Snowmaking Optimization for Select Québec Ski Areas

Prepared for:

Association des stations de ski du Québec

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Disclaimer

The views expressed and recommendations made in this report are those of the authors, consistent with the commissioning of this work as an independent assessment. This report is intended to provide ASSQ and its member ski areas insights into the opportunities for increased snowmaking efficiency, lowering operating costs, and decreasing carbon emissions.

Executive Summary

The Association des stations de ski du Québec (ASSQ) commissioned VEIC to review ten ski resorts operating in the province of Québec to determine the relative energy efficiency of snowmaking operations in Québec and identify opportunities to reduce energy use and lower operating costs. These 10 resorts are thought to be representative of all ASSQ members and feature a variety of weather and terrain conditions, snowmaking equipment, and operating capacities. A table displaying the current state of operations for all ten participants is provided below:

Description	***Units***	***Average***	***Median***	***Sum***
Annual Water Usage	gallon/year	31,616,37	24,500,000	316,163,773
Pump Output Rating	gallons/minute	1,180	1,100	11,800
Snowmaking Acreage	acres	91	70	908
Est. Annual Snow Production	acre-feet	176	136	1,756
Est. Average Snow Depth	feet	1.8	1.7	-
Snowmaking Elevation Head	feet	692	569	-
Snowmaking Electric Usage	kWh/year	600,906	425,970	6,009,060
Snowmaking Energy Intensity	kWh/acre-feet	2,947	2,271	-
Cost of Snowmaking Electricity	$/kWh	$0.1400	-	-
% of Resort Electricity Use	%	27.4%	28.8%	-
% of Resort Electricity Cost	%	28.7.%	30.3%	-
Estimated Carbon Emissions	kilograms/year	300	213	3,005

The study participants collectively used an estimated 6,009,060 kWh to manufacture snow during the 2018/2019 ski season. Using Hydro-Québec's publicly disclosed carbon intensity value of 0.5 kg CO_2/MWh, the total carbon emission from this sample attributable to snowmaking total approximately 3,005 kg. Carbon emissions due to snowmaking that are not considered include any equipment that is diesel or gasoline powered (groomers, snowmobiles, compressors, generators) and oil or gas-fired heating equipment that is used by the snowmaking operations team. Resorts that use mobile snow guns will therefore have a higher carbon intensity since fossil-fuel fired machinery is used to move these guns around the mountain.

Analysis of the sample also revealed that the average snowmaking energy intensity is approximately 3,000 kWh/acre-ft. For comparison, the energy intensity of resorts located in the Northeast U.S. averages ~3,500 kWh/acre-ft, and ~6,000 kWh/acre-ft for resorts located in the U.S. Rocky Mountains. This metric is used to determine how much energy is used to produce one acre of snow; one foot deep (0.3 meters). Warmer climates and increasing vertical drop adversely affect the energy intensity of snowmaking. This statement was again validated in this sample, with the resorts featuring the most vertical drop and warmest weather having some of the highest snowmaking energy intensities.

Review of the participant's snowmaking systems revealed a wide range of sophistication, with some resorts relying on simple systems with limited equipment, infrastructure, and capabilities, and other resorts utilizing complex systems with high capacity, redundancy, and a varying level of control and automation. In studying these facilities, we identified measures that will save the group: 1,489,180 kWh/year in electricity, 2,846 kW in demand, $293,875/year in cost savings, 744 kg in carbon reduction, at a cost of $837,975, for a Return On Investment (ROI) of 35.1%.

Identified Savings Summary

Resort Name	Measure Costs ($)	Savings (kWh)	(kW)	($)	(kg/yr Carbon)	ROI (%)
Ski Sutton	170,175	173,880	379	42,170	87.0	24.8
Le Massif de Charlevoix	113,710	293,780	453	56,400	146.8	49.6
Val Saint Come	866,600	485,300	537	91,130	242.8	10.5
Mont Orford	60,955	117,920	282	59,760	59.0	98.0
Ski Montcalm	68,230	85,880	191	16,215	42.9	23.8
Belle Neige	68,940	105,870	304	20,730	52.9	30.1
Sommet Morin Heights	387,020	201,400	592	41,330	100.9	10.7
Mont Rigaud	73,300	63,430	134	9,900	31.7	13.5
Vallee Bleue	66,750	17,540	45	4,040	8.9	6.1
Parc Du Mont St-Mathieu	29,775	39,420	99	8,750	19.8	29.4
Totals	1,905,455	1,584,420	3,016	350,425	792.7	18.4

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1.0 Introduction

Association des stations de ski du Québec (ASSQ) represents 75 ski areas throughout Québec and has commissioned a study to help their member ski areas prepare for the future. Snowmaking is a key piece of the ski area operations and long-term infrastructure needs – especially in response to changing climate. ASSQ member ski areas need to better understand their snowmaking systems in place, their energy use, and the opportunity for making system and equipment upgrades in the future. To achieve this in a cost-effective way, ASSQ identified the following 10 ski areas as representative of the broader spectrum of the 75 total ski areas:

- Mount Sutton
- Le Massif de Charlevoix
- Station touristique Val Saint-Côme
- Mont Orford
- Ski Montcalm
- Belle-Neige
- Sommet Morin Heights
- Mont Rigaud
- Centre de ski Vallée Bleue
- Parc du Mont Saint-Mathieu

This data-informed, province-wide assessment of equipment and historical operational performance at 10 ski areas will allow ASSQ member ski areas to maximize capital investments towards achieving improved snowmaking energy efficiency, greater operational resilience to climate change, and favorable return on investment. Assessing snow production, localized weather impacts, equipment efficiency, and existing barriers that are preventing system optimization will inform ASSQ in the prioritization of projects and provide for more informed planning for future expenditures.

1.1 Methodology

To deliver the information and analysis requested by ASSQ in the call for tenders, VEIC used a customized methodology aimed at providing the desired information with the optimal level of detail – balancing accuracy and cost.

VEIC held a kick-off meeting with ASSQ staff, and representatives from Hydro-Québec via telephone. In this meeting, we reviewed our proposed project plan and gathered input from ASSQ representatives. The VEIC team the gathered data on current snowmaking systems and energy use at each ski area. The VEIC team worked in coordination with ASSQ personnel and the 10 ski areas identified in the call for tenders to identify and catalog the snowmaking systems and infrastructure that are used at each ski area. VEIC also conducted telephone interviews with snowmaking managers at each site to gain further insights into existing systems and equipment used, their condition, and to identify any possible issues. VEIC conducted an analysis of current snowmaking performance at each ski area. The VEIC team used information collected to perform the following services:

- Evaluate the addition of automation and controls to improve energy efficiency and snow production for Québec ski areas.
- Evaluate the possibility of burying water supply pipes of snowguns and fans.
- Evaluation of systems or procedures to manage electricity peaks and the possibility to reduce power consumption during winter peaks of Hydro-Québec.
- Identify recommended snowmaking upgrades and develop scenarios

VEIC performed energy savings, carbon emission reductions, and economic analysis for list of upgrade measures:

- Develop CapEx estimates for recommended upgrades
- Run life-cycle cost analysis on option to install new measures against baseline of no upgrade
- Develop prioritized list of snowmaking upgrade opportunities that achieve cost savings through efficiency and optimizing performance.

