduce costs, control a portion of electric costs for an extended period of time, and reduce carbon footprint	8,609			8,609	175,000		85,494	10.4	9.6%
Install On-Site Generation Array - Ottawa Garage 70 kW A great way to reduce costs, control a portion of electric costs for an extended period of time, and reduce carbon footprint	7,938			7,938	175,000		85,494	11.3	8.9%
Install On-Site Generation Array - Seneca Garage 70 kW A great way to reduce costs, control a portion of electric costs for an extended period of time, and reduce carbon footprint	8,957			8,957	175,000		85,494	10.0	10.0%

Energy Conservation Measures Organized by System	**Annual Electric Savings**	**Annual Fuel Savings**	**Annual Operational Savings**	**Total Annual Savings**	**Turn-Key Project Price**	**Utility Rebate**	**Tax Incentives (Third Party)**	**Simple Payback (Years)**	**R.O.I.**
Domestic Hot Water Condensing Boiler - HQ Pay the delta to upgrade domestic hot water boiler to a condensing model at end of current equipment useful life.		49		49	2,300			46.9	2.1%
Domestic Hot Water Condensing Boiler - Williams Garage Pay the delta to upgrade domestic hot water boiler to a condensing model at end of current equipment useful life.		253		253	2,300			9.1	11.0%
Domestic Hot Water Condensing Boiler - Ottawa Garage Pay the delta to upgrade domestic hot water boiler to a condensing model at end of current equipment useful life.		116		116	2,300			19.8	5.0%
Domestic Hot Water Condensing Boiler - Seneca Garage Pay the delta to upgrade domestic hot water boiler to a condensing model at end of current equipment useful life.		183		183	2,300			12.6	8.0%
Replace Condensing Units and Split Systems with R-410A SEER 15 Models - HQ Drastically increase system efficiency and head off high maintenance costs due to phase out of R-22 refrigerant. (1) Approximately 3-ton Condensing Unit/Furnace.	233		633	866	9,500			11.0	9.1%
Replace Condensing Units and Split Systems with R-410A SEER 15 Models - Williams Garage Drastically increase system efficiency and head off high maintenance costs due to phase out of R-22 refrigerant. (1) 2.5 Ton Condensing Unit/Furnace and (1) 4-ton Condensing Unit/Furnace.	156		1,353	1,509	20,300			13.4	7.4%
Replace Condensing Units and Split Systems with R-410A SEER 15 Models - Ottawa Garage Drastically increase system efficiency and head off high maintenance costs due to phase out of R-22 refrigerant. (1) 15-ton Condensing Unit and Multi-Zone Air Handling Unit.	236		4,600	4,836	69,000			14.3	7.0%

Energy Conservation Measures Organized by System	**Annual Electric Savings**	**Annual Fuel Savings**	**Annual Operational Savings**	**Total Annual Savings**	**Turn-Key Project Price**	**Utility Rebate**	**Tax Incentives (Third Party)**	**Simple Payback (Years)**	**R.O.I.**
Replace Condensing Units and Split Systems with R-410A SEER 15 Models - Seneca Garage Drastically increase system efficiency and head off high maintenance costs due to phase out of R-22 refrigerant. (1) 4-ton Condensing Unit/Furnace and (1) 3-ton Condensing Unit/Furnace.	154		1,400	1,554	21,000			13.5	7.4%
Utilize High Efficiency Condensing HVAC Boilers - HQ At end of current equipment useful life, pay the delta to upgrade from a 80% base model to a high-efficiency condensing model and utilize hot water reset based on outdoor air temperature		313		313	5,800			18.5	5.4%
Utilize High Efficiency Condensing HVAC Boilers - Ottawa Garage At end of current equipment useful life, pay the delta to upgrade from a 80% base model to a high-efficiency condensing model and utilize hot water reset based on outdoor air temperature		289		289	5,800			20.1	5.0%
Utilize (2) High Volume, Low Speed Fans - HQ Decrease air stratification with high volume, low speed fans and be able to reduce HVAC thermostat setpoint (typically by 4 degrees)		828		828	13,175			15.9	6.3%
Utilize (2) High Volume, Low Speed Fans - Williams Garage Decrease air stratification with high volume, low speed fans and be able to reduce HVAC thermostat setpoint (typically by 4 degrees)		586		586	13,175			22.5	4.4%
Utilize (2) High Volume, Low Speed Fans - Ottawa Garage Decrease air stratification with high volume, low speed fans and be able to reduce HVAC thermostat setpoint (typically by 4 degrees)		851		851	13,175			15.5	6.5%

Energy Conservation Measures Organized by System	**Annual Electric Savings**	**Annual Fuel Savings**	**Annual Operational Savings**	**Total Annual Savings**	**Turn-Key Project Price**	**Utility Rebate**	**Tax Incentives (Third Party)**	**Simple Payback (Years)**	**R.O.I.**
Utilize Speed-Doors on Most Used Garage Door - HQ By decreasing the amount of time the door is open, the amount of cold air that leaks in will be reduced increasing occupant comfort and saving energy costs.		479		479	26,944			56.3	1.8%
Utilize Speed-Doors on Most Used Garage Door - Williams Garage By decreasing the amount of time the door is open, the amount of cold air that leaks in will be reduced increasing occupant comfort and saving energy costs.		305		305	26,944			88.3	1.1%
Utilize Speed-Doors on Most Used Garage Door - Ottawa Garage By decreasing the amount of time the door is open, the amount of cold air that leaks in will be reduced increasing occupant comfort and saving energy costs.		443		443	26,944			60.8	1.6%
Utilize Speed-Doors on Most Used Garage Door - Seneca Garage By decreasing the amount of time the door is open, the amount of cold air that leaks in will be reduced increasing occupant comfort and saving energy costs.		288		288	26,944			93.6	1.1%
Project Total	**$72,843**	**$4,983**	**$10,723**		**$1,403,251**	**$14,250**	**$439,685**	**15.7**	**6%**
Project Total - Financed Overview	**$72,843**	**$4,983**	**$10,723**		**$1,403,251**	**$0**	**$0**	**15.8**	**6%**
Utility Rebates					-14,250				
NPV Solar Incentives					-439,685				
Project Total - NPV Analysis	**$72,843**	**$4,983**	**$10,723**		**$949,316**	**$0**	**$0**	**10.7**	**9%**

Financing Programs & Efficiency Incentives

PACE Program

Property Assessed Clean Energy (PACE) financing is a relatively new law that allows property owners in many states to borrow money through government loans or bonds to pay for qualifying energy improvements to their properties. The amount borrowed is typically repaid via a special assessment on the property tax bill over a period of up to 30 years. This allows property owners to reduced energy expenses with no money out of pocket.

A number of protections are included in the process to ensure that both the owner and the loan holder are protected.

- First, a *reserve fund* is created by the administering government entity to provide a safety net for the lenders. This allows them to be more comfortable in the process and can help keep the interest rates lower for the end user.
- Next, the project should "make-sense" in terms of *savings-to-investment* ratio. This means that the measures being implemented need to produce significant savings from increased efficiency or renewable sources that pay for themselves within the repayment timeline.
- Finally, because the financing is assessed to the property, a *limitation of liability in foreclosure* exists to protect both the owners and lenders. If the property were foreclosed during repayment of the project, the remaining repayment would not be accelerated and would simply pass to the new owner for the remaining repayment term.

Together, these contingencies and protections make PACE a very solid financing method for all parties involved, especially in the absences of available capital funds to accomplish the necessary enhancements.

Utility Rebates

Several utilities offer a variety of rebates for energy savings upgrades performed in your facility. These rebates allow for a quicker return on investment for your projects to incentivize higher quality/higher efficiency measures when upgrading your facilities.

For your project, the majority of rebates come from lighting enhancements, though funds are available for all of the following items.

- **Lighting Enhancements**
- **HVAC Equipment**
- **Building Automation and Controls**
- **Motors, Drives, & Compressed Air**

When making facility upgrades it is important to be sure to collect all available rebate dollars you have earned. Often programs will offer incentives above and beyond the standard rebate values if you know how to correctly apply. We recommend you contact an energy-focused facility-management company like Entriq Solutions to help guide you through the process.

Tax Incentives

In addition to the rebates available to help reduce project cost, tax incentives are also a major component which makes the project even more attractive. These may include the solar investment tax credit and the EPAct 2005 tax deduction.

The solar investment tax credit is a federal credit for 30% of the total cost of the solar project. This means that your federal income tax burden is reduced dollar-for-dollar based on the size of the project, effectively reducing the system cost to 70% of the original value.

The EPAct 2005 tax deductions are another huge benefit from this project. As long as certain energy reduction levels are met, your total taxable income can be reduced by up to $1.80 per square foot, based on the following categories:

- $0.60/sq. ft. for lighting
- $0.60/sq. ft. for HVAC
- $0.60/sq. ft. for building envelope

Even if you are a non-tax paying entity there is usually a way for you to pass your credits and deductions to a vendor. This allows them to pass the savings on to you in exchange for signing over your tax incentives.

Some tax programs come and go and are reinstated retroactively at the end of each year. As with rebates, the Entriq Solutions team has years of experience in processing these incentives and can provide all required information to claim them on your behalf.

