More Snow for Less Energy: Is It Real?

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ABSTRACT

Snowmaking is a key part of the ski industry; without it, many mountains would not be able to sustain operations. The process is seemingly simple: combine high-pressure air with water at a low temperature, and you have snow. But, the amount of compressed air required to make the snow varies by a factor of 15 or more depending on the equipment and conditions, which represents significant energy savings potential. Because the amount of compressed air per gallon of water changes between the baseline and efficient conditions depending on the wet-bulb temperature, the magnitude of savings is dependent on how long the baseline and proposed guns are operated at various wet-bulb temperatures. There are many factors that affect the ability to quantify the snow-gun energy savings, including:

- Amount of natural snowfall
- Number of guns upgraded
- Size of the mountain's snowmaking operations
- Gun operator preference
- Water and compressed air system inefficiencies and capacities
- Electric versus diesel costs
- Compressor run time
- Water and compressed air flow rate
- Energy use data availability
- Snow quality

New snow guns are so efficient that they can enable operators to make more snow than the inefficient guns and extend the ski season, which makes baseline determination a challenge if only post-installation data is available. This paper provides analysts with methods to confidently assess the energy savings for snowmaking retrofit projects using rigorous, site-specific, measurement and verification based methods and a standardized calculator. Case studies illustrate the applicability of these methods and non-energy benefits associated with these projects.

Introduction

Standard efficiency snow guns can consume fifteen times as much energy as their high efficiency counterparts or more. They often represent some of the largest energy-saving projects in an energy efficiency program's portfolio, and as such, are frequently selected for review during impact evaluations. The savings from these projects come from the new, high efficiency guns' reduced compressed air consumption per gallon of water converted, or acre foot of snow produced.

Attempting to account for the many interactive factors is difficult because the efficiencies of the standard and high efficiency guns vary dramatically with weather conditions and operator preference. A season with high precipitation and low temperatures may require drastically less energy for snow production than one with higher temperatures and low precipitation. Because of the enormous reduction in compressed air and energy savings, installing high efficiency snow guns often allows ski mountains to extend their season, which can increase their revenue. It may also prompt a mountain to increase its water pumping or water storage capacity or change its rental patterns for diesel air compressors used to supplement the grid-based compressor plant. These factors may lead to increased snowmaking compared to the preexisting condition, which complicates the energy savings analysis. As is the case with the evaluation of savings from any energy efficiency measure, the data is not always as plentiful or as detailed as an analyst would like.

This paper explains the issues with, examples of, and methods for high efficiency snow gun retrofits. It describes the characteristics of typical upgrades and presents a standardized calculator to estimate energy savings prior to a project's installation. A custom approach is also presented and case studies are included to illustrate the application of this approach and to highlight the non-energy benefits achieved through snow gun upgrades.

Typical Preexisting Conditions for Snow-Gun Retrofits

The standard efficiency snow guns referred to in this paper have operating characteristics similar to those presented in Table 1, which was developed by averaging the performance characteristics of twelve preexisting snow guns at three mountains that underwent upgrades to high efficiency guns in the past 5 years. These guns include the SR7 ground and tower guns, ASC tower, Mountain View Technologies' K-2000 and K-3000E, Rogers Royal Knights, and Ratnik Snow Giant and Baby Snow Giant snow guns.

Table 1. Typical Air to Water Ratio of Standard, High, and Ultra-High Efficiency Snow Guns

Wet-bulb temperature	Standard efficiency	High efficiency	Ultra-high efficiency
Below 10°F	5	1.8	0.1
10°F–19°F	7	2.6	0.1
20°F–23°F	11	3.9	0.2
24°F–26°F	15	5.9	0.3
Above 26°F	30	7.2	0.7

The performance of these guns deteriorates with age. The particles in the water stream can build up in or near the nucleator, which mixes water and air to create ice crystals, and can negatively affect the ability of the gun to produce snow at its rated performance. However, the impact of these factors on the gun's performance can be hard to predict. The rated performance data from the manufacturer is often the most available resource for analysts to characterize the performance of a mountain's preexisting guns. However, flow meters can be used in the field to measure the water and air flow of snowmaking equipment.

There are many variations that an analyst may encounter when researching a mountain's snowmaking system. Mountains may have only standard efficiency guns, only high efficiency guns, or a mixture of both in the preexisting case. Projects can range in size from a few dozen upgraded snow guns to a few hundred; a mountain may have a handful of guns on a few trails, or it could have thousands spanning its total terrain. The snow guns can be mobile (sled-mounted) or fixed in place (on a tower), and be manually or automatically controlled. Figure 1 shows a typical, standard efficiency snow gun.

Figure 1. A typical, standard efficiency snow gun.

