Turn It Off:

Decarbonizing Your Manufacturing Operation with the Push of a Button

Takayuki Kokabu, VEIC

ABSTRACT

Operators in manufacturing facilities typically keep process equipment idling without much thought to the waste of energy and money. However, some idling machinery can waste over 60% of an equipment's rated energy. A well-designed equipment shutoff initiative can produce energy and carbon savings by training factory workers when to turn off long-idling machinery. The savings, in turn, can contribute significantly to companies' annual energy reduction goals, while also reducing their reliance on capital-intensive equipment to meet sustainability goals. A Vermont manufacturer's recent equipment shutoff protocol — essentially, a behavior change for operators — required no capital-intensive investment and yielded energy cost reductions of about 25%.

The concept of turning off equipment is simple. However, the actual implementation of appropriate protocols can be complicated. This case study describes how an internal survey of the manufacturer's equipment determined what can be turned off and when. The manufacturer subsequently engaged its workforce in changing operation protocols. An energy efficiency program then used advanced metering infrastructure (AMI) data analysis tools to identify and track the adoption of the protocols and the results. The study also uncovered ancillary benefits pertaining to compressed air loads, power factor, operator comfort, and equipment longevity. These factors have proven to be essential to a resilient and sustainable manufacturing facility.

Single-Machine Shut-It-Off Project

We typically think of factory equipment as having two modes of operation: on and off. However, a third mode of operation usually exists within this scope: idling. When machines are idle (that is, on, but not in production), they tend to draw a significant amount of energy just to be on standby.

In 2017, the University of Massachusetts Amherst's Industrial Assessment Center (MA-IAC) conducted an energy efficiency audit at a nearby Vermont manufacturing facility, identifying several machines that could be turned off when idling. The manufacturer, NSK Steering Systems, pursued a project with Efficiency Vermont, a statewide energy efficiency utility, to shut off NSK's Rhino 225 Press when the machine was not in use. The Rhino 225 Press is one of the more energy-intensive machines in NSK's facility in Bennington, Vermont, and the company was comfortable with the project's protocols for turning it off. NSK was interested in the study because MA-IAC's report had identified that about 48,000 kWh of energy could be saved by eliminating idling altogether.

MA-IAC had metered the power draw for the Rhino 225 Press for two weeks in 2017. Figure 1's graphical representation of the metered data clearly shows three levels of power consumption for on, idling, and off.