15-Year Financial Analysis

Table 18 – 15 Year Financial Overview of All Explored Measures

ODOT District 2

Financing Overview

Cumulative Net Cash Flow: $7,847

Project Cost: $1,403,251

Interest Rate: 5.50%

Net Present Value: $50,442

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Totals
Electricity Savings (3%)	72,843	75,028	77,279	79,598	81,985	84,445	86,978	89,588	92,275	95,044	97,895	100,832	103,857	106,972	110,182	**$1,354,801**
Fuel Savings (3%)	4,983	5,132	5,286	5,445	5,608	5,777	5,950	6,128	6,312	6,502	6,697	6,898	7,105	7,318	7,537	**$92,678**
Operational Savings (0%)	10,723	10,723	10,723	10,723	10,723	10,723	10,723	10,723	10,723	10,723	10,723	10,723	10,723	10,723	10,723	**$160,849**
Total Annual Savings	**88,549**	**90,884**	**93,289**	**95,766**	**98,317**	**100,945**	**103,652**	**106,439**	**109,311**	**112,269**	**115,315**	**118,453**	**121,685**	**125,013**	**128,442**	**$1,608,328**
Annual Project Payment	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**(136,961)**	**($2,054,415)**
Annual Financed Net Cash Flow	**(48,412)**	**(46,077)**	**(43,672)**	**(41,195)**	**(38,644)**	**(36,016)**	**(33,309)**	**(30,522)**	**(27,650)**	**(24,692)**	**(21,646)**	**(18,508)**	**(15,276)**	**(11,948)**	**(8,519)**	**($446,087)**
Cumulative Cash Flow	*(48,412)*	*(94,489)*	*(138,161)*	*(179,356)*	*(218,000)*	*(254,016)*	*(287,325)*	*(317,847)*	*(345,497)*	*(370,189)*	*(391,836)*	*(410,344)*	*(425,620)*	*(437,568)*	*(446,087)*	
Utility Rebates	14,250															**$14,250**
NPV Solar Incentives	439,685															**$439,685**
Total Annual Savings	**453,935**															**$453,935**
Annual Total Net Cash Flow	**405,523**	**(46,077)**	**(43,672)**	**(41,195)**	**(38,644)**	**(36,016)**	**(33,309)**	**(30,522)**	**(27,650)**	**(24,692)**	**(21,646)**	**(18,508)**	**(15,276)**	**(11,948)**	**(8,519)**	**$7,848**
Cumulative Cash Flow	*405,523*	*359,446*	*315,774*	*274,579*	*235,935*	*199,919*	*166,609*	*136,088*	*108,438*	*83,745*	*62,099*	*43,591*	*28,314*	*16,367*	*7,848*	
Net Present Value	**405,523**	**(45,173)**	**(41,976)**	**(38,819)**	**(35,701)**	**(32,621)**	**(29,578)**	**(26,571)**	**(23,599)**	**(20,662)**	**(17,757)**	**(14,886)**	**(12,045)**	**(9,236)**	**(6,456)**	**$50,442**

This does not constitute an official offer of credit

Before and After Analysis

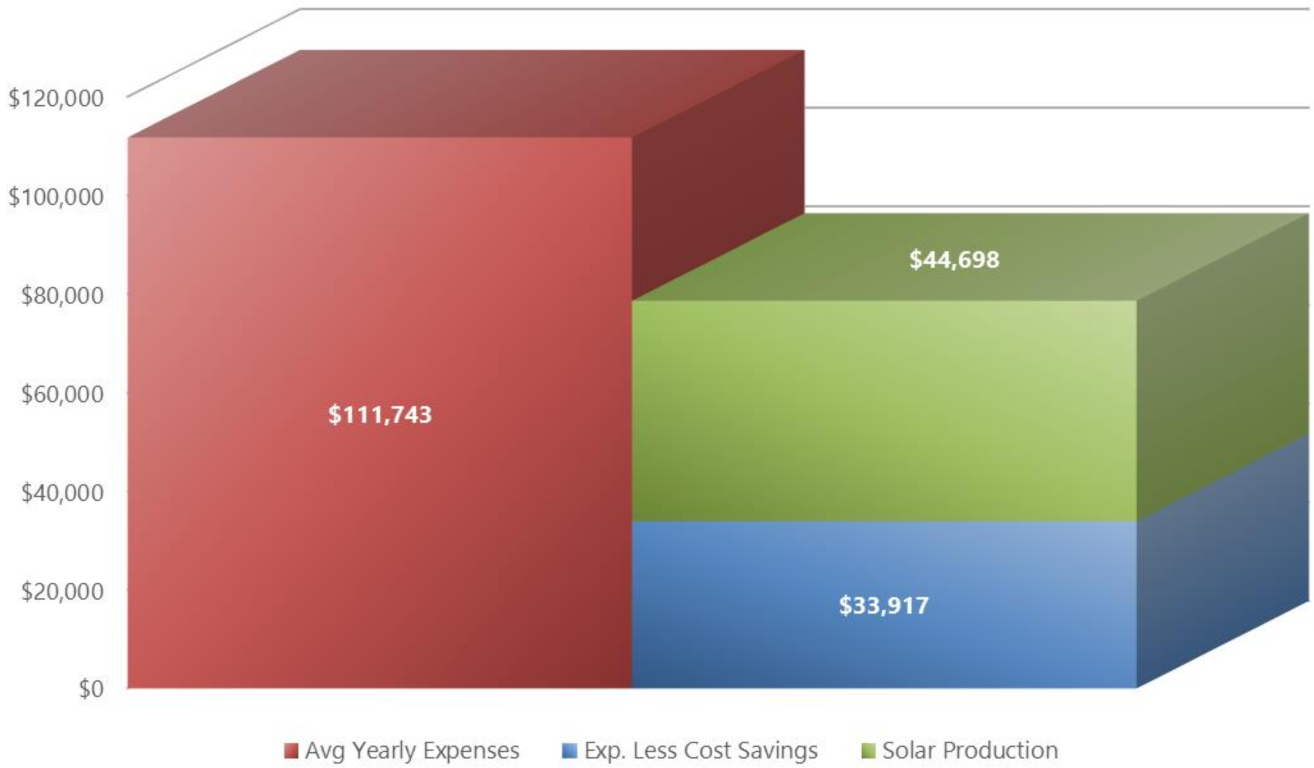


Figure 24 – Before and After Energy Expenditures for HQ, Williams, Ottawa, and Seneca

Employ Real Time Metering to More Effectively Manage Energy Consumption

Facility	Demand Reduction (kW/mo)	Energy Saved (kWh/yr)	Electric Cost Saved ($/yr)	Fuel Saved (MMBtu/yr)	Fuel Cost Saved ($/year)
HQ	0	0	0	0	0
Williams Garage	0	0	0	0	0
Ottawa Garage	0	0	0	0	0
Seneca Garage	0	0	0	0	0

Applicable Facilities:

- HQ Office
- HQ Garage

Measure Overview:

Currently the headquarters facility has one electric meter and one gas that is reported monthly from the local utility.

During heating Much like Williams, Ottawa, and Seneca garages, we propose the facility be upgraded with a real-time electric, and gas metering system to help facilities-operators better control the building and immediately identify problems (e.g. the system can send a text if evening consumption is abnormally high or low). This often leads to major cost savings by comparing usages at a week-by-week, day-by-day, or even hour-by-hour level to ensure consistent/expected operation and identify outlier data to address significant issues before they become a problem.

It is often said that "you can't control what you can't measure". With the capabilities of this system, anything that can be measured can be easily integrated and cleanly displayed through the web-based interface for any user to utilize.

Figure 25 – Real-Time Energy Dashboard

Projected Savings:

Though no direct savings are quantified for this measure, experience has proven that tremendous savings can result over time. These come from identifying issues early, and tracking the performance of various systems as changes and upgrades are made.

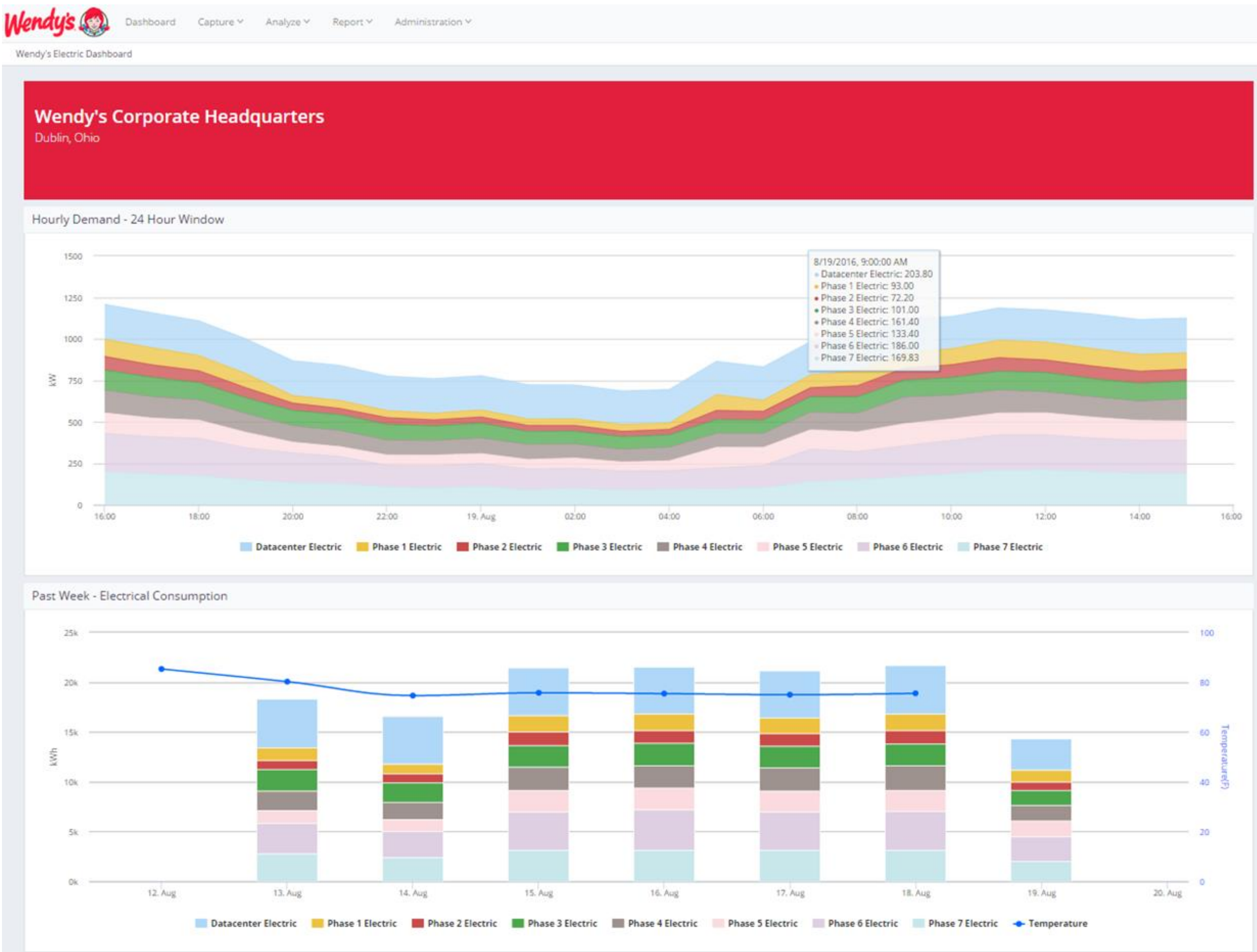


Figure 26 – The Energy Dashboard Gives You the Tools to Easily Understand Your Building

Employ High-Efficiency Lighting Technologies

Facility	Demand Reduction (kW/mo)	Energy Saved (kWh/yr)	Electric Cost Saved ($/yr)	Fuel Saved (MMBtu/yr)	Fuel Cost Saved ($/year)
HQ	0	144,242	14,509	0	0
Williams Garage	0	64,633	5,761	0	0
Ottawa Garage	0	70,547	7,096	0	0
Seneca Garage	0	0	0	0	0

Applicable Facilities:

- HQ Office
- HQ Garage
- Williams Garage
- Ottawa Garage

Measure Overview:

Like many other industries, lighting technology has advanced rapidly over the past few years. LED technologies in all shapes and sizes are now the norm, and choosing the correct fixture for a given application becomes the new challenge. Ensuring that distribution is right, color temperature is accurate, light levels are maintained, and equipment is of good quality are all critical components of and LED project design and implementation.