The elevation of the mountain, the air and water pressure, the length of the season, the temperature and precipitation, and the operation of the snow guns vary from project to project. Mountains will also differ on the depth of snow covering that is required to open a trail. A mountain might have diesel air compressors, electric air compressors, or a combination of both. Independent of the length of the ski season, snowmaking may happen only during November and December or from October to April.

Standard efficiency guns still have a place in today's snowmaking industry. Mountains use a variety of snow guns and are moving away from standard efficiency guns, except in situations where the terrain does not allow for the high efficiency technology or when they are forced to make snow in unusually warm temperatures (above 28°F wet-bulb). Ideally, ski resorts are moving away from making snow at the high, inefficient temperatures and instead are focusing on making more snow efficiently when colder temperatures (below 28°F wet-bulb) allow. There are limited applications where it makes sense to install only ultra-high efficiency snow guns because of the lower snow quality they produce at relatively warm temperatures. (C. Santry, President, HKD Snowmakers, pers. comm., March 3, 2015). When the standard efficiency guns are purchased, they are typically purchased for their ability to make high volumes of snow and high-quality snow – better quality than that produced by high efficiency guns – especially in warmer temperatures. Ski mountains sometimes select less efficient guns for their signature trails, which open at the beginning of the season. While it is possible to produce the desired amount and quality of snow across a mountain with only standard efficiency guns and high efficiency guns, this is not true for the ultra-high efficiency guns.

Baseline Considerations for New Construction and Capacity Expansion Projects

New construction and capacity expansion snowmaking projects are a different category from retrofit projects, which are the focus of this paper. In the case of new construction, there is no preexisting equipment and selecting an appropriate baseline can be a challenge, especially given the significant industry changes. Market adoption rates of snow guns often spark questions regarding the appropriate baseline for a project. This paper does not propose a definitive method for developing the baseline for new construction projects, but highlights the challenges faced in defining new construction baselines. The authors provide a case study that illustrates how they addressed an expansion in snowmaking capacity.

Typical Snow Gun Upgrades

High efficiency guns create snow using high pressure water and compressed air travelling through a small nozzle. Many of the projects surveyed for this paper upgraded to the HKD Impulse or HKD SV10 models. Both guns use internal mixing nucleation, where the creation of ice crystals occurs inside the head of the snow gun; however, the Impulse uses a hybrid combination of internal and external nucleation (where the ice crystals form in the atmosphere). Figure 2 shows a typical high efficiency snow gun. This gun, HKD Snowmakers' Viper, has variable airflow and can be classified as an ultra-high efficiency snow gun at its lower airflows.

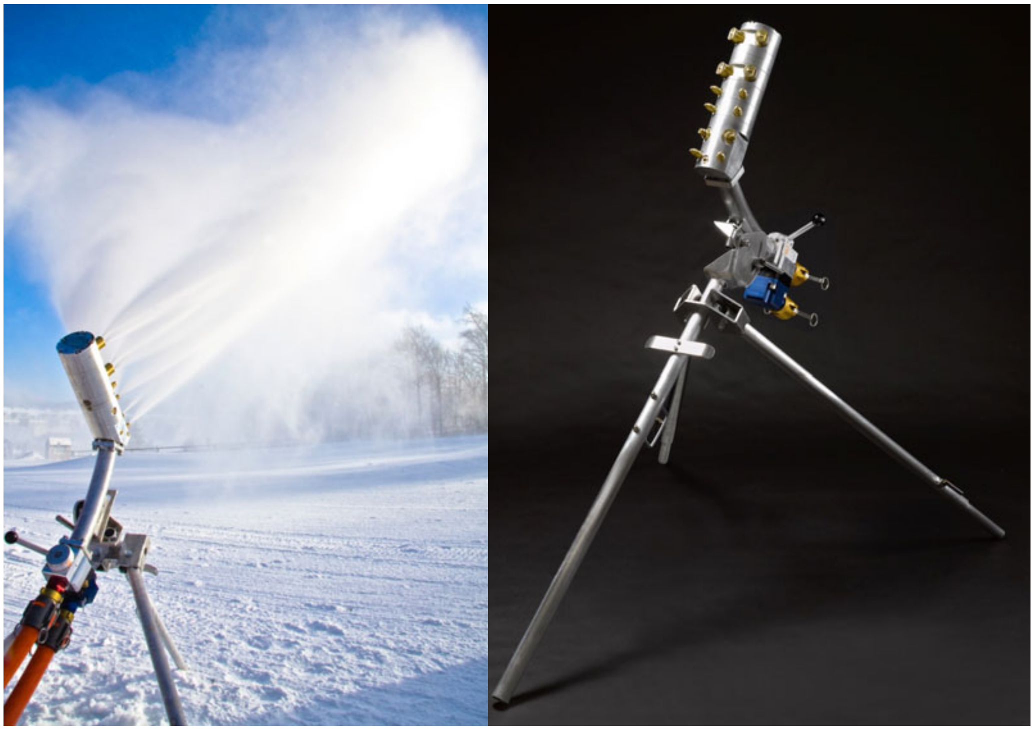


Figure 2. HKD Snowmakers' High Efficiency Viper Snow Gun. *Source:* Mark Horton, HKD Snowmakers.