Using the evaluation and analyses, VEIC staff developed recommendations for improving snowmaking efficiency, operational performance, and cost effectiveness at each ski area identified in the call for tenders.

2.0 Energy Analysis of Snowmaking Systems

The 10 ski resorts participating in this study utilize snowmaking systems that range from very simple systems with a single snowmaking pump, three fan guns, and long hoses for water, to very complex systems with retention ponds, multiple water pump stations, variable flows and pressures, compressor plants, VFD's, sophisticated networks of water and air piping, and snowgun automation. Most resorts report commencing snowmaking operations in early to mid-November, with operations completing in late December or early January. Participants who are limited in snowmaking capacity or are located in warmer climates reported they need to make snow later into the season. Numerous participants also commented that they cease snowmaking prior to January to avoid high electric demand charges. Reviews of the utility bills revealed that certain resorts do finish making snow by the end of the calendar year, while others continue to make snow into February.

Review of the data collected from each resort survey reveals a wide range of snowmaking equipment and capabilities at the participating resort. A summary of these capabilities is provided in the tables below:

Resort Name	Annual Water Usage (gal/yr)	Pump Output Rating (gpm)	Snowmaking Acreage (acres)	Annual Snow Production (acre-ft)	Average Snow Depth (ft)
Parc Du Mont St-Mathieu	9,250,000	400	32	51	1.6
Ski Montcalm	11,000,000	450	40	61	1.5
Centre de ski Vallée Bleue	10,800,000	450	50	60	1.2
Mont Rigaud	16,000,000	600	60	89	1.5
Belle-Neige	20,000,000	700	70	111	1.6
Sommet Morin Heights	29,000,000	1,500	70	161	2.3
Mont Sutton	41,333,680	1,500	115	230	2.0
Mont Orford	50,280,093	2,400	162	279	1.7
Val Saint-Côme	58,500,000	1,500	134	325	2.4
Le Massif de Charlevoix	70,000,000	2,300	175	389	2.2
Average	31,616,377	1,180	91	176	1.8

Table 1: Snowmaking Water Use and Acreage

As indicated in Table 1, the average snow depth for each resort did not deviate strongly from the sample average of 1.8 feet (0.55 meters). This is encouraging since deep slabs represent wasted energy and cost if they remain after the season ends. An exception to this would be terrain parks, where snow is heaped for features. Earth work is nonetheless strongly encouraged on trails and in terrain parks to reduce the amount of snow that must be made to cover terrain variations or build terrain park features. All other trends relating to water usage and snowmaking are nearly linear, as can be observed above.

2.1 Energy Consumption

Significant amounts of energy are needed to manufacture snow from water. Energy is first needed to move water from a source to the slope, where additional energy is needed for nucleation and distribution of the water droplets. Nucleation is usually carried out with the aid of pressurized air. Pressurized air also acts as a motive force for the droplets with air/water snowguns, while the motive force is provided by a fan with aptly classified fan guns.

Pressurizing air requires the use of a compressor. Typical air compressor designs used for snowmaking include centrifugal, screw, and reciprocating, and often exceed a total electric demand of 1MW. Air compressors use approximately 20 kW per 100 ACFM of compressed air produced. Snowguns requiring a large volume of compressed air therefore consume a significant amount of energy and increase electric demands for a resort.

In addition to air, water for snow must be pressurized in order to flow up the hill to the snowgun. Traditional turbine or centrifugal pumps are used to perform this operation, sometimes in series to boost the pressure high enough to overcome the elevation gain and resistance of the piping network (static head). The vertical drop of the snow making system (elevation head) therefore influences the pumping power requirements, with higher elevation heads needing higher power. Small-diameter pipes and other flow restrictions (elbows, valves, junctions, etc.) also increase the static head and consequently pumping requirements.

The combined power requirements of air compressors, water pumps, and fans constitute a significant portion of a ski resort's electric usage. To quantify this amount, electricity for snowmaking was disaggregated from each participant's electric utility data. Utility data was provided by Hydro-Québec. Each resort was asked to identify which accounts were affiliated with snowmaking. Using this electric use data as well as the water data detailed in table 1, the electric use and energy intensity of each ski resort's snowmaking operation was calculated. Table 2 depicts the results of this analysis. The table is sorted according to the elevation head of the snowmaking system.

Resort Name	Annual Electric Usage (kWh/yr)	Energy Intensity (kWh/acre-ft)	Snowmaking Elevation Head (ft)	Carbon Emissions (kg/yr)
Le Massif de Charlevoix	852,960	2,193	-100	426
Centre de ski Vallée Bleue	58,800	980	364	29
Mont Rigaud	171,720	1,932	394	86
Ski Montcalm	143,520	2,349	450	72
Belle-Neige	224,640	2,022	515	112
Parc Du Mont St-Mathieu	104,400	2,032	728	52
Sommet Morin Heights	627,300	3,894	623	314
Val Saint-Côme	898,200	2,764	984	449
Mont Sutton	1,069,800	4,659	1,133	535
Mont Orford	1,857,720	6,651	1,601	929
Average	600,906	2,947	669	300

Table 2: Snowmaking Energy Use, Intensity, and Carbon Emissions

Table 2 shows a strong correlation between energy intensity and elevation, with a possible reason explained in the previous paragraphs. The obvious outlier using elevation head as a determining factor is Le Massif de Charlevoix, which has the snowmaking ponds, pump, and compressor stations at the summit. Gravity therefore aids in their onsite pumping operation. They do, however, need to pump all their water from a lake offsite, which offsets some of the energy advantages of having a retention pond at the summit.

Other possible explanations for differences in energy intensity between resorts include efficient/inefficient snowguns, air and water leaks, no onsite water source, number and frequency of interruptions, start-up time, purge events, compressor controls, and more. The electric data does not indicate the nature of inefficiencies. It does however illustrate whether a resort may have a problem, or if their snowmaking equipment is not energy efficient. The average energy intensity of the sample is ~3,000 kWh/acre-ft, with a median sample value of ~2,300 kWh/acre-ft.