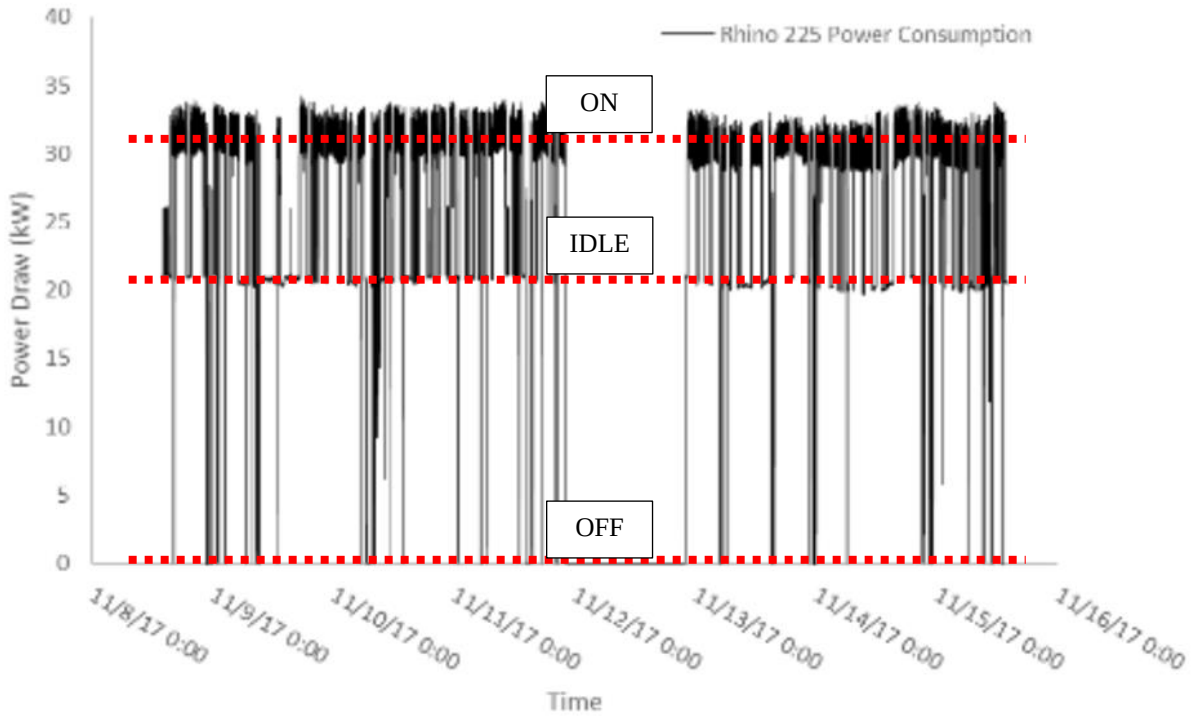

Figure 1. Rhino 225 Press power draw in kW across one week of operation.

Table 1 shows each mode of operation at the NSK facility for the Rhino 225 Press, and the operation modes' respective power draws.

Table 1. Simple machinery modes of operation, and the Rhino 225 Press's power draw

Operation mode	Description	Average power draw
On / cycling	Productive energy use	30.82 kW
Off	Saved energy	0.00 kW
Idling	Unproductive / wasted energy	20.52 kW (66% of On)

In 2018, Efficiency Vermont confirmed the validity and reliability of the metered data with its own two-week data collection. However, the efficiency program reassessed MA-IAC's energy savings from turning off the Rhino 225 Press whenever it was idling. Efficiency Vermont concluded that the estimate accounted for every single moment that the machine was idling. However, the expectation that operators would turn off a machine for only a few minutes or seconds did not seem realistic. Thus, Efficiency Vermont re-evaluated the savings, taking into consideration only machine idle times of 15 minutes or longer. Under these assumptions, Efficiency Vermont estimated that NSK could turn off the idling machine for about 1,120 hours per year and annually save about 23,000 kWh and approximately $3,200 in energy costs.

NSK implemented this efficiency measure in early 2019 along with a few other energy efficiency projects. It soon became apparent that the company would be well short of its targeted 5% energy reduction for that year. Rather than pursue other lines or machines to implement a shut-it-off protocol, NSK pursued an equipment shut off initiative for the entire manufacturing facility.

Facility Overview

NSK's Bennington facility manufactures steering columns for automobiles. They are a 3-shift operation that is composed of more than 300 presses, swagers, grinders, washers, welders, and plastic coating and assembly machines. Their annual energy use before the Shut-It-Off program was about 6.5 million kWh. Although management preferred to turn off the air compressor during the weekends, they did not have any specific protocols about shutting off equipment when not in use. This changed in the first quarter of 2019 when NSK began its plant-wide shut off project.

Plant-wide Project

Surveying the Facility

NSK's Environmental Manager surveyed 314 machines (see Figure 2) in NSK's facility to verify which machines could be turned off. In industrial facilities, machines are often kept running continuously but are seldom productive during their entire runtime. Industrial customers frequently cite the following reasons for not shutting down equipment:

- Uncertainty about losing programming, controls, and / or data
- Avoiding long ramp-up times that could affect production schedules
- Continuing to operate in ways that have always worked in the past

By talking to engineers and operators about different lines and equipment throughout the plant, the Environmental Manager noted that 271 of the 314 machines could be turned off if they were idling. That was 86% of the facility! Figure 2 presents the results of her survey. Green cells indicate machines that could be turned off; red cells indicate those that should not be turned off.