The high efficiency guns described in this paper have operating characteristics equal to or exceeding the efficiencies presented in the middle column of Table 1, above. These values assume a delivered compressed air pressure of 100 psi and a water pressure of 250 psi. A comparison of the standard efficiency and the high efficiency guns' performance shows that the high efficiency snow guns are over twice as efficient as their standard efficiency counterparts.

Snow guns with performance equal to or exceeding the values presented in the far right column of Table 1, above, are considered ultra-high efficiency in this paper. These values assume an available compressed air pressure of 90 psi and water pressure of 600 psi. These ultra-high efficiency guns are almost twenty times more efficient than the high efficiency options at most points on the curve. This is mainly due to the nucleation package in the head of a snow gun and the angle, positioning, and volume of the water jet that meets the ice crystals created by the nucleation. The nucleation packages are proprietary to each snow gun manufacturer and have been developed to work with a specific air-to-water ratio either inside or outside of the chamber to create the ice crystals needed to seed the snow. After the crystals leave the nozzle, they are met with a jet of water that creates the majority of the snow by forming around the crystals (C. Santry, President, HKD Snowmakers, pers. comm., March 3, 2015). Ultra-high efficiency guns require higher water pressure than standard and high efficiency guns, are challenged in higher winds, and sacrifice snow quality in marginal temperatures. These facts limit many locations on the mountain where ultra-high efficiency snow guns can be used. Ski area operators must evaluate whether the ultra-high efficiency technology is appropriate for their application to realize this significant energy savings potential without sacrificing the quality of snow produced. Figure 3 shows a graph of the air-to-water ratios comparing snow gun efficiencies.

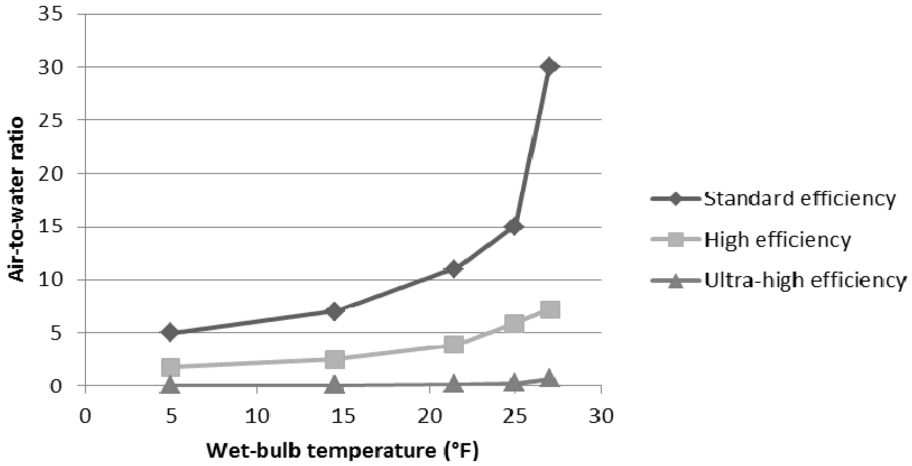


Figure 3. Comparison of snow gun efficiencies.

If compressed air capacity was the limiting factor in a mountain's snowmaking operations prior to the retrofit, the installation of high efficiency snow guns allows the mountain to pump more water with the same amount of or less compressed air.