LEDs use 50% less energy (or better)

Various lighting technologies including Metal Halide High Intensity Discharge (HID) lighting both interior and exterior as well as fluorescent technology throughout each facility.

Figure 27 – LED High-Bay Fixtures

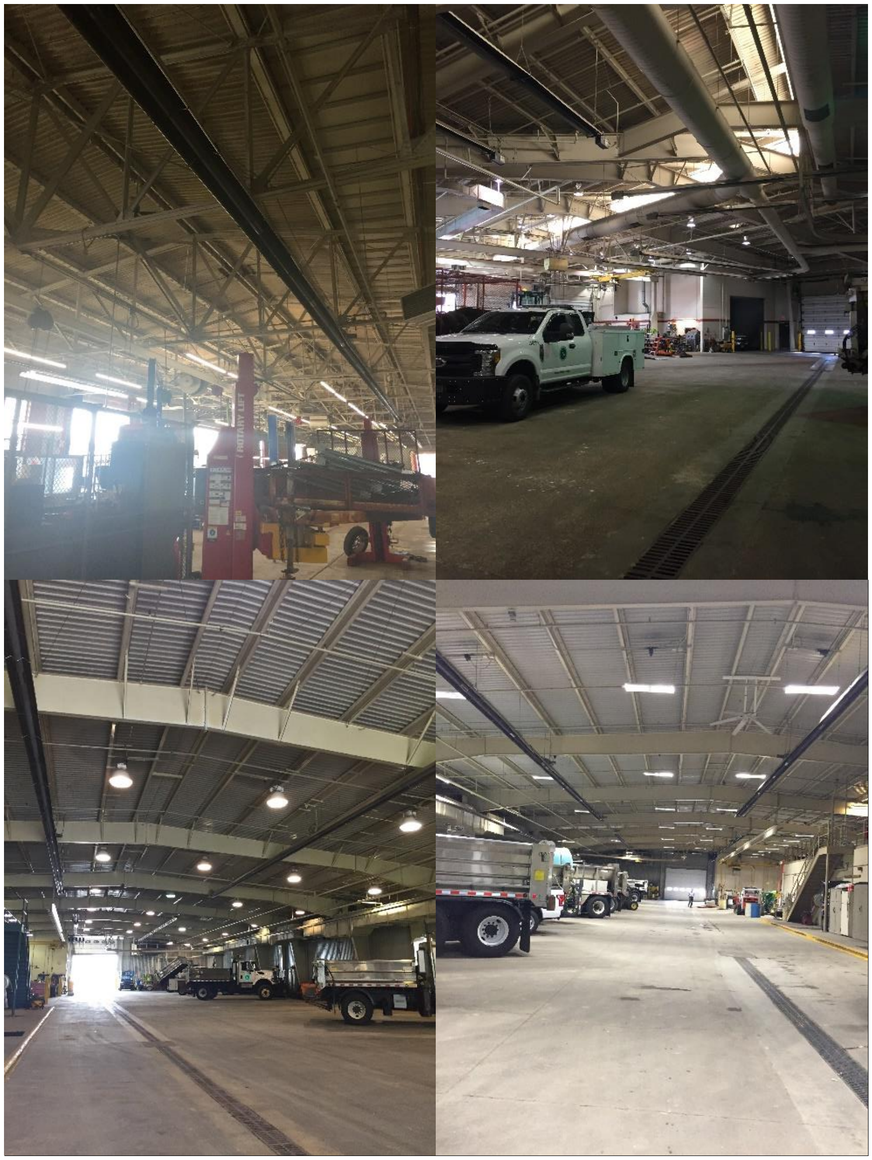


Figure 28 – Existing Lighting in ODOT Facilities

Because of the long and consistent run hours of the facility lights, there is a huge opportunity to upgrade and save. We recommend retrofitting each fixture (interior and exterior) with an LED replacement specifically designed to mimic the photometry of the existing fixtures. These will provide a better quality of light, better color, and a much longer life.

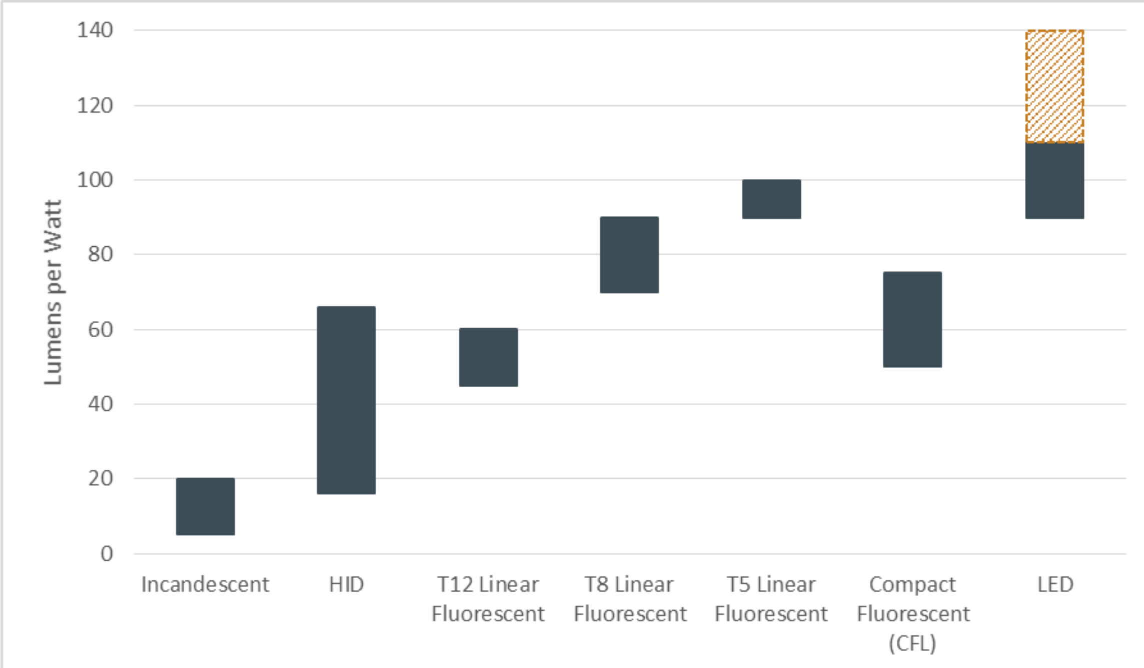


Figure 29 – Lighting Technology Comparison

Recommended Lighting

The Illuminating Engineering Society of North America (IESNA) publishes recommended lighting levels for various tasks and spaces. IESNA recommended lighting levels for some common spaces are shown in the following table (IESNA Handbook, 9th Edition).

In general, recommended lighting levels increase as the size and contrast of the visual task decrease. Thus, the recommended lighting level will be near the lower level of the ranges shown in the table below when the visual task is large in size and/or high contrast. Conversely, the recommended lighting level will be near the upper level of the ranges when the visual task is small in size and/or low contrast.

For example, we generally recommend 15 fc for warehouses with large bulk items and 25 fc for warehouses with hand-stocked items. Similarly, we recommend 30 fc for general manufacturing and up to 50 fc for manufacturing tasks requiring visual precision.

Table 19 – IESNA Recommended Lighting Levels

Task / Location	Recommended Lighting Level (fc)
Offices and classrooms	30-50
Corridors and aisles	5-10
Restrooms	5
Dining areas	10
Merchandise display	50
Warehouse	5-30
Manufacturing	30-50
Task lighting / Inspection	50-100

Light Quality

Our eyes evolved to see in natural sunlight. Thus, we distinguish colors best in sunlight. Light from electric lamps is generated at lower temperatures than sunlight and reduces our ability to distinguish between colors. Color Rendering Index (CRI) describes the effect of a light source on the color appearance of an object. CRI varies between 0 and 100. Approximate CRIs of various types of lighting are shown in the following table.

Some tasks, such as inspection and painting, clearly require high-quality light. In addition, most people prefer to work and live in light that is as close to sunlight as possible; thus the CRI of a light source should always be a consideration when selecting lights. For example, many people report seeing better under fluorescent lights with a CRI of 85 than under high-pressure sodium lights with a CRI of 22, even though the measured illuminance level under the high-pressure sodium lights is higher. Thus, using a light source with a higher CRI but lower light output (lumens) is generally better and more energy-efficient.

Table 20 – CRI Levels of Common Lighting Technologies

Light Source	CRI
Sunlight	100
Incandescent	99
T8 and T5 Fluorescent	75-85
Metal Halide	65
T12 Fluorescent	60

Glare

Glare is uncomfortably high illuminance. Glare can be problematic with large windows with direct sunlight and with direct high-intensity artificial lighting, especially with a dark background. For this reason, windows are often equipped with some type of shading, luminaries are often designed to diffuse light and ceilings are painted a light color.

Projected Savings:

The savings from lighting upgrades are among the simplest to calculate. With the only major assumption being the hours of operation, the remaining factors of wattage before and after can be accurately quantified. Based on these few inputs and the simple equations that follow, demand savings, energy savings, and total cost savings can be quickly determined.

$$Demand\ Savings = \frac{We - Wp}{1000\ W/kW}$$

$$Energy\ Savings = \frac{(We \times He) - (Wp \times Hp)}{1000\ W/kW}$$

$$Cost\ Savings = (Es \times Ce) + (Ds \times Cd)$$

Where:

We = Total wattage of existing system
Wp = Total wattage of proposed system
He = Weighted average operating hours of existing system
Hp = Weighted average operating hours of proposed system
Ce = Electrical energy cost
Cd = Electrical demand cost

Utilizing these parameters, the savings have been calculated on a space-by-space basis in the table that follows. The results are shown in the table below.