Carbon emissions due to snowmaking were calculated using the collected electric usage data, as well as Hydro-Québec's published carbon intensity value of [1]0.5 kg CO_2/MWh. The total carbon emission from this sample attributable to snowmaking total approximately 3,078 kg. Carbon emissions due to snowmaking do not include any diesel or gasoline powered equipment

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[1] https://www.hydroQuébec.com/data/developpement-durable/pdf/co2-emissions-electricity-2019.pdf

(groomers, snowmobiles, compressors, generators) which power the system or move snowguns around the mountain.

2.2 Operating Cost Comparison

As mentioned in the previous section, snowmaking operations consume a large amount of energy and constitute a large percentage of a ski resort's total energy use. The utility data provided by Hydro-Québec was analyzed according to its function to create Table 3, depicting the percentage of electricity used for snowmaking operations versus the entire resort. Also calculated and included in Table 3 is the percentage of each resort's electric cost that is attributed to snowmaking.

Resort Name	*Electricity Usage*			*Electricity Cost*		
	Entire Resort (kWh/yr)	*Snowmaking* (kWh/yr)	% of Entire Resort	*Entire Resort* ($/yr)	*Snowmaking* ($/yr)	% of Entire Resort
Centre de ski Vallée Bleue						
Ski Montcalm						
Parc Du Mont St-Mathieu						
Mont Rigaud						
Belle-Neige						
Val Saint-Côme						
Mont Sutton						
Sommet Morin Heights						
Mont Orford						
Le Massif de Charlevoix						
Average	2,196,847	600,906	27.4%	$294,686	$84,106	28.7%

Table 3: Electricity Usage and Cost Summaries

This sample revealed that the percentage of each resort's electric use attributable to snowmaking ranges between 17-38%. The percentage of each resort's electric cost attributable to snowmaking did not necessarily align with their usage percentage. In most cases, resorts paid more for the electricity used for snowmaking than all other services. Table 4, which compares the blended cost of electricity per resort and function further articulates this point.

Resort Name	*Entire Resort* ($/kWh)	*Snowmaking* ($/kWh)
Val Saint-Côme	$0.1225	$0.1176
Centre de ski Vallée Bleue	$0.1231	$0.1151
Le Massif de Charlevoix	$0.1232	$0.1358
Parc Du Mont St-Mathieu	$0.1240	$0.1254
Belle-Neige	$0.1289	$0.1456
Mont Rigaud	$0.1314	$0.1323
Ski Montcalm	$0.1334	$0.1590
Mont Orford	$0.1376	$0.1398
Mont Sutton	$0.1392	$0.1596
Sommet Morin Heights	$0.1583	$0.1451
Weighted Average	$0.1341	$0.1400

Table 4: Average Electricity Cost

The difference between the resort wide and snowmaking electricity rates is in part due to the intermittent and high demand nature of the snowmaking operations. Rates tend to favor constant loads as opposed to large intermittent peaks, which stress the electrical network and are more difficult for a utility to serve cost-effectively. Since most snowmaking operations utilize high horsepower air compressors and water pumps and only operate for 400-700 hours per year, they pay a significant amount in demand charges, leading to a higher than average blended electric rate.

One strategy to lower the cost of electricity is to consolidate electric machines of a similar power that do not operate at the same time on to the same account. An example of this would be fan guns on the chair lift circuit. Many resorts that operate fan guns use the same power supply as the chairlifts and operate when the chairlift not running. By doing this, the customer is only paying for the demand once. This strategy increases the utilization factor (FU) and lowers the demand costs. Additional opportunities to reduce electricity costs will be described in the following sections.

Electrical Cost Saving Opportunities

Analysis of each resorts' electric use and cost has revealed a discrepancy between the price paid for electricity by each resort. For most of the study participants, snowmaking operations paid a higher blended electric rate than other users at the resort. While the nature of this discrepancy is largely understood, significant cost savings were also identified while reviewing utility data. These cost savings are described and quantified in the following section and would help to lower the blended rate of electricity paid for snowmaking.

Power Factor Correction

Nearly all study participants had at least one electric account that was being financially penalized, due to a poor power factor. Some of these penalties are quite high and contribute significantly to a high cost of operation. Utility accounts were selectively reviewed according to the blended rate, difference between the recorded kW and kVA, and minimum billed demand. The power factor correction cost and electricity cost savings were then calculated for each reviewed account. Table 5 summarizes the power factor correction estimates:

Resort Name	Total Power Factor Costs (CAD/yr)	Est. Capacitors Needed (kVAR)	[2] Estimated Capacitor Cost (CAD)[2]	Est. Simple Payback (years)
Belle-Neige	$3,088	54	$4,050	1.3
Le Massif de Charlevoix	$17,477	559	$41,925	2.4
Montcalm	$2,555	43	$3,225	1.3
Mont Orford	$36,101	669	$50,175	1.4
Parc Du Mont St-Mathieu	$3,726	85	$6,375	1.7
Mont Rigaud	$0	0	$0	0.0
Mont Sutton	$10,380	375	$28,125	2.7
Sommet Morin Heights	$0	0	$0	0.0
Val Saint-Côme	$2,722	69	$5,175	1.9
Centre de ski Vallée Bleue	$1,811	68	$5,100	2.8
Total	**$77,860**	1,922	$144,150	**1.6**

Table 5: Power Factor Penalties and Correction

The possible power factor savings identified in this review amount to nearly $78,000 per year. Nearly $49,000 of this savings is due to the avoiding the specific power factor penalty, with the other $29,000 in savings due to reductions in demand charges.

Realizing these savings will require the installation of capacitors, needed to correct the power factor. An installed cost of $75CAD/kVAR has been used to estimate the power factor correction cost and estimate a simple payback for these improvements. Review of the utility data also indicated that a few of the penalized accounts may already have a capacitor bank installed but still suffer from a poor power factor at certain times of the year. In these instances, the temporary power factor problem may be due to the location of the capacitors, the control technique, or an interruption in operation. Since much of the necessary equipment would already be in place, it is expected that such problems could be addressed at a relatively low cost.