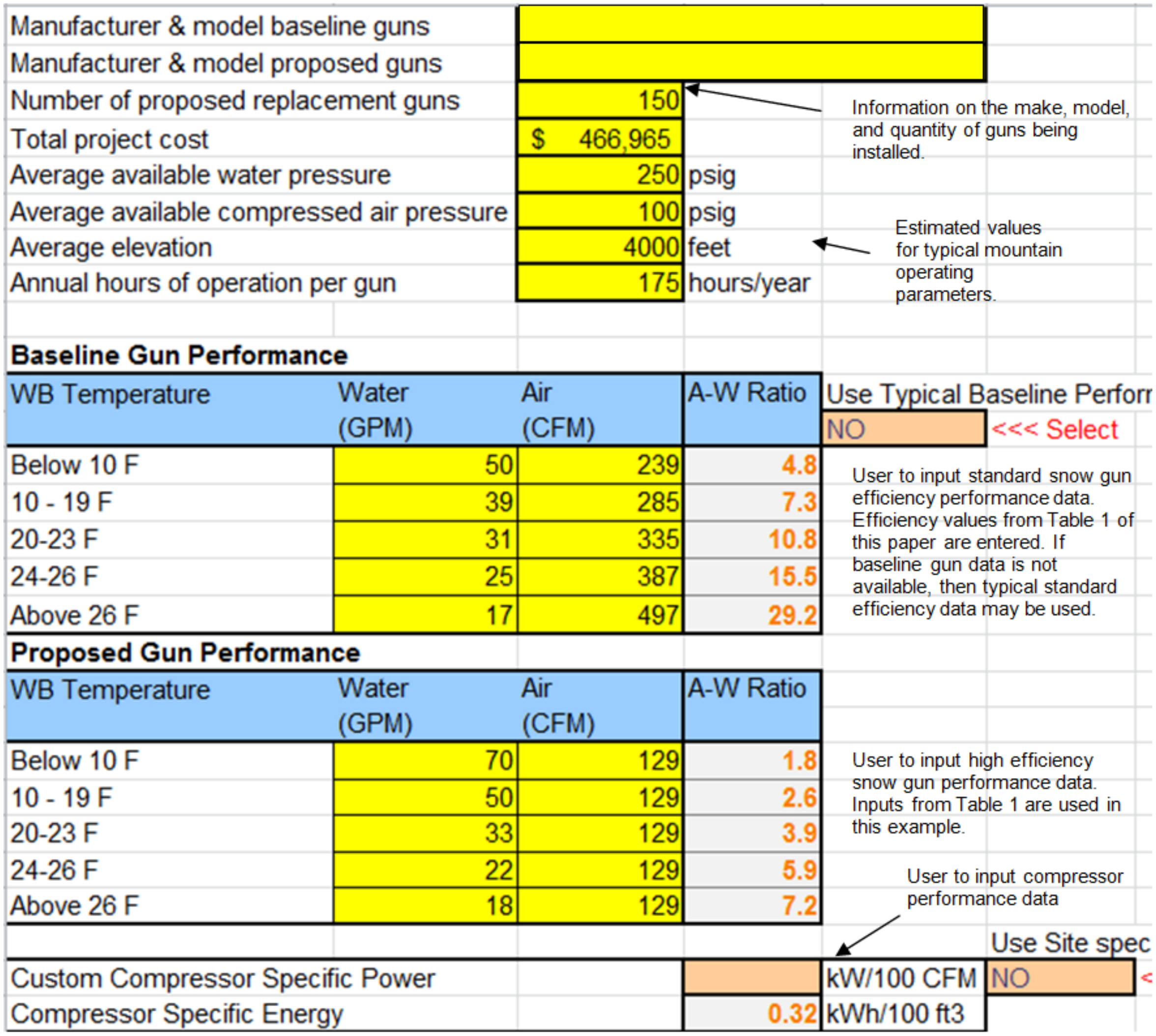
Standardized Calculator

ERS created a quasi-prescriptive approach that allows an efficiency program to predict the energy savings for snow gun upgrades based on equipment characteristics, weather data, and a few predictable operating characteristics. This approach is most useful when trying to estimate the energy savings prior to the completion of the upgrade. This analysis requires that an equal number of preexisting, standard efficiency guns are retired when the new, high efficiency guns are installed. In at least two states (Maine and Vermont), incentive programs require documentation of gun recycling or disposal to provide financial support to retrofit snow gun projects. The standardized calculator requires the applicant to input the following information:

- Manufacturer, model, and quantity of guns to be eliminated and guns proposed

- Manufacturer, model, capacity in cfm, and estimated run hours per year for each compressor used for snowmaking (if available)
- Average available water and compressed air pressure
- Average elevation
- Annual hours of operation per gun
- Existing and proposed gun performance data for five wet-bulb temperature bins

The tool contains a stipulated distribution of hours during which snow is made in each wet-bulb temperature bin. This must be site-specific; a temperature distribution for mountains in Maine differs significantly from those in California. The inaccuracy in this distribution can be a major source of discrepancy between the claimed and evaluated savings, as evidenced by the Hunter Mountain case study described later in this report. While it is impossible to know the exact temperature distribution of future snowmaking operations, it is worth using local weather data and information from the mountain to make an informed estimate. Figures 4 and 5 show the standardized calculator in spreadsheet format.



Manufacturer & model baseline guns		
Manufacturer & model proposed guns		
Number of proposed replacement guns	150	
Total project cost	$ 466,965	
Average available water pressure	250	psig
Average available compressed air pressure	100	psig
Average elevation	4000	feet
Annual hours of operation per gun	175	hours/year

Information on the make, model, and quantity of guns being installed.

Estimated values for typical mountain operating parameters.

Baseline Gun Performance

WB Temperature	Water (GPM)	Air (CFM)	A-W Ratio
Below 10 F	50	239	4.8
10 - 19 F	39	285	7.3
20-23 F	31	335	10.8
24-26 F	25	387	15.5
Above 26 F	17	497	29.2

Use Typical Baseline Perfor

NO <<< Select

User to input standard snow gun efficiency performance data. Efficiency values from Table 1 of this paper are entered. If baseline gun data is not available, then typical standard efficiency data may be used.