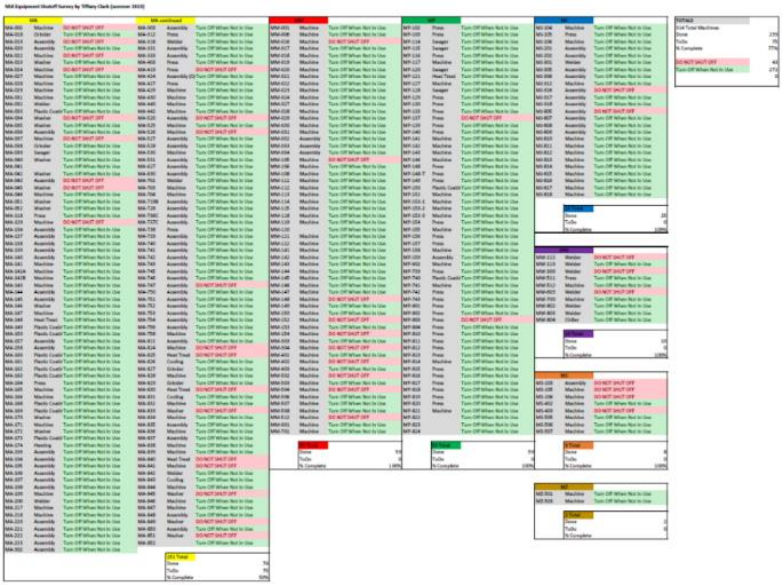

Figure 2. The NSK survey leading to the protocols for the company's Shut-It-Off program.

Implementing the Program

Behavioral energy efficiency projects are relatively difficult to design and successfully implement. Unlike typical installations of equipment and controls with known measure lives and uses (from which energy savings can be evaluated, measured, and verified after installation), changing human behavior is more complicated. Even with expert training not all trainees can be relied on to manage energy savings protocols equally. Maintaining new behavior across the long term is even more difficult; however, some behavioral-change protocols, like those in a shut-it-off initiative, can be delivered at low cost and produce high-yield results.

After the facility-wide survey the first step for the NSK Shut-It-Off campaign was to set up signs and stickers at each machine to indicate conditions for turning it off (or not) when it was idling (see Figure 3). The company used these prompts in conjunction with orientation and training sessions with operators to provide the new instructions.

Figure 3. NSK identified if each machine can be turned off or not using stickers.

NSK launched the project in early July 2019. However, the energy use data showed that the behavioral change was not immediately effective. E-mails from NSK described the difficulties:

- July 2019: "…we are fully implemented with the shut off project. Now it's just getting people to listen to me. I have been checking and finger wagging people who don't turn their machines off or e-stop. Hopefully they will get sick of my nagging and start complying."
- September 2019: "Shut off program is going ok, still some struggles with getting people to remember to turn off…"

By the fourth quarter of 2019, the data suggested that NSK was starting to shed significant amounts of electrical use compared to the previous year(s). NSK told Efficiency Vermont that this trend was not due to any variation in production schedules.

Seeing the Savings

Efficiency Vermont monitored the progress and effectiveness of the Shut-It-Off campaign with monthly electricity use data and 15-minute interval data.

Monthly energy use for January and February 2020 appeared to be 135,000 kWh lower than for the respective months in 2019. Those energy savings translated to $18,000 per month of electricity use. Even accounting for other measures that contributed to electricity savings, it can be assumed that about 107,000 kWh of monthly savings can continue to be realized under similar production levels. This would result in about $15,000 per month of savings from behavior changes alone.

These annual savings are equivalent to about 4,700 kWh per machine for the 271 machines that can be turned off during idle times.

The equipment shutoff program during normal facility production saves NSK about 20 to 25% of its electricity use, compared to pre-program facility operations.

The study has not been able to obtain a full year of utility and energy use data that reflect normal operations, because the plant shut down most of its production in mid-March 2020 to comply with COVID-19 lockdown protocols. The facility reopened a few months later and quickly ramped up to full production mode. The first few months thereafter were higher than usual in production (and facility energy use) because NSK tried to catch up with lost production from the lockdown. By the end of 2020, production had leveled off to normal levels.

Graphical Representations of the Equipment Shutoff Effects

Figures 4 through 7 and Table 2 show the significant reduction in load that the equipment shutoff initiative has created.

Figure 4 shows NSK's monthly electricity use from July 2018 through 2020. The energy savings from the Shut-It-Off initiative starts to become apparent in the fourth quarter of 2019. By 2020, there is a consistent significant drop in electricity use, compared to previous years' monthly use. See Figure 5 for a breakdown of Figure 4's energy savings.