Use of Short-term, Flexible, and Curtailable Electricity Tariffs

In addition to power factor correction, some accounts and customers could reduce their energy costs by changing to a more favorable rate structure. Review of each resort's utility data revealed several instances where cost savings could be achieved, simply by changing to a short-term tariff. Table 6 outlines the savings identified during a quick review of each customer's utility data:

Resort Name	Estimated Annual Savings (CAD/yr)
Mont Orford	$7,224
Mont Rigaud	$1,508
Mont Sutton	$3,647
Val Saint-Côme	$1,856
Total	$14,235

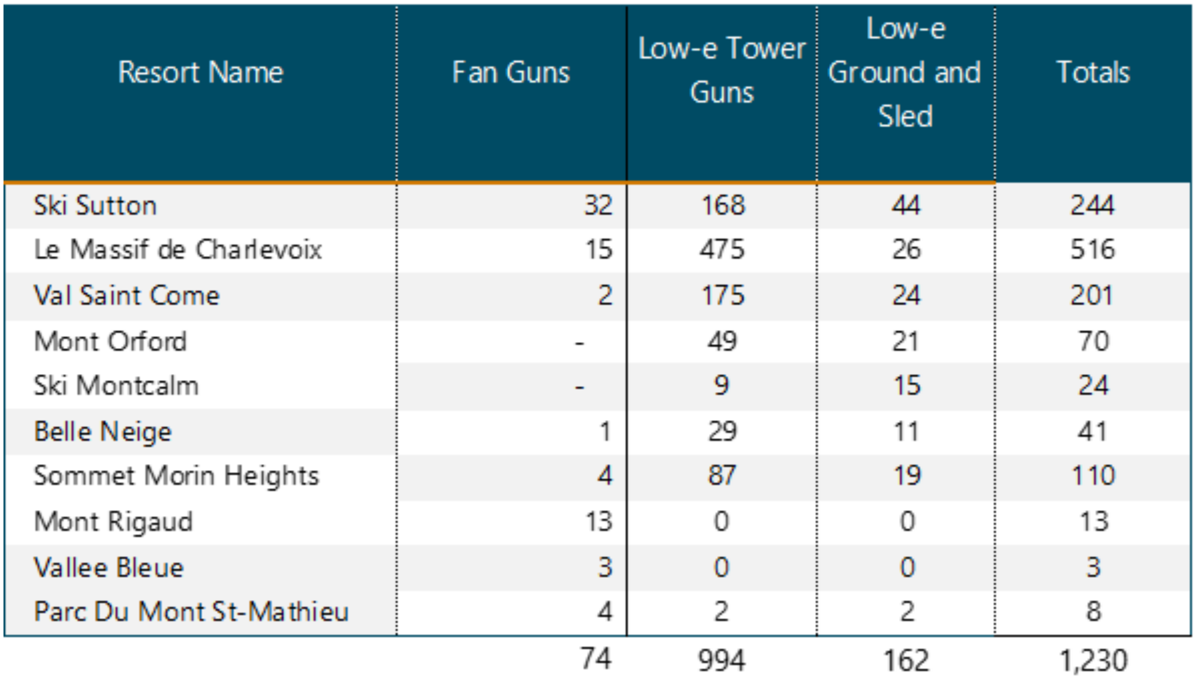
Table 6: Rate Change Savings

All electric accounts summarized in the table above were enrolled as G9 accounts during the 2018/19 ski season. All these accounts displayed high use characteristics during the ski season and were largely dormant during the remainder of the year. The minimum demand factor that carried through during the off-season added significant overall cost these accounts. If these accounts were migrated to a G9 Short-term tariff, the savings outlined above may be possible. Since no additional equipment is required to make this change, these savings could be acquired essentially without cost. The trade-off in this scenario is a loss of flexibility, since power would not be available for a significant portion of the year. It is also important to note that the charge per kW of demand is much higher ($6.03/kW higher) for the G9 short-term tariff. If ski areas are not able to manage their demand within the calendar months, demand carrying over to another month will come at a premium and possibly negate any savings or even penalize a customer on a short-term rate.

In addition to short-term rates, "flex" and curtailable rates are also offered by Hydro-Québec, which may present cost saving opportunities customers. Use of these rates varied amongst the study participants. Some members report large savings while others cited complications with the use of such rates. Not all customers are able to participate in these lower cost offerings since their systems are not flexible enough to meet the rate requirements and still maintain the snow and services at their resorts. Our general recommendation would be for each resort to review the potential to utilize short-term, flexible, and curtailable electric rates, and discuss the options and benefits with their Hydro-Québec representative.

3.0 Snowmaking Technology Evaluation

3.1 Snowgun Technology



Resort Name	Fan Guns	Low-e Tower Guns	Low-e Ground and Sled	Totals
Ski Sutton	32	168	44	244
Le Massif de Charlevoix	15	475	26	516
Val Saint Come	2	175	24	201
Mont Orford	-	49	21	70
Ski Montcalm	-	9	15	24
Belle Neige	1	29	11	41
Sommet Morin Heights	4	87	19	110
Mont Rigaud	13	0	0	13
Vallee Bleue	3	0	0	3
Parc Du Mont St-Mathieu	4	2	2	8
	74	994	162	1,230

Table 7: Snowgun Inventory

There are three main types of snowguns: the internal-mix, the external-mix, and the fan gun. They create snow by mixing compressed air and water, then expelling it through one or more nozzles. Each type differs in the location where air and water are mixed, as well as the means of propulsion.

Internal mix snowguns combine all the compressed air and water in a chamber inside the snowgun. The mixture is then forced out through a nozzle. The first type of snowgun developed, internal-mix guns are also the least efficient of the three.

External mix snowguns, by contrast, combine air and water in more controlled, discrete ways. Highly engineered nozzles confine the compressed air to nucleators. In these chambers, air combines with a small amount of water to create an ice particle called a nucleus. These nuclei seed the plume of water mist with which they are ejected from the nucleators. Water envelopes the nuclei, freezes, and repeats the process, creating layers, until the particles fall to the ground.

Due to their highly engineered nucleators and water nozzles, external-mix guns use much less compressed air than internal-mix guns. In fact, in the last five years, external-mix snowguns have been developed by manufacturers that consume less than 1% of the compressed air of a comparable internal-mix snowgun. Though they require far less compressed air than their internal-mix cousins, today's external-mix guns still produce an equal amount of snow.

A third kind of snowgun, the fan gun, uses compressed air and water in conjunction with an electric fan blade, which ejects nucleates and bulk water mist into the atmosphere. Fan guns manufacture snow with moderately high efficiency; they also serve well in wide-open and/or high-wind areas where a large volume of snow must be quickly produced. Though they are relatively efficient, fan guns typically range in price from $25,000 to $50,000: ten times the cost of external mix snowguns. Because of their high first expense, fan guns are often only used at the base areas of mountains, or everywhere on mountains that have made the decision not to install compressors and compressed air piping networks. Modern fan guns have the added benefit of being able to purchase them with on-board automation. They are equipped with a basic weather station that measures temperatures and then continuously adjusts air-water ratios to optimize operation.

The 10 ski areas that are included in our study reported that they currently owned 1,230 Low-e snow guns. 6% of the guns were fan guns, 81% were low-e tower type guns, and 13% were low-e ground, tripod, or sled mounted guns.