Proposed Gun Performance

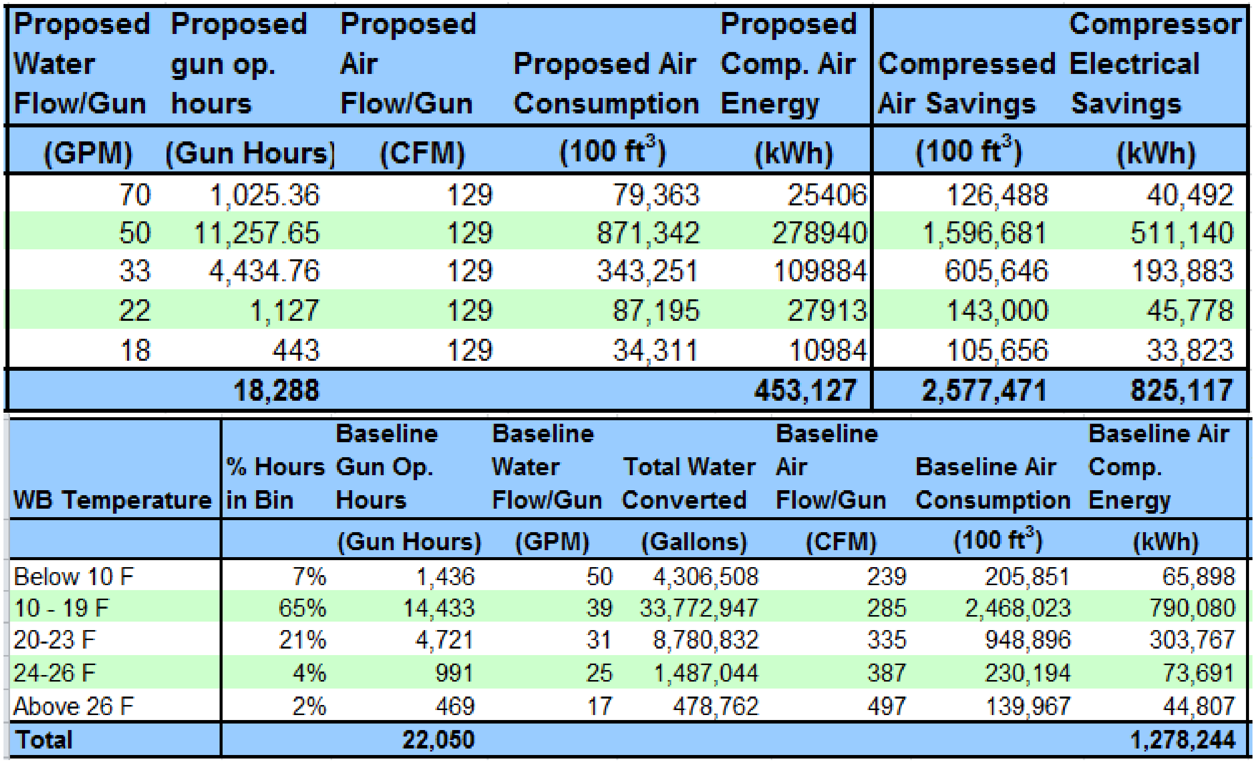
WB Temperature	Water (GPM)	Air (CFM)	A-W Ratio
Below 10 F	70	129	1.8
10 - 19 F	50	129	2.6
20-23 F	33	129	3.9
24-26 F	22	129	5.9
Above 26 F	18	129	7.2

User to input high efficiency snow gun performance data. Inputs from Table 1 are used in this example.

User to input compressor performance data

			Use Site spec
Custom Compressor Specific Power		kW/100 CFM	NO <
Compressor Specific Energy	0.32	kWh/100 ft3	

Figure 4. Standardized calculator input example.



Proposed Water Flow/Gun (GPM)	Proposed gun op. hours (Gun Hours)	Proposed Air Flow/Gun (CFM)	Proposed Air Consumption (100 ft^3)	Proposed Comp. Air Energy (kWh)	Compressed Air Savings (100 ft^3)	Compressor Electrical Savings (kWh)
70	1,025.36	129	79,363	25406	126,488	40,492
50	11,257.65	129	871,342	278940	1,596,681	511,140
33	4,434.76	129	343,251	109884	605,646	193,883
22	1,127	129	87,195	27913	143,000	45,778
18	443	129	34,311	10984	105,656	33,823
	18,288			**453,127**	**2,577,471**	**825,117**

WB Temperature	% Hours in Bin	Baseline Gun Op. Hours (Gun Hours)	Baseline Water Flow/Gun (GPM)	Total Water Converted (Gallons)	Baseline Air Flow/Gun (CFM)	Baseline Air Consumption (100 ft^3)	Baseline Air Comp. Energy (kWh)
Below 10 F	7%	1,436	50	4,306,508	239	205,851	65,898
10 - 19 F	65%	14,433	39	33,772,947	285	2,468,023	790,080
20-23 F	21%	4,721	31	8,780,832	335	948,896	303,767
24-26 F	4%	991	25	1,487,044	387	230,194	73,691
Above 26 F	2%	469	17	478,762	497	139,967	44,807
Total		**22,050**					**1,278,244**

Figure 5. Standardized calculator output example.