Table 21 – Lighting Upgrade Savings Summary

Facility	Energy Saved (kWh/yr)	Electric Cost Saved ($/yr)
HQ	144,242	14,509
Williams Garage	64,633	5,761
Ottawa Garage	70,547	7,096

Install High-Efficiency Domestic Hot Water Heaters

Facility	Demand Reduction (kW/mo)	Energy Saved (kWh/yr)	Electric Cost Saved ($/yr)	Fuel Saved (MMBtu/yr)	Fuel Cost Saved ($/year)
HQ	0	0	0	7	49
Williams Garage	0	0	0	36	253
Ottawa Garage	0	0	0	17	116
Seneca Garage	0	0	0	26	183

Applicable Facilities:

- Williams Garage
- Ottawa Garage
- Seneca Garage

Measure Overview:

Several of the facilities currently utilize standard efficiency hot water boilers to heat incoming water for domestic use. These boilers were originally designed to operate at 80% efficiency but it is unlikely they are still operating at this design point.

When combusting fuel to provide heat a significant amount of water vapor is formed as a byproduct of the reaction. Normally, this water vapor is exhausted taking large amounts of unclaimed heat with it. A high-efficiency condensing boiler extracts much of this wasted heat out, causing the water vapor to cool and condense in the exhaust stream. Normal boilers are unable to take advantage of this as the water vapor will degrade the weaker materials of these units.

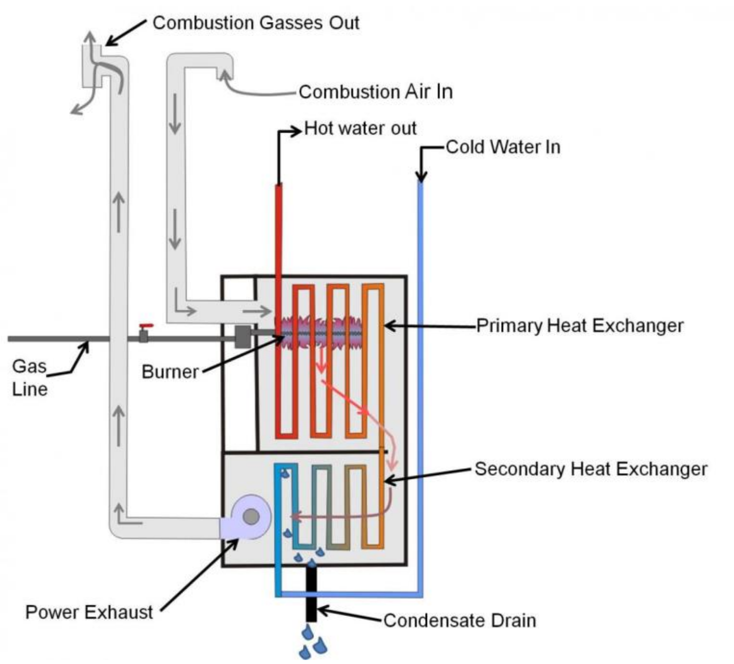


Figure 30 – Diagram of a Condensing Boiler in Operation

A condensing boiler is specifically designed to extract these extra heat and move the water down a condensate drain with no corrosion or wear on the boiler materials. Many of these boilers are able to attain efficiencies near 95% at certain fire ratios and water temperatures. Condensing boilers are especially suited to producing lower domestic water temperatures (120-140 F) at high efficiency.

Figure 31 – Existing Standard Efficiency Boilers (Williams, Ottawa, Seneca)

Figure 32 – Proposed Condensing Domestic Boiler (A.O. Smith BTX-80 or Equivalent)

We recommend the existing standard efficiency boilers be replaced with condensing boilers operating at 120 F at the end of current equipment's useful life.

Projected Savings:

Condensing boilers extract additional heat out of exhaust vapors. The extent to which the boiler is capable of this extraction depends upon the inlet water temperature. Domestic boilers are uniquely suited to serving domestic systems in that inlet temperatures are often very low, especially in more northern climes. The figure below shows an example "Boiler Curve" or efficiency at a given inlet water temperature.

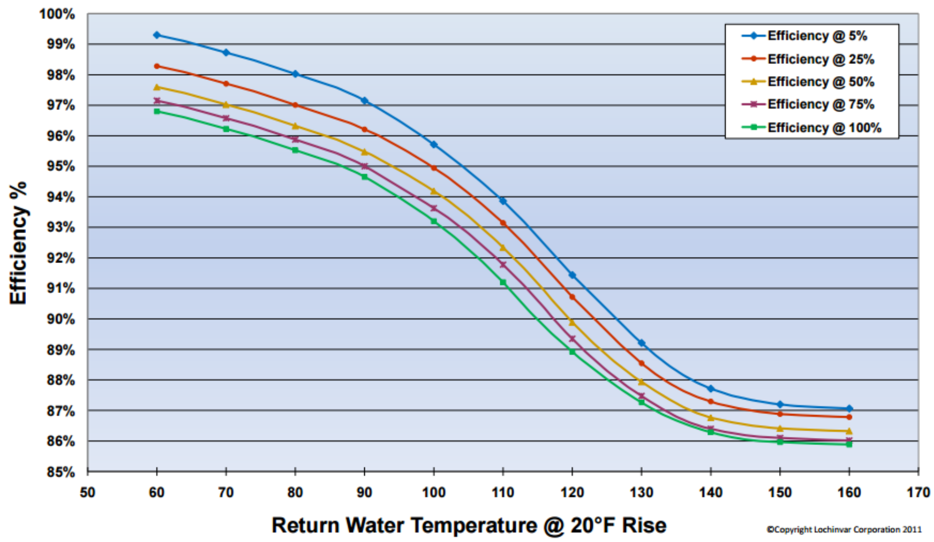


Figure 33 – Condensing Boiler Efficiency Curve

This curve was used to estimate the combustion efficiency at the given inlet temperature for the facility region (based on TMY3 weather data). Using this combustion efficiency and the current domestic fuel consumption (or independent fuel usage) the annual energy savings resulting from upgrading to a condensing system is estimated below for each facility.

Table 22 – Condensing Domestic Boiler Upgrade for Headquarters

Parameters	Equation	Value	Units
Variable Parameters			
System Information			
Boiler Installed in HVAC or Domestic Hot Water System?		Domestic	
Current Domestic Fuel Consumption (Fdhw1)		36	MMBtu/Yr
Nearest TMY3 Location (Weather Data)		725360 - TOLEDO EXPRESS AIRPORT	
Existing System Efficiency (η1)		78%	
Fuel Cost (Cf)		7.00	$/MMBtu
Calculations			
Domestic Water Inlet Temperature (Tdwin)	AVG(Toa)	49	F
Existing System Efficiency (η2)	Efficiency of Boiler When Tdwin = Treturn	97%	
Proposed Domestic Fuel Consumption (Fdhw2)	(Fdhw1 x η1) / η2	29	MMBtu/Yr
Proposed Annual Fuel Savings (Sf)	[Σ(Current Fuel Consumed) - Σ(Proposed Fuel Consumed)] x PL OR = Fdhw1 - Fdhw2	7	MMBtu/year
Proposed Annual Cost Savings (Sc)	**Sf * Cf**	**49**	**$/year**

Table 23 – Condensing Domestic Boiler Upgrade for Williams Garage

Parameters	Equation	Value	Units
Variable Parameters			
System Information			
Boiler Installed in HVAC or Domestic Hot Water System?		Domestic	
Current Domestic Fuel Consumption (Fdhw1)		186	MMBtu/Yr
Nearest TMY3 Location (Weather Data)		725360 - TOLEDO EXPRESS AIRPORT	
Existing System Efficiency (η1)		78%	
Fuel Cost (Cf)		7.00	$/MMBtu
Calculations			
Domestic Water Inlet Temperature (Tdwin)	AVG(Toa)	49	F
Existing System Efficiency (η2)	Efficiency of Boiler When Tdwin = Treturn	97%	
Proposed Domestic Fuel Consumption (Fdhw2)	(Fdhw1 x η1) / η2	150	MMBtu/Yr
Proposed Annual Fuel Savings (Sf)	[Σ(Current Fuel Consumed) - Σ(Proposed Fuel Consumed)] x PL OR = Fdhw1 - Fdhw2	36	MMBtu/year
Proposed Annual Cost Savings (Sc)	**Sf * Cf**	**253**	**$/year**

Table 24 – Condensing Domestic Boiler Upgrade for Ottawa Garage

Parameters	Equation	Value	Units
Variable Parameters			
System Information			
Boiler Installed in HVAC or Domestic Hot Water System?		Domestic	
Current Domestic Fuel Consumption (Fdhw1)		85	MMBtu/Yr
Nearest TMY3 Location (Weather Data)		725360 - TOLEDO EXPRESS AIRPORT	
Existing System Efficiency (η1)		78%	
Fuel Cost (Cf)		7.00	$/MMBtu
Calculations			
Domestic Water Inlet Temperature (Tdwin)	AVG(Toa)	49	F
Existing System Efficiency (η2)	Efficiency of Boiler When Tdwin = Treturn	97%	
Proposed Domestic Fuel Consumption (Fdhw2)	(Fdhw1 x η1) / η2	69	MMBtu/Yr
Proposed Annual Fuel Savings (Sf)	[Σ(Current Fuel Consumed) - Σ(Proposed Fuel Consumed)] x PL OR = Fdhw1 - Fdhw2	17	MMBtu/year
Proposed Annual Cost Savings (Sc)	**Sf * Cf**	**116**	**$/year**

Table 25 – Condensing Domestic Boiler Upgrade for Seneca Garage

Parameters	Equation	Value	Units
Variable Parameters			
System Information			
Boiler Installed in HVAC or Domestic Hot Water System?		Domestic	
Current Domestic Fuel Consumption (Fdhw1)		134	MMBtu/Yr
Nearest TMY3 Location (Weather Data)		725360 - TOLEDO EXPRESS AIRPORT	
Existing System Efficiency (η1)		78%	
Fuel Cost (Cf)		7.00	$/MMBtu
Calculations			
Domestic Water Inlet Temperature (Tdwin)	AVG(Toa)	49	F
Existing System Efficiency (η2)	Efficiency of Boiler When Tdwin = Treturn	97%	
Proposed Domestic Fuel Consumption (Fdhw2)	(Fdhw1 x η1) / η2	108	MMBtu/Yr
Proposed Annual Fuel Savings (Sf)	[Σ(Current Fuel Consumed) - Σ(Proposed Fuel Consumed)] x PL OR = Fdhw1 - Fdhw2	26	MMBtu/year
Proposed Annual Cost Savings (Sc)	**Sf * Cf**	**183**	**$/year**

Replace Aged HVAC Condensing Units and AHU Coils

Facility	Demand Reduction (kW/mo)	Energy Saved (kWh/yr)	Electric Cost Saved ($/yr)	Fuel Saved (MMBtu/yr)	Fuel Cost Saved ($/year)
HQ	0	2,332	233	0	0
Williams Garage	0	1,750	156	0	0
Ottawa Garage	0	2,332	236	0	0
Seneca Garage	0	1,595	154	0	0

Applicable Facilities:

- HQ Garage
- Williams Garage
- Ottawa Garage
- Seneca Garage

Measure Overview:

The existing office areas and a few small areas in each facility utilize split systems for heating and air conditioning. Some of these units have already exceeded their expected life. All units run on R-22 refrigerant, currently being phased out across the country. Each is controlled by a thermostat in the space.