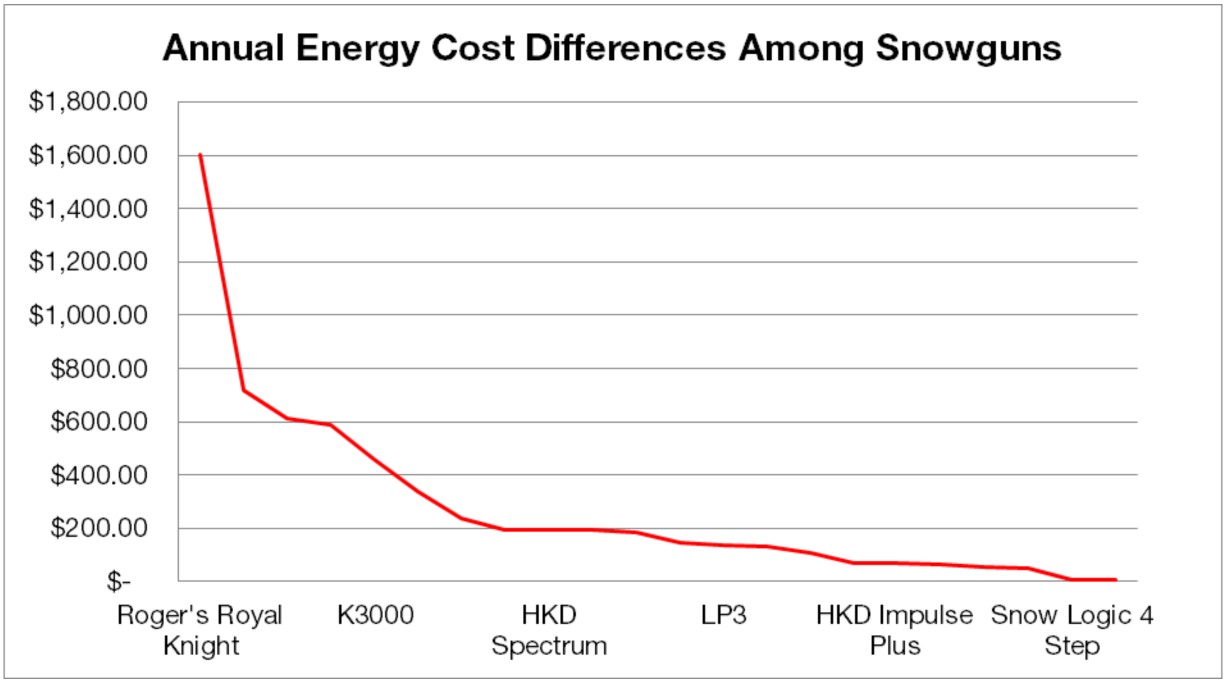


Figure 1: Annual Energy Cost Differences among Snowguns ($.07/kWh)

Québec ski areas have relatively high electricity costs, so they have been early adopters of low-energy gun technologies and have converted close to 100% of their snowgun inventories to low-e, external-mix snowguns over the last 20 years.

Early low-e guns were fixed flow units that had stages to turn-on banks of nozzles but operated with a fixed 100 cfm of compressed air. This was a huge improvement over internally mixing snowguns that frequently used 350 – 500 cfm of compressed air, but over time the low-e guns have developed to operate at multiple stages, and significantly less air flow. Due to the low operating hours of Québec snowguns it wouldn't be cost effective to replace the early low-e guns, but they can be optimized. Also, when new guns are purchased, it will pay to upgrade to the newest technology.

Examples of low-e gun optimization include nozzle replacements, and nucleator optimization. Over time impurities in the water and piping system erode the passages through the nozzles snow guns. The eroded passageways allow higher water flows relative to fixed air flows. As a result, less atomization of the water occurs which causes wetter snow. To maintain a consistently good quality snow, the snowmaker must reduce the water/air ratio on the gun which reduces production efficiency. To improve snowmaking quality and efficiency the snowmaking nozzles should be replaced as wear becomes significant. Please note the erosion will vary depending on the grittiness of the water source, and the cleanliness of the water piping.

Replace nucleators on hybrid mix and internal mixing type tower guns. More recent developments in nucleator selection allows certain tower guns to operate with 30% less compressed air. Compressed air is very expensive to produce, and this change significantly improves the efficiency of operation.

These measures apply to low-e ground and tower guns, as well as fan guns.

3.2 Snowmaking Temperature Evaluation

The duration of snowmaking in specific temperature bins has a direct influence on energy use, with warmer periods producing less snow per cubic foot of compressed air than would be required in colder temperatures. Québec is blessed with colder winter temperatures and significant natural snowfall by January and February, so that most manmade snow is produced between the end of November (average temperature 0 C), and the end of December (average temperature -6 C) so that the ski areas can be fully open by Christmas. Only two of the 10 ski areas we spoke with regularly make snow in January, and none of the group make snow after January 15th. What this means is that on average snow is being generated at warmer average temperatures, and that snowgun nozzle configurations should be optimized for about -5 C.

3.3 Air Compressors

Ski Area Name	Make/Model	Horsepower	Quantity	Total Horsepower	Peak kW	Est CFM
Le Massif de Charlevoix		300	4	1200	895	5,400
Ski Montcalm	Gardner Denner	300	2	600	448	2,700
Sommet Morin Heights	Ingersol Rand, SSR 1200L	275	3	825	615	3,713
Ski Sutton Inc.	Ingersol Rand, Centac	600	2	1200	895	5,400
Ski Sutton Inc.	Ingersol Rand, SSR-2000	400	2	800	597	3,600
Val Saint Come	Sullair	50	1	50	37	225
Val Saint Come	Sullair	150	1	150	112	675
Val Saint Come	Quincy	250	1	250	187	1,125
Val Saint Come	Canadian Air	350	1	350	261	1,575
Mont Orford	Centac II	600	2	1200	895	5,400
Mont Orford	Centac	800	1	800	597	3,600
Parc du Mont Saint Mathieu	Hydrovane	10	3	30	22	135
Parc du Mont Saint Mathieu	Hydrovane	5	3	15	11	68
Parc du Mont Saint Mathieu	Hydrovane	5	2	10	7	45
Ski Belle Neige	Sullair	300	1	300	224	1,350
				7780		35,010

Table 8: Compressor Inventory

Air Compressor Evaluation

It is estimated that there are approximately 60,000 hp of connected snowmaking compressed air capacity in Québec's 75 ski areas. While the specifications for the snowguns give the ski areas an approximate flow rate of compressed air required to make a given amount of snow, the actual amount of compressed air that is used, is generally at least 20% higher. This higher consumption is due to compressed air leaks, lack of modulation, and compressor bypassing – suggesting further compressed air savings opportunities.

Compressor Efficiencies

Efficiency ratings for neither the electric motors nor the compressors themselves were attainable; therefore, VEIC assumed a conservative motor efficiency of 95% and 4.5 Cubic Feet per Minute per Horsepower (CFM/HP) compressor efficiency.