The calculator computes the cubic feet of snow production, compressed air required, and compressor energy use for each wet-bulb temperature bin directly from the input data, including appropriate calibration to site-specific elevation and pressure settings. Then, holding the snow production constant, the calculator computes the proposed system's air requirement using the new air-to-water ratio and, in turn, compressor energy use.

If the average specific energy of the on-site compressors is available, that value should be used. If not, 20 kW/100 cfm can be used as a standard value. This value was derived from 35 compressor data sheets from the Compressed Air and Gas Institute (CAGI) online compressor database (CAGI, 2012). These compressors were from three different manufacturers and had different capacities, cooling types, and other characteristics (standard and oil-free compressors were included). The specific package input power of these compressors, adjusted for part load consideration, was averaged to create this standard value.

This method requires some customized inputs from the site. Because of the many factors affecting snow gun performance, any method with fewer customized inputs than described above will not produce reliable results. It is also necessary to add in constraints for the preexisting water capacity or compressed air plant capacity at the mountain.

Case Studies

The three case studies that follow illustrate energy savings analysis methods and results for high efficiency snow gun upgrades. The first case study shows the method that ERS formulated to quantify the energy savings of these projects. The second describes one project's significant non-energy benefits, which are common byproducts of these types of installations and which serve as examples of the interactions between the pumping and compressor energy when assessing the savings. The third case study adds historical context to projects implemented in between multiple, consecutive seasons at one mountain by analyzing the effect the projects have had on the mountain's snowmaking operations.

Each case study was analyzed using custom analysis methods largely because there was post-installation data available. Should such data have been unavailable, the standardized calculator could have been used to estimate the savings. As will be illustrated by the case studies, even with comprehensive post-installation data, accurately quantifying the energy savings associated with snow gun upgrades is complex and can be subject to significant uncertainty.

Case Study 1: Custom Analysis Method with Post-Installation Operator Logs

The snowmaking upgrade at Hunter Mountain, in Hunter, New York, demonstrates a measurement and verification (M&V) based method to calculate the energy savings for a snowmaking project given a typical amount of data available to the analyst after the measure's installation. Hunter Mountain replaced 147 preexisting, standard efficiency guns with high efficiency models. This project resulted in an annual energy savings of close to 1,700,000 kWh. The original application used a method to predict savings that was similar to the quasi-prescriptive approach just presented. ERS later evaluated the project and, with the benefit of hindsight, found materially different savings (about 30% less than the original savings estimate).

A review of snowmaking shift operation logs from the season after equipment installation revealed markedly different annual hours and distribution of hours over the temperature bins compared to expectations. Other less significant adjustments that affect savings included adjusting production rates for the significant temperature distribution over the mountain. The timeline of the analysis did not allow for metering during the snowmaking season, so the analysis does not include metered data. The following steps outline the analysis method:

- The analyst calculated a unitary power input value (kW/cfm) for the compressors based on the manufacturer's performance data, the mountain's elevation, and the delivered air pressure.
- The snowmaking logs were used to derive a distribution of snow gun hours at various wet-bulb temperatures.
- In the absence of metering, rated performance data for the baseline and efficient case snow guns were verified against multiple baseline and efficient case snow guns seen in snow gun upgrade projects at other mountains.
- The compressed air required by the baseline and efficient snow guns was calculated for the amount of water converted in each snowmaking shift.
- The total difference between the compressed air used in the baseline case and that used in the efficient case was multiplied by the specific energy of the compressor, which determined the project's annual savings.
- The air compressor and water pump operating hours were used to validate the evaluation's assumptions and findings.
- The electric meter that served the snowmaking equipment was used to cross-check the evaluation results.

This spreadsheet-based approach included algebraic formulas to predict more precise air and water flows for each operating temperature as compared to the step function outlined by the manufacturer's specifications. The resulting regression equations determined the compressed air used in the pre-retrofit and as-built snow guns for each snowmaking shift, based on the gallons converted and the specific average temperature. The difference in calculated savings between using the step function and using the smooth algebraic equations to characterize snow gun performance was not significant.

The largest challenge in this analysis was the determination of the compressor plant unitary power and energy values because of the unavailability of metered compressor data. The site was not visited during the snowmaking season and the compressor system did not have an automated sequence of operations; thus, it was difficult to determine the overall efficiency of the compressor plant based on which compressors functioned as primary compressors, which functioned as trim or backup compressors, and whether this varied from month to month or year to year. If available, metered compressor data during the snowmaking season should be used to minimize this uncertainty.