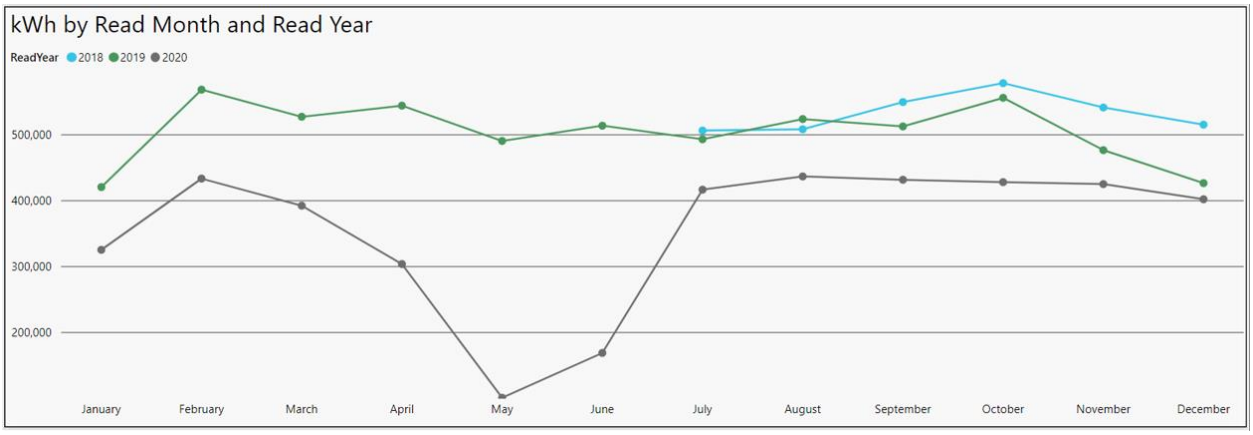

Figure 4. Monthly electricity usage for May 2018 – March 2020 at the NSK facility.

Note: For Figure 4 and Figure 5, the months on the x-axis represent billing dates. Thus, January reflects the Christmas / holiday break, and March 2020 reflects pre-COVID production in February 2020.

Figure 5 shows the monthly electricity savings in 2020. The equipment shutoff savings are compared to 2019 electricity use for the first 8 months. Since the equipment shutoff program was starting to show savings for the latter part of 2019, the study has switched the baseline for these months to 2018.

The figure shows that the program accounts for about 90,000 to 135,000 kWh of monthly savings. After the lockdown, the equipment shutoff savings were understandably smaller. The incremental reductions during lockdown were offset by the increased production rates the facility experienced when it began to catch up on lost production.

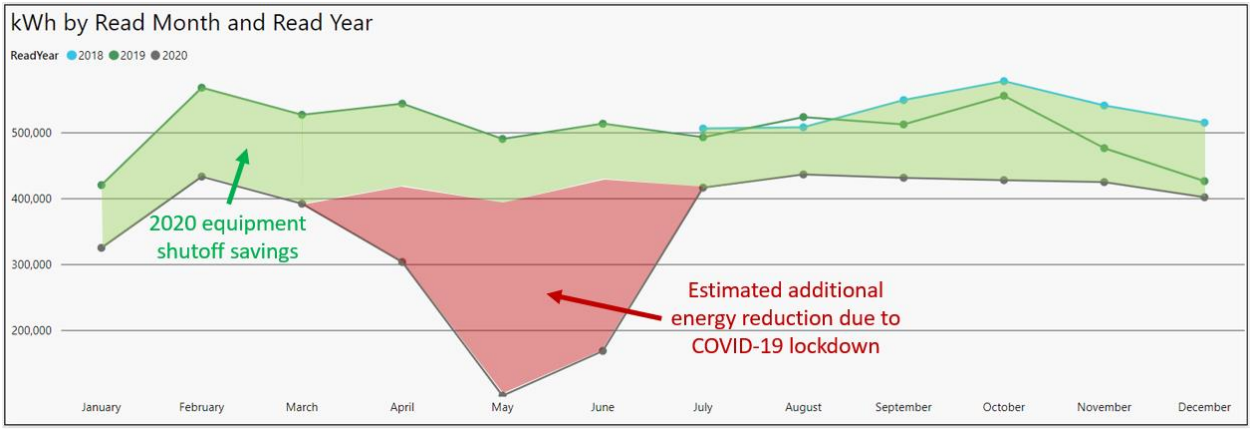

Figure 5. Monthly electricity savings, as billed to NSK for 2020.