Figure 34 – Ottawa Garage Multi-Duct AHU Condensing Unit

Figure 35 – Headquarters Garage Condensing Unit

Figure 36 – Williams Garage Condensing Units

Figure 37 – Seneca Garage Condensing Unit

An opportunity exists in modernizing the HVAC systems. In upgrading these condensing units, the same base system efficiencies will return on the heating side when the new units are installed and operating at peak design level. In addition, the cooling side efficiencies will be greatly improved as units will be upgraded from roughly 8 SEER to a recommended 15 SEER.

In replacing these units, all refrigerant will also be replaced with a more environmentally friendly R-410a refrigerant. Since the existing R-22 is already being phased out, prices will continue to rapidly increase and future repairs will become more and more costly. This, combined with the age of the units, means that all of them would likely be replaced in the next 10 years anyway.

Projected Savings:

Savings from these efficiency improvements are shown in the following tables.

Table 26 – Condensing Unit Upgrade for Headquarters

Cooling System			
Parameters	**Equation**	**Value**	**Units**
Variable Parameters			
Current Weather Dependent Electrical (Ce1)		5,028	kWh/year
Current Cooling System Efficiency (ηe1)		1.66	kW/ton
Proposed System Efficiency (ηe2)		0.89	kW/ton
Electrical Cost (Ce)		0.100	$/kWh
Calculations			
Current Coefficient of Performance (COP1)	[12,000 Btu/ton] / [3.412 Btu/kWh] / ηe1	2.12	
Current Cooling System Demand (De)	Ce1 x COP1	10,654	kWh-heat/year
Proposed Coefficient of Performance (COP2)	[12,000 Btu/ton] / [3.412 Btu/kWh] / ηe2	3.95	
Proposed Cooling System Consumption (Ce2)	De / COP2	2,696	kWh/year
Electrical Savings (Es)	Ce1 - Ce2	2,332	kWh/year
Electrical Cost Savings (Cse)	Es x Ce	233	$/year

Table 27 – Condensing Unit Upgrade for Williams Garage

Cooling System			
Parameters	**Equation**	**Value**	**Units**
Variable Parameters			
Current Weather Dependent Electrical (Ce1)		3,773	kWh/year
Current Cooling System Efficiency (ηe1)		1.66	kW/ton
Proposed System Efficiency (ηe2)		0.89	kW/ton
Electrical Cost (Ce)		0.0891	$/kWh
Calculations			
Current Coefficient of Performance (COP1)	[12,000 Btu/ton] / [3.412 Btu/kWh] / ηe1	2.12	
Current Cooling System Demand (De)	Ce1 x COP1	7,993	kWh-heat/year
Proposed Coefficient of Performance (COP2)	[12,000 Btu/ton] / [3.412 Btu/kWh] / ηe2	3.95	
Proposed Cooling System Consumption (Ce2)	De / COP2	2,023	kWh/year
Electrical Savings (Es)	Ce1 - Ce2	1,750	kWh/year
Electrical Cost Savings (Cse)	Es x Ce	156	$/year
Total Savings (Ts)	**Csf + Cse**	**156**	**$/year**

Table 28 – Condensing Unit Upgrade for Ottawa Garage

Cooling System			
Parameters	**Equation**	**Value**	**Units**
Variable Parameters			
Current Weather Dependent Electrical (Ce1)		5,028	kWh/year
Current Cooling System Efficiency (ηe1)		1.66	kW/ton
Proposed System Efficiency (ηe2)		0.89	kW/ton
Electrical Cost (Ce)		0.1010	$/kWh
Calculations			
Current Coefficient of Performance (COP1)	[12,000 Btu/ton] / [3.412 Btu/kWh] / ηe1	2.12	
Current Cooling System Demand (De)	Ce1 x COP1	10,654	kWh-heat/year
Proposed Coefficient of Performance (COP2)	[12,000 Btu/ton] / [3.412 Btu/kWh] / ηe2	3.95	
Proposed Cooling System Consumption (Ce2)	De / COP2	2,696	kWh/year
Electrical Savings (Es)	Ce1 - Ce2	2,332	kWh/year
Electrical Cost Savings (Cse)	Es x Ce	236	$/year

Table 29 – Condensing Unit Upgrade for Seneca Garage

Cooling System			
Parameters	**Equation**	**Value**	**Units**
Variable Parameters			
Current Weather Dependent Electrical (Ce1)		3,438	kWh/year
Current Cooling System Efficiency (ηe1)		1.66	kW/ton
Proposed System Efficiency (ηe2)		0.89	kW/ton
Electrical Cost (Ce)		0.0967	$/kWh
Calculations			
Current Coefficient of Performance (COP1)	[12,000 Btu/ton] / [3.412 Btu/kWh] / ηe1	2.12	
Current Cooling System Demand (De)	Ce1 x COP1	7,285	kWh-heat/year
Proposed Coefficient of Performance (COP2)	[12,000 Btu/ton] / [3.412 Btu/kWh] / ηe2	3.95	
Proposed Cooling System Consumption (Ce2)	De / COP2	1,843	kWh/year
Electrical Savings (Es)	Ce1 - Ce2	1,595	kWh/year
Electrical Cost Savings (Cse)	Es x Ce	154	$/year

Replace Older Model Boilers with High-Efficiency Condensing Boilers and Utilize Hot Water Reset

Facility	Demand Reduction (kW/mo)	Energy Saved (kWh/yr)	Electric Cost Saved ($/yr)	Fuel Saved (MMBtu/yr)	Fuel Cost Saved ($/year)
HQ	0	0	0	45	313
Williams Garage	0	0	0	0	0
Ottawa Garage	0	0	0	41	289
Seneca Garage	0	0	0	0	0

Applicable Facilities:

- HQ Garage
- Ottawa Garage

Measure Overview:

Currently both the Headquarters facility and the Ottawa garage use a natural gas boiler to serve a portion of the heating load for each facility. We estimate that for each facility this system is responsible for consuming about 30% of the heating-dependent natural gas load at each facility.

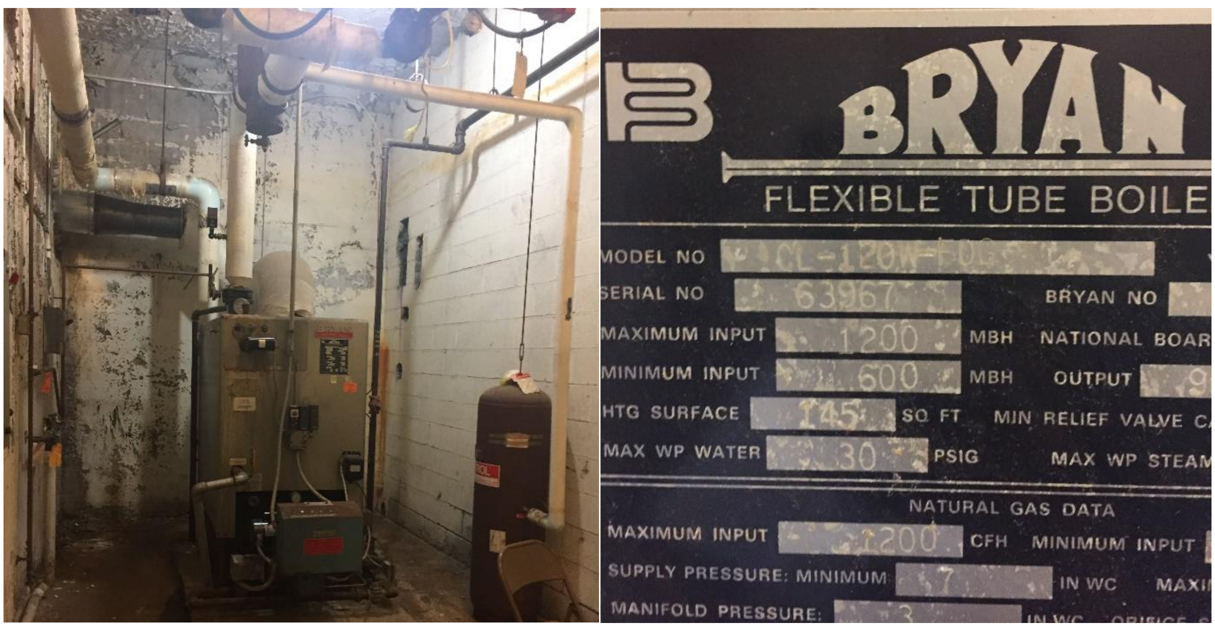
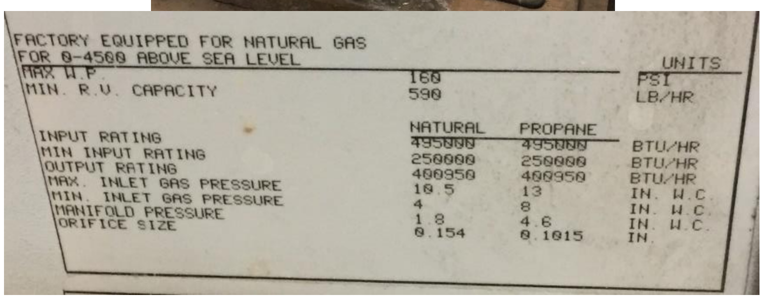


Figure 38 – Headquarters Existing Boiler



FACTORY EQUIPPED FOR NATURAL GAS
FOR 0-4500 ABOVE SEA LEVEL

			UNITS
MAX W.P.	160		PSI
MIN. R.V. CAPACITY	590		LB/HR
	NATURAL	PROPANE	
INPUT RATING	495000	495000	BTU/HR
MIN INPUT RATING	250000	250000	BTU/HR
OUTPUT RATING	400950	400950	BTU/HR
MAX. INLET GAS PRESSURE	10.5	13	IN. W.C.
MIN. INLET GAS PRESSURE	4	8	IN. W.C.
MANIFOLD PRESSURE	1.8	4.6	IN. W.C.
ORIFICE SIZE	0.154	0.1015	IN.