Although it is difficult to quantify savings at individual ski areas due to the implementation of these measures, we estimate that approximately 4,540 kW of electrical demand could be eliminated by performing annual leak testing and repair of network piping, by reducing or limiting compressor blow-off, and by implementing better compressor control sequencing at all the ski areas in Québec. This would equate to an annual savings of 2,029,400 kWh/year and $284,100/year for all the Quebec ski areas.

Ideally, less efficient air-compressors should be replaced with high-efficiency, VFD operated units, however, new high-efficiency air compressors are very expensive. New compressors sized to the needs of Quebec ski areas would likely cost between $250,000 and $1,000,000 each. The compressors have very large connected loads of up to 900 kW at the ski areas we assessed. Unfortunately, these existing compressors have very few run hours each year and therefore savings are limited. Replacing the compressors with new high-efficiency units equipped with VFD's could save approximately $10,000 to $15,000/year, but this investment would be difficult to justify based on cost savings. The payback would be in the range of 50 to 100 years. Therefore, we do not recommend early replacement of existing compressors with high-efficiency units – only when the existing units must be replaced at end-of-life.

3.4 Pumps

Ski Area Name	Make/Model	Type	Horsepower/ pump	Quantity	Total Horsepower	Peak kW
Le Massif de Charlevoix	Pompes a Turbines Verticale	Transfer	400	1	400	298
Le Massif de Charlevoix	Pompes a Turbines Verticale	Transfer	100	1	100	75
Le Massif de Charlevoix	Pompes a Turbines Verticale	Transfer	25	1	25	19
Le Massif de Charlevoix	Pompes a Turbines Verticale	Transfer	350	2	700	522
Le Massif de Charlevoix	Pompes a Turbines Verticale	Booster	350	2	700	522
Mont Rigaud	US Electrical Motors	High thrust	250	1	250	187
Ski Montcalm	Carver	Main	150	1	150	112
Ski Montcalm	Goulds Vertical	Priming/Cooling	6	1	6	4
Sommet Morin Heights	Ingersol Rand	Vertical turbine	300	2	600	448
Ski Sutton Inc.	Gould VIT-FF 13 ALC/2	Transfer	150	2	300	224
Ski Sutton Inc.	Gould VIT-FF 11AHC	Main	350	2	700	522
Ski Sutton Inc.	Gould VIT-FF 10 AHC	Booster	200	1	200	149
Ski Sutton Inc.	Flight B-2151	Cooling	30	1	30	22
Val Saint Come	General Electric, Vertical	Main	400	1	400	298
Val Saint Come	General Electric, Vertical	Main	450	1	450	336
Val Saint Come	General Electric	Cooling	40	1	40	30
Mont Orford	Ingersol Rand	Main	500	2	1000	746
Mont Orford	Gould/VIT	Main	500	1	500	373
Mont Orford		Transfer	300	2	600	448
Parc du Mont Saint Mathieu	Ingersol Rand	Main	200	1	200	149
Ski Belle Neige	Unknown Model "1951"	Main	300	1	300	224
Vallee Bleue	High Thrust, U.S. Motors	Main	125	1	125	93
					7776	

Table 9: Pump Inventory

VEIC estimates there are approximately 60,000 hp of connected snowmaking pumping capacity at all ski areas in Québec. Prior to the adoption of low energy snowgun technologies the largest energy consumer at ski areas were the air compressors. Typically, air compressor and pump horsepower's were similar for a given facility but at warmer temperatures all the compressors ran, while only a limited number of the water pumps ran. We describe this as "the system was air-constrained". As ambient air temperatures dropped typically there was a break-even point at about 14 F or -10 C where all the air-compressors and all the water pumps could run simultaneously and be uniformly loaded. At even lower ambient temperatures the pumps would be running at full capacity, but some of the compressors would be shut down. Now with low energy snowguns there is a significant reduction in compressed air load, so the largest energy user at the ski areas is the water pumps.

The water pumps at ski areas are typically of three types: transfer, main, and booster. Not all ski areas require all three varieties. Transfer pumps move water from rivers, streams, or lakes to the ski area. These typically are high volume/ low pressure pumps that are used to move water distances, but often without significant elevation changes. Many ski areas have snowmaking water containment ponds, so the transfer pumps run to fill the pond, and then shut down. At areas without containment ponds, the transfer pumps deliver water at low pressure to the inlet of the main pumps and must run whenever the main pumps run.

Main pumps tend to be high pressure/ high volume pumps that need to overcome the static pressure associated with pumping water to the top of the mountain's snowmaking system and delivering the water at pressure to the snowguns. Newer low-e snowguns work best when water pressure at the gun is at or exceeds 300psi for adequate atomization. To develop these high-pressure vertical turbine multi-stage pumps are typically employed. Higher pressures require high-horsepower pumps that are very large energy consumers. At larger ski areas with extensive snowmaking systems multi-pressure snowmaking systems can be employed to reduce pressure serving secondary peaks, and for making snow at lower altitudes. These multi-pressure systems can be configured as a main pump system plus a booster pump system, or by using pumping systems that vary flow and pressure though the use of variable speed drives (VFD's). In the booster pump arrangement, a main pump system may deliver 600 psi flow to make snow at the lower portion of the mountain, and an in-line or serial flow pump that raises the pressure to a 1000 psi to make snow at the top of the mountain.

One of the big challenges with these high-pressure pump systems is that when the piping network is shut down with hydrants closed, and snowguns not operating, excess pressure can develop in the systems which can result in pipe and pump failure. To prevent these system disruptions, it is common for facilities to either leave hydrants open on the mountain, or bypass flow at the pumps. From an energy perspective this is bad because a lot of energy is going into the water to pressurize it and move it through the pipes, and then this high energy water is being wasted (no snow is being produced for the energy in). These bypass situations occur when the snowmaking systems are being started-up and snowguns are being brought online, when snowguns are being moved, and when the systems are being shut down. Overall, the time that the pumps are running at full flow and pressure, but not delivering the full flow out the snowguns represents a significant portion of snowmaking energy consumption. Therefore, installing VFD on the pumps to vary flow and pressure can offer significant savings opportunities, both to reduce flow without by-passing, and to lower system pressure when making snow at the base of the mountain. The implementation of VFD control for pumps can be somewhat dependent on the piping network configuration with respect to downflow piping, recirculation loops, and valving. So, each system must be individually evaluated for specific requirements.

4.0 System Control and Reliability

4.1 Automation and Controls

Snowmaking automation provides labor savings and faster startup and shutdown times. Automation may also improve snow quality and save a small amount of energy. Large, centrally controlled automation systems may be worthwhile for large ski areas, who can realize economies of scale and reduced staff time through automation. Smaller ski areas may not be able to reduce staff through automation, since a few snowmakers are needed to monitor and control any system, no matter how small it is.

Faster startups and shutdowns from automation can be particularly beneficial if ski areas are participating in utility curtailment programs.