The accuracy of the rated performance data for the pre-retrofit and as-built snow guns introduced doubt, especially because of the degradation of the pre-retrofit guns' performance over time. In the absence of metered data during the snowmaking season, this is the most reliable data available for use in an analysis. The uncertainty can be minimized by comparing the performance data to the data representing similar equipment installed on other mountains. Some uncertainty also exists regarding the accuracy and precision of the snowmaking log data representing average wet-bulb temperatures and the number of snow guns used in each snowmaking shift over the sample year. This uncertainty will be reduced as the automation of the snowmaking operations increases, which will decrease the opportunity for human error.

This method is appropriate for analyzing the energy savings of one-for-one snow gun replacement projects with at least one complete season of post-installation data. It is also crucial that the snowmaking logs capture the run time of the replaced guns only, or separate the retrofitted snow gun hours from those of the guns that were not replaced. If the total number of snow guns changed around the time of the project, if a complete season of post-installation gun run time is not available, or if it is impossible to separate the run-time hours of the guns replaced through the project from the unchanged snow guns, this method becomes invalid.

Case Study 2: Pumping Energy Usage, Non-electric, and Non-Energy Benefits

Peek N Peak, a ski area in Clymer, New York, is an example of the complexity of the energy impacts associated with snow gun upgrades and illustrates the common non-electric and non-energy benefits resulting from these types of projects. The mountain recognized that the project would reduce the compressed air required per acre foot of snow to the point that the water pumping capacity would replace the compressed air capacity as the limiting factor in its snowmaking capacity. To make as much snow at once as the compressed air capacity would allow, the mountain almost doubled its water delivery capacity as part of the project. This required the analysts to calculate a water-pumping penalty associated with the project. Alternatively, calculating this portion of the savings as a new construction project could also be considered and would involve a two-tiered baseline of preexisting snow gun efficiency and new, standard gun efficiency for the capacity expansion.

Additionally, the mountain had used diesel-fueled air compressors to supplement the electric compressors to make as much snow as soon as possible at the beginning of the season. The mountain has not needed to rent these diesel compressors in the last two post-installation years. The increased water capacity and ability to make more snow more quickly allowed the mountain to add 2 weeks to the beginning of the ski season. These additional non-electric benefits required that the evaluators convert some of the electricity savings into diesel fuel savings (which increased the accounting of the project's carbon reduction), adjust the length of the two post-installation seasons to reflect the shorter season that would have occurred without the upgrade, and limit the snow produced at one time to the pre-installation maximum.

This project also illustrates an example of how applying a quasi-prescriptive approach would have been challenging. Not only did this upgrade represent an expansion in capacity, it also resulted in significant diesel fuel savings and increased pumping energy – neither of which is accounted for in the standard method. In such an instance, the standardized calculator could be used to project the compressor energy savings, assuming the capacity expansion baseline was similar to the existing snow guns, but the custom post-processing and mountain-specific information would still be required to accurately quantify the electric versus diesel benefits of the project and determine the pumping penalty associated with the upgrade. The pumping penalty presents additional complexity to the analysis, as it requires knowledge of whether the pumps are constant or variable speed, and whether the pressure on the pumps is relatively constant.

Case Study 3: Historical Context

Evaluating a project or reviewing it for rebate approval can take the project out of the context of past efficiency upgrades, especially if the historical data is not submitted with the project files or application. Sunday River, a ski mountain in Maine, serves as an example of the typical effect of snowmaking upgrades across many consecutive seasons. The mountain has roughly 2,200 total snow guns on its trails and has upgraded up to few hundred guns over the past 20 years. It has also collected 15 years of snowmaking water consumption and electrical usage data that shows the cumulative effect of the upgrades. Figure 3 shows the historical compressor energy and water used for the snowmaking at Sunday River.