Figure 39 – Ottawa Garage Existing Boiler

When the useful life of the current system is complete, we recommend paying the slight premium to upgrade to a high-efficiency "condensing" boiler model with hot water reset programming based on outdoor air temperature. When operated at low temperatures, condensing boiler are able to extract latent heat that is typically left in the combustion products. While traditional boilers will corrode due to the highly acid nature of the condensate produced during this process, condensing boilers are specifically designed to accommodate this issue.

Figure 40 – Example Condensing Boiler

Using “hot water reset” programming to reduce the loop temperature as much as possible based on load and outdoor air temperature, the boiler can operate in the condensing range as often as possible. This results in drastically improved efficiencies, even at full load conditions. A specific example of this is shown in the following graph.

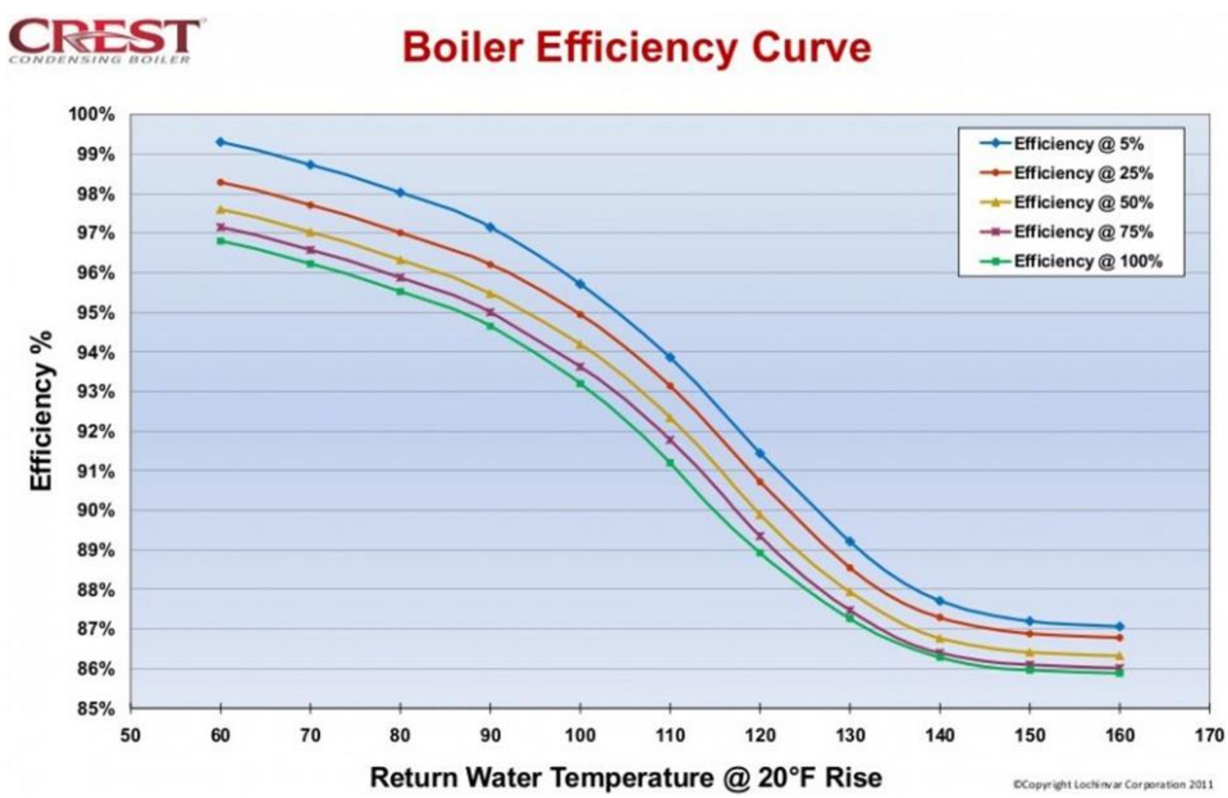


Figure 41 – Example Boiler Efficiency Curve (Lochinvar Corporation 2011)

Projected Savings:

Using the utility models developed in this report applied to TMY3 weather data to confirm our understanding of approximate fuel consumption of the boiler systems, combined with the condensing boiler curve above, an approximate expected savings can then be calculated simply as follows.

Table 30 – Condensing Boiler Upgrade for Headquarters

Heating System			
Parameters	**Equation**	**Value**	**Units**
Variable Parameters			
Current System Consumption (Cf1)		370	MMBtu/year
Current Boiler System Efficiency (ηf1)		80%	
Proposed System Efficiency (ηf2)		91%	
Fuel Cost (Cf)		7.00	$/MMBtu
Calculations			
Current Boiler System Demand (Df)	Cf1 x ηf1	296	MMBtu/year
Proposed Boiler System Consumption (Cf2)	Df / ηf2	325	MMBtu/year
Fuel Savings (Fs)	Cf1 - Cf2	45	MMBtu/year
Fuel Cost Savings (Csf)	Fs x Cf	313	$/year

Table 31 – Condensing Boiler Upgrade for Ottawa Garage

Heating System			
Parameters	**Equation**	**Value**	**Units**
Variable Parameters			
Current System Consumption (Cf1)		342	MMBtu/year
Current Boiler System Efficiency (ηf1)		80%	
Proposed System Efficiency (ηf2)		91%	
Fuel Cost (Cf)		7.00	$/MMBtu
Calculations			
Current Boiler System Demand (Df)	Cf1 x ηf1	274	MMBtu/year
Proposed Boiler System Consumption (Cf2)	Df / ηf2	301	MMBtu/year
Fuel Savings (Fs)	Cf1 - Cf2	41	MMBtu/year
Fuel Cost Savings (Csf)	Fs x Cf	289	$/year

Utilize Large Fans to Reduce Stratification and Increase Comfort

Facility	Demand Reduction (kW/mo)	Energy Saved (kWh/yr)	Electric Cost Saved ($/yr)	Fuel Saved (MMBtu/yr)	Fuel Cost Saved ($/year)
HQ	0	0	0	118	828
Williams Garage	0	0	0	84	586
Ottawa Garage	0	0	0	122	851
Seneca Garage	0	0	0	0	0

Applicable Facilities:

- HQ Garage
- Williams Garage
- Ottawa Garage

Measure Overview:

During heating months, warmer air rises to the ceiling rather than remaining at floor level. This phenomenon is known as thermal stratification and is due to the change in density of air with temperature. This effect is more pronounced in plants with higher ceilings. According to facility staff, even though the garages employ radiant heaters, this effect is experienced in the spaces. In fact, some garage staff shared their observation of garage exhaust fans turning on in the winter due to high temperatures at the ceiling. This indicates a good opportunity to reduce temperature stratification.

Figure 42 – Example High Volume Low Speed Fan

High-volume, low-speed (HVLS) ceiling fans reduce thermal stratification by pushing warm air from the ceiling down to the plant floor, as shown in the figure below. Installing HVLS ceiling fans would decrease the heating load by increasing the temperature that the thermostats experience and would further increase garage occupant comfort.

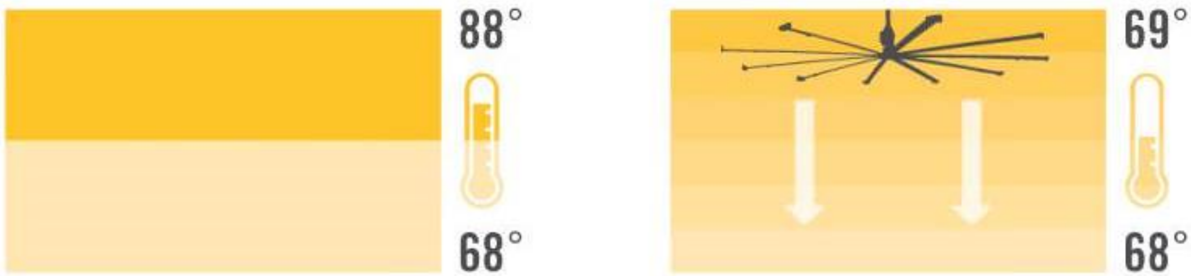


Figure 43 – Temperature stratification without and with HVLS fans

Finally, by moving warmer air across garage surfaces, evaporation rates are increased and less condensation and spill liquid remain on the floor. This will decrease the likelihood of slips and injuries and will slightly improve occupant safety.

Projected Savings:

Energy savings from HVLS fans are achieved when the floor-level air temperature is increased by destratifying facility air. This changes the air temperature the thermostats see as they are mounted near the floor, and the facility HVAC equipment will turn on less often as a result. Although our analysis was performed during the summer months and as such we could not observe firsthand the air stratification, we estimate that employing HVLS fans in the garage would allow the thermostat set points to be decreased by roughly 4 degree Fahrenheit. If so, for each degree a setpoint is reduced roughly 3% of heating energy is saved. Thus, we estimate that for the garages employing HVLS fans, roughly the following will be saved:

Table 32 – High Velocity, Low Speed Fan Savings Summary

Facility	Fuel Savings (MMBtu/year)	Cost Savings ($/year)
HQ Garage	118	828
Williams Garage	84	586
Ottawa Garage	122	851

This estimate is supported by the annual fuel differences between Seneca and Williams of roughly 49 MMBtu/year before a lighting change.

Utilize Speed-Doors to Minimize Air Infiltration

Facility	Demand Reduction (kW/mo)	Energy Saved (kWh/yr)	Electric Cost Saved ($/yr)	Fuel Saved (MMBtu/yr)	Fuel Cost Saved ($/year)
HQ	0	0	0	68	479
Williams Garage	0	0	0	44	305
Ottawa Garage	0	0	0	63	443
Seneca Garage	0	0	0	41	288

Applicable Facilities:

- HQ Garage
- Williams Garage
- Ottawa Garage
- Seneca Garage

Measure Overview:

Currently each of the ODOT garage facilities utilize sectional garage doors. These doors are a major source of energy loss during heating months, both because of the heat lost due to conduction through the doors but also because of the large amounts of air infiltration when the garage door is opened to drive a vehicle in or out.