Prerequisites for Automation

HKD KLIK Hydrant

(HKDsnowmakers.com)

To make terminal unit automation useful, ski areas need to have many snowguns that are set on fixed towers with self-draining hoses and hydrants. If snowmakers are required to manually set up and drain hoses, or move guns around, the benefits of automation are minimal, and risk of damage is high.

Fixed snowguns with self-draining hoses provide good labor savings even without automation. As snowguns are upgraded, ski areas should do their best to reduce reliance on mobile snowguns and on manual hose set-up and draining. Proper installation is crucial to success of these systems.

Hydrant-based self-draining valves may add about $4,000 CAD to $5,000 CAD in materials cost for each snowgun.

Zone Flooding

One of the oldest forms of snowmaking automation is zone flooding. Snowmaking is partially automated with zone flooding by leaving hydrants and snowguns open, then charging entire trails at once. This method is used for air/water snowguns.

Snowmaking startup and shutdown can be faster with zone flooding. However, snowguns will not automatically adjust for conditions, so staff must manually adjust the snowguns for temperature unless fixed flow snowguns are used.

Zone-flooding is inexpensive relative to more comprehensive snowgun automation because no special equipment or control is needed at individual snowguns. The valves that control zone-flooding have been unreliable and prone rapid degradation in the past. Newer systems may have improved reliability. Labor savings to this automation are relatively small because a snowmaker could always be sent to manually open a valve to flood the zone.

Snowgun Automation

Fan Snowgun Automation

Fan snowguns are easy to automate. Because fan snowguns require power, and usually have microprocessor controls onboard, the addition of automation controls is relatively simple and low-cost.

Automatic fan snowguns should be considered standard snowmaking equipment. The additional cost of automation is in the range of $6,500 CAD per snowgun, or about 20% extra cost. These snowguns can be simply switched on by snowmaking staff and left to run. They will automatically maximize snow production at a pre-set target snow quality.

SMI Polecat automatic fan snowgun (www.Smowmakers.com)

Central Control

Even smaller fleets of fan snowguns can benefit from central control systems. Fan guns in fixed locations with auto-draining hoses and onboard de-icing systems are extremely reliable. Central control can save more labor, provide system visibility, and maximize production. Mobile fan snowguns are harder to manage from a central control system and may be better suited to onboard controls only.

TRAIL: 2 SELECTED	PROGRESS	WET BULB	MODE	HYDRANT	GUN	QUALITY	WATER	AIR
Tempest 1	[illegible]	19.1 °F	Manual	Open	5	2	520	111
Tempest 2	[illegible]	19.1	Auto	Open	4	2	503	102
Tempest 3	[illegible]	19.1	Auto	Open	4	2	492	97
Tempest 4	[illegible]	19.1	Auto	Open	4	2	486	94
Upper Tempest 5	[illegible]	17.8	Auto	Open	5	2	425	82
Upper Tempest 6	[illegible]	17.8	Auto	Open	4	2	0	0
Upper Tempest 7	[illegible]	17.8	Manual	Closed	Off	2	0	0
Upper Tempest 8	[illegible]	17.8	Manual	Closed	Off	2	0	0
Upper Tempest 9	[illegible]	17.8	Manual	Closed	Off	2	0	0
Upper Tempest 10	[illegible]	17.8	Manual	Closed	Off	2	0	0
Dreamcatcher 1	[illegible]	20.9	Manual	Closed	Off	2	0	0
Dreamcatcher 2	[illegible]	20.9	Manual	Closed	Off	2	0	0
Dreamcatcher 3	[illegible]	20.9	Manual	Closed	Off	2	0	0
Dreamcatcher 4	[illegible]	20.9	Manual	Closed	Off	2	0	0
Dreamcatcher 5	[illegible]	20.9	Manual	Closed	Off	2	0	0
Dreamcatcher 6	[illegible]	20.9	Manual	Closed	Off	2	0	0

Snowgun Control Dashboard

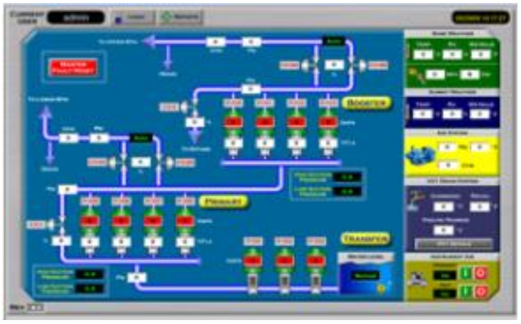
Snowlogicusa.com

Air/Water Snowgun Automation

Air/water snowguns are more challenging to automate than fan snowguns. Fixed towers with self-draining hydrants and hoses are needed. Actuators are needed at each snowgun to control water and air flow. For some (but not all) systems, power and/or communications wires must be installed to each snowgun, so only centrally located trails may be accessible for automation.

The cost to automate air/water snowguns is often budgeted at about $13,000 CAD per snowgun. Because air/water snowguns usually produce less than half as much snow per season as fan snowguns, the automation cost per unit of snow produced by an air/water snowgun is much higher. If snowguns are installed at 80-foot intervals on a trail, the cost of automation is about $160 CAD per foot of trail.

Central Snowmaking Plant Automation



Central Plant Monitoring

(Snomatic.com)

Before automating snowguns, most ski areas should plan to automate central plant controls. A single monitoring and control system can pull together data for pumps, compressors, valves, pressures, and weather. Operators can use these systems to start and stop pumps and compressors, troubleshoot problems, and trend data. Centralizing data and control can help to mitigate problems: compressor, pump, or pipe problems can be detected remotely, and actions can be taken immediately to help prevent disaster.

Completely new control systems for a large, complex mountain operation can cost $130,000 CAD to $200,000 CAD, depending on the site's existing equipment. For a large ski area with some existing control hardware or for a small ski area, prices could range from $26,000 CAD to $52,000 CAD.

Central plant automation will record many data points. These data points can be evaluated at the end of the season to check efficiency. Some systems may offer add-ons to show operators the energy-efficiency of their system in real time. These systems can encourage efficiency by comparing real-time efficiency to expected system efficiency at real-time temperature and water flows.

Conceptual Automation Opportunities for Select Representative Ski Areas

Specific automation recommendations are difficult to provide due to the large number of variables involved in the snowmaking systems at each ski area. The following section provides conceptual automation opportunities for small, medium, and large ski areas. The intent is to show the range of automation that can be employed at various sized ski areas.

The small ski area selected as an example is The Centre de Ski Vallee Bleue. The medium ski area is Sommet Morin Heights. The large ski area is Val Saint-Come. A significant challenge for deploying snowmaking automation in Quebec is the few hours of snowmaking operation. Fewer hours of run time erode the potential savings and make the payback on the investment for these projects very long. It would, however, be beneficial to the ski areas if governmental and/or utility incentives were available to help lower the investment costs of these systems. Further lowering of the investment costs are possible if the ski areas can perform much of the labor for the system installations in-house.