Figure 6 shows that the average power output for 2018 and most of 2019 was approximately 900 kW on weekdays. The figure shows a significant drop in weekday energy demand in late 2019, to about 700 kW, and stays reduced through mid-March (when the plant was shut down).

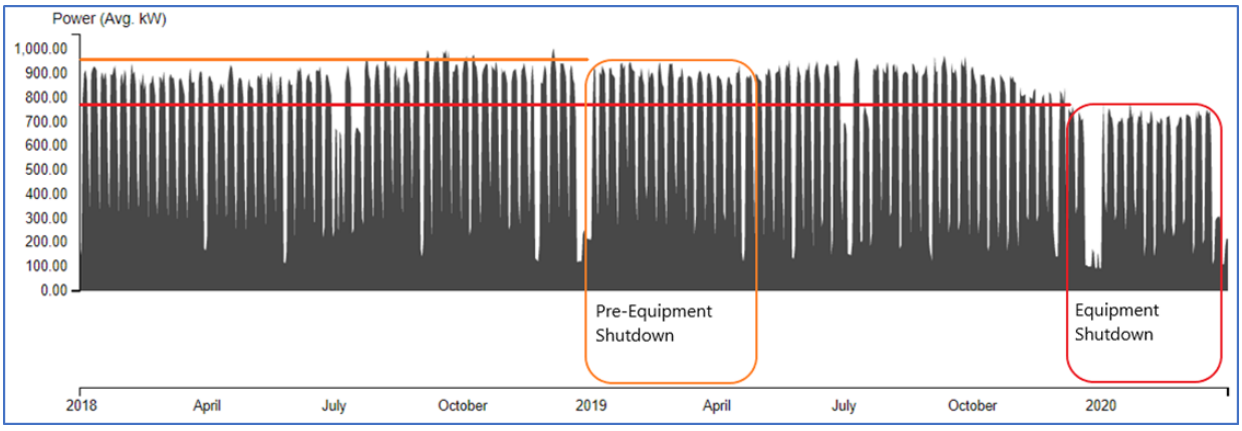

Figure 6. Daily average energy demand for 2018 to 2020 at the NSK facility.

Figure 7 is a heat map showing the date (x-axis) and time of day (y-axis). The colors represent different relative levels of electricity use: red / orange is high, yellow is medium, light green is low, and dark green is very low. The red / orange readings are not necessarily bad; they happen to be the highest readings recorded across the whole sample. The AMI heat map allows staff and researchers to deduce information such as:

- The time intervals of the three shifts
- How the first shift is more energy intensive than second and third shifts
- The times that the operators typically take breaks
- How weekends involve low or no production
- Occurrence of holiday breaks

Heat maps for other facilities can be designed to show the characteristics of other major systems like seasonal HVAC use, making evaluation relatively straightforward.

This heat map shows that in the fourth quarter of 2019, the electrical draw from the facility reduced significantly throughout all parts of the day, especially in the second and third shifts, when more machines might have been idling. In comparing the first quarters of 2019 and 2020, the color schemes are drastically different, demonstrating how much less energy intensive the facility had become by simply pressing the "off" button.

Table 2 shows that although the project was launched in July, significant savings did not occur until November. On subsequent electricity bills for January and February production the savings are more apparent. The data for the months affected by the COVID lockdown beginning in March 2020 prevented a simple comparison between consecutive years, thus making it difficult to derive prolonged savings. The facility shut down for a couple of months, then production levels became subsequently higher than usual to catch up with the production lost during the shutdown. Although an apples-to-apples comparison was not possible due to the lockdown, the electrical use for the rest of 2021 shows that the behavioral changes at NSK are not only present, but persistent.