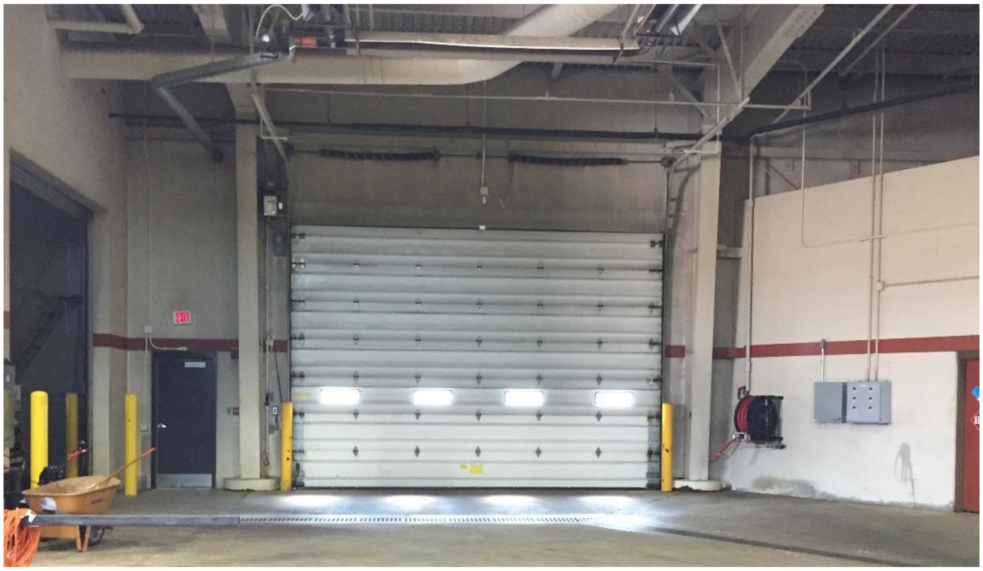


Figure 44 – Ottawa Garage Sectional Garage Door

An alternative is to utilize “Fast-Seal” doors or “Speed-Door” units. These typically will sacrifice a small thermal insulation (R-Value) change (compared to sectional doors) to reduce the amount of time the doors are open to minimize air infiltration.

Figure 45 – Example “Fast-Seal” Garage Door

Beyond energy effectiveness, these doors can improve safety due to a counter-balanced and tensioning system door design that responds to obstacles gently and almost instantly. These doors also increase garage occupant comfort by limiting the size of infiltration drafts.

Projected Savings:

Energy consumption will be altered in two main ways. First, when the existing sectional door is closed the higher R-Value results in less heat loss through the door during the heating season. Second, by minimizing the time each door is open, the Fast-Seal doors will result in less heat loss due to cold air infiltration. The balance of these two effects will result in the net energy savings.

Each ODOT facility was analyzed by a representative from Rytec Doors. The following table details the proposed change by Rytec for an average ODOT garage door.

Table 33 – Rytec Proposed Garage Door Changes

Doors

	Existing/Planned Door	Alternative 1
Door	Sectional Door	Fast-Seal
Material	Insulated Steel	3-ply Rilon
Voltage	115V	460V
Defroster Options	None	None
Defroster Cycle On Time (Min)	0	0
Defroster Cycle Off Time (Min)	0	0
Installed Cost ($)	$0.00	$26,944.38
Annual Maintenance Cost ($)	$1,500.00	$0.00
Reclose Time (Door Hang Time)	10	10
Cycles/Day	40	40
Days/Week	5	5
Blocked Open (hours/month)	16	0
Add'l Gap From Wear (sq. in.)	0.00	0.00
Overrides		
Opening Speed (in./second)	15.00	50.00
Closing Speed (in./second)	15.00	40.00
R-Value	14.86	0.10

Modeling the above changes, Rytec's analysis resulted in the following table, displaying their estimate of total energy and cost savings.

Table 34 – Rytec Energy Analysis

		
Dollars (Annual)	**Existing/ Planned Door**	**Alternative 1**
Door	Sectional Door	Fast-Seal
Energy Cost Due to Door Operation ***(Motor power usage)***	$1.96	$1.47
Air Flow Energy Cost ***(HVACR due to door open time & gaps)***	$3,645.79	$788.42
Conduction Energy Cost ***(HVACR due to R-Factor)***	$9.62	$118.15
Defroster Operating Energy Cost ***(Blowers, heaters, lamps)***	$0.00	$0.00
Energy Cost Due to Defroster Heat Gain ***(HVACR due to blowers, heaters, lamps)***	$0.00	$0.00
Total Energy Cost $	$3,657.37	$908.04
Consumption (Annual)		
Door Operating Consumption (kWh) ***(Motor power usage, electric)***	19.61 kWh	14.67 kWh
Conditioning Energy Consumption (kWh) ***(Building HVACR system usage, electric)***	0.00 kWh	0.00 kWh
Conditioning Energy Consumption (Therms) ***(Building HVACR system usage, gas)***	5,222.02 Therms	1,295.10 Therms
Conditioning Energy Consumption (MBtu) ***(Building HVACR system usage, MBtu)***	0.00 MBtu	0.00 MBtu
Defroster Operating Consumption (kWh) ***(Blowers, heaters, lamps usage, electric)***	0.00 kWh	0.00 kWh
Total Electric Consumption (kWh)	19.61 kWh	14.67 kWh
Total Gas Consumption (Therms)	5,222.02 Therms	1,295.10 Therms
Total Steam Consumption (MBtu)	0.00 MBtu	0.00 MBtu

However, we believe these figures to be aggressive given the utility baseline of each facility. We estimate that actual savings from retrofitting the most used door in each facility will be somewhere around 5% of total annual consumption. If so, and assuming the electrical savings are negligible, the following table shows the estimated energy and cost savings:

Table 35 – Quick Door Savings Summary

Facility	Fuel Savings (MMBtu/year)	Cost Savings ($/year)
HQ Garage	68	479
Williams Garage	44	305
Ottawa Garage	63	443
Seneca Garage	41	288

Employ On-Site Generation to Reduce Long-Term Costs and Carbon Footprint

Facility	Demand Reduction (kW/mo)	Energy Saved (kWh/yr)	Electric Cost Saved ($/yr)	Fuel Saved (MMBtu/yr)	Fuel Cost Saved ($/year)
HQ	0	190,830	19,194	0	0
Williams Garage	0	89,054	$8,609	0	0
Ottawa Garage	0	89,054	$7,938	0	0
Seneca Garage	0	89,054	$8,957	0	0

Applicable Facilities:

- HQ Office
- HQ Garage
- Williams Garage
- Ottawa Garage
- Seneca Garage

Measure Overview:

Currently the ODOT facilities purchase 100% of its power from local utilities and a third-party supplier.

We recommend the consideration of the utilization of either roof-mounted or ground-mounted solar photovoltaic arrays (solar electric). These arrays will serve to offset a small portion of each facility's electrical costs and generate positive cash flow, but also as a risk management mechanism by locking in a portion of the facility's costs over the next 15 years or beyond. Finally, the arrays will serve to drive positive public relations and marketing for the ODOT brand.

Figure 46 - Roof-Mounted Solar Array

Figure 47 - Ground-Mounted Solar Array

System size will likely be determined by available ground space or roof availability. However, to avoid any situation in which the facility would sell excess power back to the utility (often for pennies on the dollar), we recommend that the total output any solar option pursued not exceed 80% of the lowest month's electrical consumption.

It is important to note that quality solar panels often come with 15-year or more output/degradation warranties. Any system that is considered should include these kinds of protections to ensure the long-term benefits of the array.

Finally, as ODOT is not a tax paying entity and significant tax incentives for solar exist, we recommend employing solar through the structure of a Power Purchase Agreement (PPA). In this structure a third party would own and manage the array and sell power back to the facility. In this way, the third party owner can claim the tax credits and pass the system savings on to ODOT through the purchase agreement.

Projected Savings:

A little-known fact is that the Midwest has a relatively high amount of solar resource compared to other areas of the world that have transformed their economies to rely on solar. One of the better known solar countries, Germany, has significantly less solar resource than we do in the Midwest.

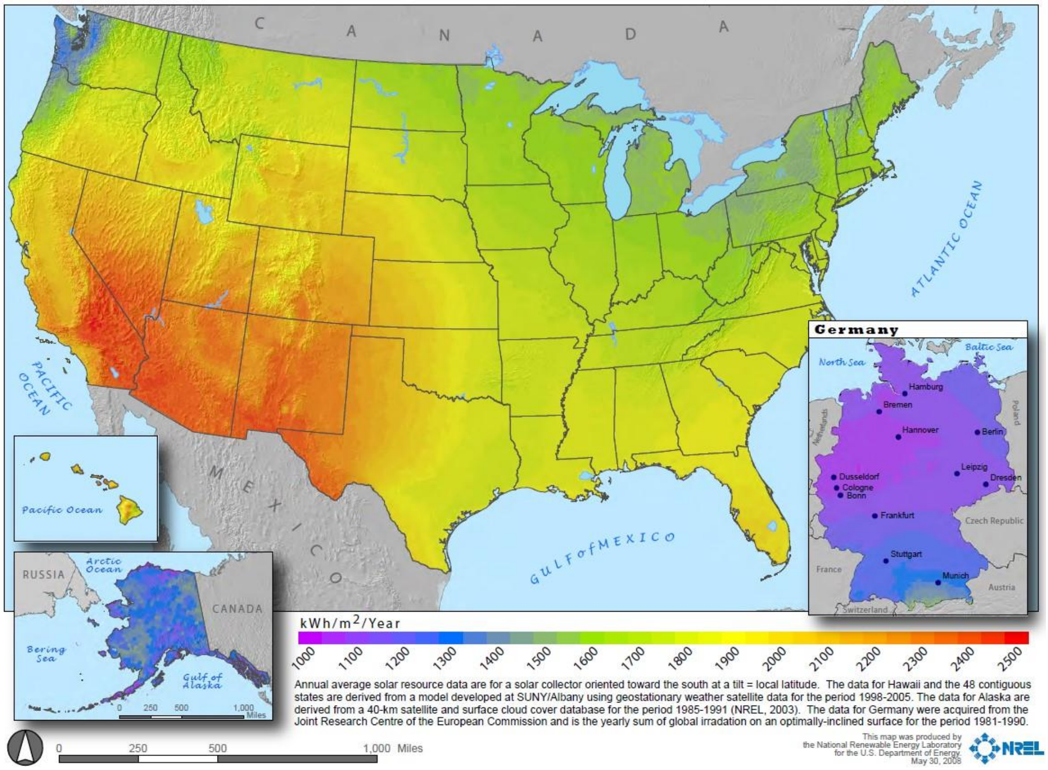


Figure 48 – Solar Resource Map (NREL)

Because the rate of savings for each unit of energy (kWh) a system produced is much higher than the rate at which the utility will buy back excess power, we typically recommend that a system be sized to produce no more than 80% of the annual consumption of a facility.