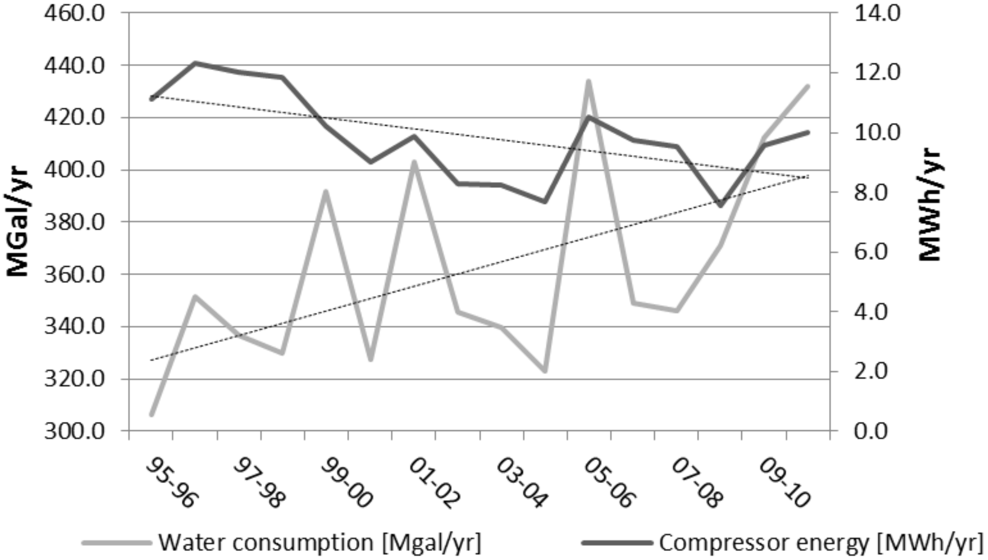


Figure 3. Historical water and energy consumption data at Sunday River.

No diesel compressors have been used at Sunday River since 1995. It is obvious that compressor energy has decreased over time, yet the water usage increases sharply. This graph illustrates that, while these high efficiency guns save energy, they allow a significant increase in snowmaking capacity at a mountain and should not be treated as an apples-to-apples replacement of a standard efficiency gun. In any accurate evaluation of a snowmaking project, the capacity increase allowed by the guns must be considered.

Sunday River opened up new trails over the course of this timeline, which account for some of the increased water usage. Like the Peek N Peak project, this increase in water usage necessitates an increased pumping capacity, which must be accounted for in the analysis. As illustrated in the second case study, above, the question of capacity expansion comes into play.

The analyses of these snow-gun upgrade projects require a comprehensive assessment of the effects on the snowmaking system as a whole. The calculator would be insufficient for this situation, as it ignores the increased trail coverage, pumping capacity, and potential early start to the snowmaking season. The custom approach could be used as long as the operation of the guns that were replaced on a one-to-one basis could be separated from the rest of the mountain's snow guns.

Exceptions to the Rules

Despite the attempts made to account for the major variables in a snowmaking project and the substantial data logs, it is still possible that the uncertainty of the project is greater than 100% of the project savings. ERS has experience with two scenarios where this was the case:

- In the first analysis, the mountain supplied the detailed logs of the air flow, water flow, and snow gun run time, and the installed snow guns made up roughly 10% of the total snow guns on the mountain. It was impossible to determine the savings because of too much variation in the system's operation from year to year and too much uncertainty in the savings due to the relatively small number of snow guns upgraded compared to the overall system capacity.
- In the second case, although the snow gun run-time hours, compressed air, and water data were provided, ERS was unable to corroborate the snow gun hours with the compressed air and water data provided. This led to a level of uncertainty that required the project to be deemed un-evaluable.

In both of these cases, the standardized calculator may be the only means of estimating the measure savings. This estimate could be checked against the custom analysis methods and metered data from the mountain to determine if the calculator's estimates are reasonable and within the uncertainty projected with the detailed airflow, water flow, and gun run-time data. If it is within the uncertainty, and if the required level of rigor of the analysis allows for it, the results of the calculator may be used to arrive at an estimate of savings, even when more custom approaches fail.

Conclusion

Because the efficiency of the standard, high, and ultra-high efficiency guns varies widely with wet-bulb temperature and precipitation in a given year and greatly affects the amount of snow that a mountain will produce, it is impossible to predict exactly how much snow will be produced or at what efficiency, even if extensive data is available. It is clear that the high efficiency guns and ultra-high efficiency guns consume significantly less energy per snowflake produced than standard efficiency guns; however, snow gun upgrades often come with non-energy impacts – specifically, an increase in a mountain's revenue through a longer ski season with more terrain open at any given time, a mountain's ability to transition off of diesel-powered compressors, or an increase in snowmaking capacity. These benefits often result in energy savings and greater snow production, which become apparent when looking at the cumulative effect of a mountain's consecutive seasons of snow gun upgrades.

Both the rigorous and semi-prescriptive methods are available to calculate the energy savings for high efficiency snow gun projects. It is always advisable to use site-specific information in an analysis when possible, but detailed pre-and post-installation information are not always available – especially in the case of a project's analysis prior to the rebate approval. In either situation, it is advisable that program implementers verify that the existing compressed air plant capacity is capable of serving the predicted production levels with the pre-retrofit equipment to verify that a retrofit baseline is appropriate. The accuracy of a snowmaking retrofit analysis is highly dependent on the availability of detailed, post-installation snowmaking logs for the retrofit guns, compressor performance and sequencing, and pumping system specifics such as the variability of flow, pressure, and consistency of water draw from season to season. While not all snowmaking projects are the same, when installed as a retrofit of existing guns, these projects unquestionably result in substantial energy savings.

References

CAGI (Compressed Air and Gas Institute). 2012. *Performance Verification Data Sheets.* http://www.cagi.org/performance-verification/data-sheets.aspx