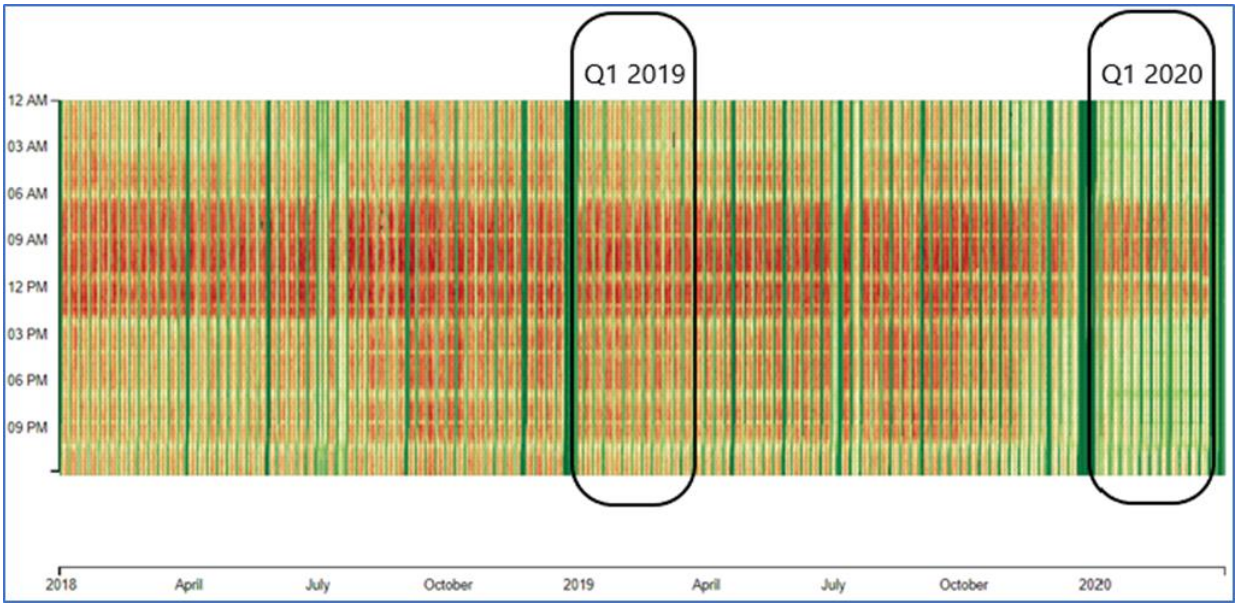

Figure 7. Heat map of electricity use for 2018 to 2020 at the facility (15-minute interval AMI data).

Table 2. Reductions in monthly kWh use at the NSK facility

Billing date	Total kWh	Billing date	Total kWh	kWh difference
April 6, 2018	507,983	April 8, 2019	544,235	- 36,252
May 5, 2018	516,991	May 7, 2019	490,673	26,318
June 7, 2018	535,032	June 6, 2019	513,771	21,261
July 9, 2018	506,477	July 8, 2019	493,136	13,341
August 7, 2018	508,354	August 7, 2019	523,901	- 15,547
September 7, 2018	549,691	September 6, 2019	512,677	37,014
October 8, 2018	578,349	October 8, 2019	556,131	22,218
November 6, 2018	541,388	November 6, 2019	476,706	**64,682**
December 6, 2018	515,390	December 5, 2019	426,646	**88,744**
January 7, 2019	420,605	January 6, 2020	325,385	**95,220**
February 6, 2019	568,484	February 5, 2020	433,521	**134,963**
March 7, 2019	527,386	March 5, 2020	392,398	**134,988**

Interactive Effects | Operator Comfort and Safety

Space Heating

Each machine on the facility floor produces waste heat that can offset heating costs in the winter months. When large numbers of machines are turned off, the resulting lower amounts of waste heat may necessitate more space heating to maintain occupant comfort and effective equipment operation. The amount of extra heat is dependent on the customer's facility-level preferences and precedent. Because of the variability in the amount of space heating necessary to make up for lost waste heat from equipment shutdowns, there is room for further exploration about typical manufacturing space needs to derive assumptions about the effect of the lost waste heat.

NSK did not see any significant changes in operator comfort or heating costs during the heating months.

Space Cooling

Conversely, lower amounts of waste heat can benefit operators and the manufacturing space by requiring less cooling and ventilation during the summer months. Like many manufacturing facilities, NSK has had to consider efficient workstation fans and other measures to keep operators cool under hot summer conditions. This project has helped to partially offset this issue.