Following this rough rule of thumb, we recommend the following system sizes be considered:

Table 36 – Recommended Solar Array System Sizes

Facility	Recommended System Size
District 2 Headquarters	150 kW
Williams Garage	70 kW
Ottawa Garage	70 kW
Seneca Garage	70 kW

NREL's PVWatts® Calculator is a web application developed by the National Renewable Energy Laboratory (NREL) that estimates the electricity production of a grid-connected roof- or ground-mounted photovoltaic system based on a few simple inputs. Using this software to model the system sizes above for the Toledo region, the following results are found:

Table 37 – 150 kW Annual Array Production

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	2.66	10,981
February	3.78	14,036
March	4.31	16,900
April	5.09	18,455
May	5.59	20,345
June	5.37	18,555
July	5.62	19,625
August	5.46	19,268
September	5.15	17,929
October	4.02	15,240
November	2.79	10,744
December	2.10	8,752
Annual	4.33	190,830

Table 38 – 70 kW Annual Array Production

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	2.66	5,124
February	3.78	6,550
March	4.31	7,887
April	5.09	8,613
May	5.59	9,494
June	5.37	8,659
July	5.62	9,158
August	5.46	8,992
September	5.15	8,367
October	4.02	7,112
November	2.79	5,014
December	2.10	4,084
Annual	4.33	89,054

Using the avoided costs for each facility, the photovoltaic systems would savings the following each year:

Table 39 – Total Cost Savings of On-Site Generation

Facility	Annual Energy Production (kWh)	Annual Cost Savings ($/year)
District 2 Headquarters	190,830	$19,194
Williams Garage	89,054	$8,609
Ottawa Garage	89,054	$7,938
Seneca Garage	89,054	$8,957
Total	**457,992**	**$44,698**

Furthermore, in the final site design it is important that the array have a clear south-facing exposure. Each array will take up roughly 110-220 ft^2/rated-kW. Ground-mounted systems take up the higher end of that spectrum as space is left between each row for access. For example, a ground-mounted Seneca Garage 70-kW array will take up a maximum of 15,400 ft2, which is shown as an example red area in the figure below.

Figure 49 – Ground-Mounted Array Size for Seneca Garage (Google Maps)

Finally, by utilizing a Power Purchase Agreement (PPA) through a tax-paying third party, the project would be eligible for tax incentives in the former of the Solar Investment Tax Credit and Rapid Depreciation of the asset. Typically, these agreements last from 5-10 years with ownership passing the land-owner (ODOT) at the expiration of the agreement.

Appendix VII - New Building Design Recommendations

In overview of a number of the existing facilities in operation, it is apparent that the design and construction standards currently in place produce solid results. As new technologies are brought to the market, opportunities for improvement present themselves. General recommendations for all new building designs include but are not limited to;

Radiant heating system for ODOT Full Service Garages or Outposts

Use of in-floor radiant heating is feasible for the Truck storage area for these facilities.
The truck wash area is not a good candidate for in floor radiant due to the high heating demand and the transient heating loads caused by the truck-wash drainage.
A radiant floor system may have added benefits in assisting the removal of snow and ice build-up on the undercarriages of tracks that are parked in the garage.

Design Considerations for Radiant Floor Heat

In-floor radiant could result in improved energy performance, but the system has a relatively slow response to changes in operating conditions. The frequent utilization of roll-up doors is of specific concern. A reduction in uncontrolled infiltration at roll-up doors will be needed to allow the radiant system to maintain control. The use of air-doors should be considered as a part of the in-floor radiant solution to mitigate the impact of rapid changes in infiltration. The air door would need to be coordinated with the roll-up door design.

The North Baltimore facility is small and would not require multiple in-floor system zones. The radiant piping layout must be coordinated with the floor slab design.

To improve energy performance the in-floor radiant system could be designed to operate at low water temperatures (130 degrees or lower). The low temperature operation would work well with a condensing boiler, to achieve 90 to 94% combustion efficiency. The heating system would require a hot water boiler. The radiant heating system boiler should be located in an area that is serviceable, potential area may be in the pressure washer room.

Other items to keep in mind while designing for Radiant Floor Heat

- Design for both vertical and horizontal insulation around entire pad for separation of this thermal mass
- Provide for a thermal break between shop are and offices if the office area is not heated by radiant heat
- If the size of the shop area justifies multiple zones, provide thermal breaks between each zone
- Consider keeping a small amount of hanging radiant tube heaters to supplement and improve response time on the coldest days. This would eliminate the need for diesel heaters presently used as supplement heat in some of the existing facilities.
- Continue use of traditional hanging tube heaters in wash bays.
- Do not use night set back of radiant floor temperatures due to thermal lag.
- Epoxy the floors so as to reduce harm from salt. Spec a high friction finish so as to reduce the risk of falls.

Additional HVAC Efficiency Considerations

The separate small light commercial HVAC system could continue as the basis of design for the office area. A small air-to-air total energy heat recovery unit should be considered to improve energy performance and help maintain a level of humidity control year-round.

Some form of pre-heating for the truck wash is desired to prevent freezing during washing. Using the garage area exhaust for preheating the truck wash could help reduce heating demand. The current design utilizes air transferred from the garage/storage area to provide preheated air to the truck-wash. A heat reclaim system (like a run-around loop) for the make-up air may reduce the energy use and should be considered.

Solar Photovoltaic Arrays

Utilizing either a roof-mounted or ground-mounted solar photovoltaic array (solar electric) would serve to offset a small portion of each facility's electrical costs. This could also serve as a risk management mechanism by locking in a portion of the facility's costs over the next 15 years or beyond.

Projected Energy Savings of Radiant Heat System

Because of the tremendous heat exchange area afford by a floor-based radiant heat HVAC system, the HVAC condensing boiler would be able to operate at maximum efficiency all hour of the year. The following table estimates the potential savings of a radiant floor HVAC system for a theoretical new garage facility.

Table 40 – Potential Savings of Floor-Based Radiant Heat HVAC System

Heating System			
Parameters	**Equation**	**Value**	**Units**
Variable Parameters			
Current System Consumption (Cf1)		828	MMBtu/year
Current Boiler System Efficiency (ηf1)		80%	
Proposed System Efficiency (ηf2)		94%	
Fuel Cost (Cf)		7.00	$/MMBtu
Calculations			
Current Boiler System Demand (Df)	Cf1 x ηf1	663	MMBtu/year
Proposed Boiler System Consumption (Cf2)	Df / ηf2	705	MMBtu/year
Fuel Savings (Fs)	Cf1 - Cf2	123	MMBtu/year
Fuel Cost Savings (Csf)	Fs x Cf	864	$/year

Please note that the above analysis is performed at fuel prices in 2017. As markets change the actual realized savings could be lower or, more likely, much higher.

Appendix VIII - Case Studies

Hancock Wood Energy Coop

Phone conversation with Humpy Flores and Bob Hausmann on 10/16/17
Humpy is employed with HWE Coop
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614.494.2266

Their facility was built in 2008 before he joined them. They are an electric co-op serving 13,000 members.
The shop area is 40,000 sf that houses trucks, bob cats, mini back hoes, etc.
They have 12 each 16' overhead doors that are open and closed frequently, even in the winter.
The air temperature quickly recovers back to the 65 degrees in the winter.
They do use 12 each large ceiling mounted fans to drive the heat back down towards the floor in the winter.
They do NOT cool the space in the summer.
The main HVAC system is a Geothermal system consisting of nearly 8 miles of pex tubing buried in the floor slab. The source is a 2-acre pond that is approximately 13' deep.
They have 11 manifolds split between 3 zones.
The system was installed by Indian Geothermal out of Indiana. They have a 50-year warranty on the system. His point of contact with that group is Mr. Burkhardt. Humpy was cutting grass when we talked but can provide that contact info at a later date if desired. They have had NO ISSUES to date.
They have a 1mm BTU propane back up boiler that has run once – several years ago on an extremely cold couple of days. Last year they doubled the size of the pipe placed in the pond in an effort to upsize the capacity of the system and avoid using the propane boiler at all.
They maintain, easily, 65 degrees in their shop area during the winter.
The slab is 6.5" thick with insulated exterior edges and a poly film below the slab.
They have epoxied the floor so as to protect the concrete from the road salts in the winter. They have not experienced any floor damage. Only cracks apparent are those associated with typical concrete shrinkage.

Humpy's bottom line conclusion

Given the opportunity to install this system again in another facility, he wouldn't hesitate to do so.

MNDOT

Phone conversation with Paul Dragich and Bob Hausmann on 10/26/17
Mechanical Engineer, MnDOT – Building Services
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MnDOT self-designs and constructs their own facilities while working side by side with the facility managers throughout the State.

Paul has been employed by MnDOT for 5 years. He believes that radiant floors do provide significant more comfort within the working environment of the garage space and that the radiant floors do a much better job of melting down ice from underneath the vehicles.

When MnDOT make use of radiant floors, they also use it in combination with unit heaters. He believes that the unit heaters are needed for quick recovery from the doors being opened during the winter months. He pointed out that their climate tends to be much harsher in the winters than Ohio's.

MnDOT has used both GEO thermal and gas boilers as the heat source.

Paul is not a big fan of GEO thermal because of the length of winters in Minnesota. He questions the long-term value of the same if you are taking more heat out of the ground (winter conditions) than giving back (since summers are short and they don't provide AC in this space). Also with the current price of gas, it's hard to justify the front end additional cost with GEO.

Their facilities range in size from 10,000sf to 50,000sf. On the 50,000sf facilities, they have used 60 tons of ground source. Their overhead doors are similar to those of OH facilities both in size and quantity.

Paul discussed the concept of air circulation. They have tried several types of fans to re-circulate the upper air;

- Typical paddle fans
- Zoo fans located at the roof line and between the vehicles. These fans do a great job of forcing the air down from above within a particular area.
- Box fans located on the floors between the vehicles. They do not use these fans in the radiant floor facilities but rather a standard design

MnDOT has been tracking the operating cost per SF of their facilities the last several years. They have not noticed a significant swing in cost no matter the design of the mechanical system(s). When questioned, Paul stated that they have not thought about lowering the set points of room temperatures knowing that the radiant system is a lot more comfortable at the level closest to the floor. He said that doing so would indeed have a significant pay-back. They too have not made use of setbacks, zone controls, etc.

Paul stated that they would love to see a research project that bench marked more information relative to radiant floors.