Noise

Operator comfort is not restricted to just cooling and heating; noise is another feature of equipment operation. The reduction in the number of machines running in the facility could decrease ambient noise levels. Data from this likelihood remain to be explored further.

Safety

The reduction in running machines also translates to an improvement in safety. Manufacturing facilities are full of heavy machinery with powerful motors and kinetic force from moving parts. Despite the countless safety protocols in place, the facility space can always be made safer. Fewer moving parts mean fewer hazards in the workplace.

Interactive Effect | Power Factor

The implementation of the equipment shutoff program appears to have helped with the facility's power factor (PF) as well. PF is the ratio of working power to apparent power, expressed in a percentage of the electricity entering a facility that is being converted to run equipment. Some generic ways to improve PF in a facility:

- Installing a capacitor bank
- Replacing old motors
- Operating equipment near their rated capacity
- Minimizing the operation of lightly loaded or idling inductive equipment (for example, motors, presses, molding equipment, and HVAC)
- Installation of variable frequency drives on partially loaded equipment

The Shut-It-Off campaign has helped optimize the plant PF by eliminating lightly loaded or idling equipment, as shown in Table 3. The monthly PF readings from NSK's utility bills show how the campaign significantly increased the plant's efficiency for 2020.

Table 3. Monthly power factor at NSK's Bennington facility

Billing date	Power factor (%)
April 8, 2019	97
May 7, 2019	97
June 6, 2019	96
July 8, 2019	97
August 7, 2019	97
September 6, 2019	97
October 8, 2019	97
November 6, 2019	97
December 5, 2019	98
January 6, 2020	99
February 5, 2020	99
March 5, 2020	99

Most utilities require a minimum PF level of 90%, with penalties assessed on those who do not comply. NSK already had a high PF level (of 96 - 97%), which would have prevented them from any present or future penalties from the local utility, Green Mountain Power. That utility was ready to increase the 90% threshold to 95% in April 2020. Regardless, Table 3 shows

that the Shut-It-Off campaign increased NSK's PF to 99%. This is an added benefit to the efficiency of the facility.

For any facilities struggling to meet a utility's PF requirements, a Shut-It-Off campaign could be a cost-effective alternative to installing capacitor banks or replacing old motors. A kaizen event (continuous improvement or strategic energy management), energy treasure hunt tour, or sleeping plant tour[1] could help identify opportunities in a facility.

Interactive Effect | Compressed Air System

Compressed air is an extremely inefficient manufacturing commodity. When producing compressed air, the compression process turns approximately 88% of the electricity into waste heat. Thus, any reduction to compressed air use is a significant energy saver in any facility.

An effective method for reducing compressed air use is to reduce leaks. Typically, this means using ultrasonic detection equipment and then repairing identified leaks. However, unused compressed air can also "leak" from idling equipment, as well as from equipment that is turned off. The following two scenarios are typical:

- Equipment that has compressed air "running through" it, even when the machine is shut off, can be identified in a sleeping plant tour. By definition, these tours occur when the plant is not in operation; the relative quiet in the building makes it easy to hear and identify which machines are experiencing leaks.
- It is important too to identify idling equipment that is still consuming compressed air, as if the machine is on.

In both cases, there are ways to seal the machine from unnecessary compressed air use. Installing solenoid valves (shutoff valves) for compressed air lines on these individual machines is one common and effective method. These valves will close whenever the machine is turned off.

Figure 8 shows the reduction in compressed air use between 2019 and the first quarter of 2020. Turning off idling equipment appears to have stopped the unnecessary use of some compressed air in the system, thus further reducing the facility's electricity consumption.

[1] For more on kaizen events, energy treasure hunts, and sleeping plant tours, see Baker, Greg, 2017. "Tools to Build the Framework for Engaging Employees in Making Industrial Buildings Better." *Proceedings of the 2017 ACEEE Summer Study on Energy Efficiency in Industry*. Washington, DC: American Council for an Energy-Efficient Economy: 3-23 – 3-30. https://www.aceee.org/files/proceedings/2017/data/polopoly_fs/1.3687863.1501159043!/fileserver/file/790258/filename/0036_0053_000053.pdf.

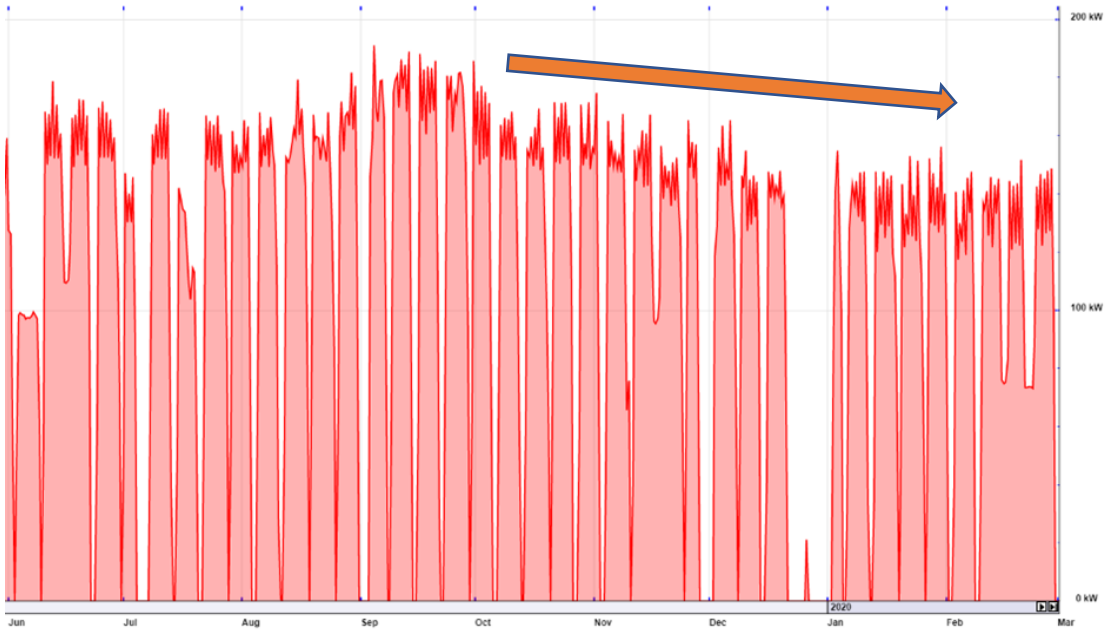

Figure 8. NSK's compressed air use from June 2019 through March 2020.

Interactive Effect | Equipment Longevity

Less equipment runtime means an increase in equipment longevity. In the Rhino 225 Press example, Efficiency Vermont estimated the elimination of approximately 1,120 hours of idle runtime per year. These hours quickly add up. The Shut-It-Off initiative shaved off significant numbers of run-hours of a machine, thereby adding years of service a machine can contribute to the facility's operations.

Electrical Operating Cost Savings

Some of the overall savings in the utility and AMI data come from other efficiency projects that NSK has undertaken with Efficiency Vermont (e.g., LED lighting upgrades). Assuming there might be other factors that are attributable to part of these savings, the Efficiency Vermont project staff have also applied a healthy margin of 10% to account for those factors.

Thus, the Shut-It-Off campaign appears to have saved NSK about 107,000 kWh per month, or $15,000 per month in electricity costs. That rate, annualized, could account for $180,000 in savings, assuming a normal production period (i.e., a time when extraordinary shutdowns are not occurring).

Conclusion

NSK's Bennington facility realized a reduction of 20 - 25% in electricity use by implementing a plant-wide equipment shutoff program. Conducting a sleeping tour plant and / or a kaizen event to tour the plant during normal operations (and even during different shifts) can help identify many opportunities for implementing energy efficiency measures. As for an equipment shutoff program, it is important to survey a facility's types of machines and the typical protocols for turning them off. The potential for compressed air "leakages" from

machines that are idling and off could add further value to an equipment shutoff program. These valuable pieces of information are essential to informing an effective Shut-It-Off program.

To better understand how much power an idling machine can consume and how often it is idling, building operators can spot-sample a few pieces of different equipment to submeter. This method quantifies the potential effects of a planned Shut-It-Off program.

Regardless of the magnitude of impact such a program could have on a facility, implementing a behavioral change is a cost-effective way to build a sustainable business, even if it requires persistence and patience.