Example 1 – Small Ski Area

Vallee Bleue is a community ski area with 50 skiable acres, and a single 75 horsepower snowmaking water pump, with three older, non-automated fan guns. Annual electrical energy consumption for snowmaking is approximately 59,000 kWh/year at a cost of $6,800/year. Their snowmaking operation lasts approximately 350 hours/year and much of the work is performed by existing staff members. Typical automation systems produce savings on the order of 6% to 10% of the electrical kWh cost per year. This would equate to $400 - $600/year savings which would be relatively insignificant to the cost of a full automation system. There is opportunity however to monitor and control demand at the facility to avoid establishing demand peaks that they would then have to pay for throughout the year. Therefore, it is recommended that they monitor their instantaneous demand as means to avoid demand spikes that can occur from operating large loads simultaneously. In this case it would be helpful to meter the snow making pump, the fan gun circuit, and the ski area overall. A typical system used for this work would be similar to an eGauge meter station.

From a different perspective, fan-gun performance can be significantly improved through on-board automation systems that optimize fan gun operation relative to weather conditions by controlling water flow relative to prevailing wet-bulb temperatures. The current fan guns are not automatically controlled. Fan-guns with automation cost approximately $30,000 CAN new. To add automation to existing fan guns costs approximately $22,000/gun. It is usually not cost effective to upgrade older fan guns, but it can be cost effective to add automation to fan guns when purchasing new units.

Estimated Financial Performance:

Demand Metering

eGauge system	$8,000
Annual demand savings (9.1 kW)	$210
Simple payback	38.1 years

Fan-Gun Automation

Fan gun automation incremental cost	$19,500
Annual energy savings (3,650 kWh/yr)	$420/year
Simple payback	46.4 years

Example 2 – Medium Ski Area

Sommet Morin Heights is a medium-sized ski area with 70 acres of snowmaking. They have two (2) 300 hp snowmaking pumps, three (3) 375 hp air compressors, (4) four fan guns, (106) mobile ground guns, and (71) fixed-base tower guns. They use approximately 627,000 kWh/year for snowmaking at a cost of $91,200/year. The facility has a centralized iSno monitoring and control system to monitor system demand, and to control the pumps, and the compressors. The system currently doesn't log system data, or remotely operate snowmaking guns. They are on a curtailable utility rate structure which is worth $70/average kW that they can dispatch during Utility peak periods.

The next automation steps for SMH to take would be to add hardware and software elements to the iSno system that would allow them to log operating data in order to optimize their operation, and to automate the operation of the fixed base snowguns.

Estimated Financial Performance:

• Investment cost for automation	$280,000
• Annual energy savings (36,530 kWh/yr)	$5,300
• Annual labor savings	$12,000
• Simple payback	16.2 years

Example 3 – Large Ski Area

Val Saint-Come is a larger sized ski area with 134 acres of snowmaking. They have two (2) 400 hp & 450 Hp snowmaking pumps, four (4) air compressors (50 hp, 150 hp, 250 hp, and 350 hp), (2) automated fan guns, (24) mobile ground guns, and (175) fixed-base tower guns. They use approximately 898,200 kWh/year for snowmaking at a cost of $105,650/yr. The facility runs all the snowmaking equipment manually.

There are two potential next automation steps for this operation. The first is to provide a centralized snowmaking monitoring and control system to start/stop the pumps and compressors and to monitor/control the equipment operation to optimize efficiency. The second step would be to automate the operation of the 175 fixed base tower guns.

Estimated Financial Performance:

Controls Front-End -

• Automation cost	$60,000
• Annual Energy Savings (53,570 kWh/yr)	$6,300

Simple payback	9.5 years

Tower-Gun Automation

Automation cost	$700,000
Annual energy savings (35,710 kWh/yr)	$4,200
Annual labor savings	$30,000
Simple payback	20.5 years

4.2 Burial of Pipe

Snowmaking pipe is traditionally buried in the American West, but Eastern ski areas usually install most of their pipe on the surface. Management at each resort typically makes the decision whether to bury water lines, based on the perceived advantages and conditions local to each mountain. For example, the current perceived advantages stem from the electric savings possible by ceasing snowmaking operations during utility-called demand events, as well as the ability for resorts to more rapidly start-up their snowmaking systems to take advantage of favorable weather windows. If a customer operates via diesel-powered air compressors or generators, or is not offered a curtailable electric rate, the perceived advantage is limited to response times. These advantages must be weighed against the current and future snowmaking capability and capacity, challenges with pipe installation and maintenance, and cost.

It is important to note that snowgun automation does *not* require buried pipe. Buried pipe is more operationally convenient, but automation systems work just as well if pipe is aboveground with adequate overflows or a recirculation system. The benefits and challenges associated with burying piping will be discussed in the following sections.

Operational Benefits

Burying water pipe below the frost line prevents freezing and has numerous benefits including mitigating freezing hazards caused by snowmaker errors, reduced overflows (improved water availability), and possible pump energy savings associated with reduced overflows. Since buried (frost-free) pipe does not freeze, it can be left charged with water, allowing for a much faster start-up of systems. This advantage will become more and more important as our climate warms and the frequency and duration of favorable snowmaking weather lessens.

Another time-related benefit of burying water piping is reducing the length of snowmaking disruptions created by interruptible electric utility rates. For resorts that are eligible, interruptible and flexible electric rates reward resorts with lower cost electricity in exchange for limiting or managing their demand when called upon. These events typically coincide with the coldest days of the winter, which creates a significant freeze-hazard for wet piping systems. The day before an event, the utility notifies the ski resort of an upcoming three to four hour shut-down event scheduled for the following day. On the day of the shut-down, the resort must reduce their load to meet their previously agreed upon base power commitment or face a potential penalty.

Most resorts typically meet this requirement by shutting down their entire snowmaking system (pumps and compressors), which requires that they drain the system to prevent freezing. Snowmaking crews sometimes take advantage of these shut-downs to perform non-energy related tasks such as maintenance and repositioning snow-guns. Once the shut-down event has expired, snowmakers flood the system and bring the guns back online, which can take a significant amount of time. In general, the ski areas interviewed indicated that they all lose a work shift of 8-10 hours for each shutdown. These shutdowns represent a painful loss for resorts/snowmakers which would otherwise be operating their system and guns at maximum water (snow) output and carry a typical labor cost of about $500/event for non-productive work.

To reduce the impact of these shut-down losses for the mountains, the distribution headers and potentially the primary distribution mains can be buried up to valve boxes to significantly reduce the amount of the system that must be drained in a shut-down. Additionally, freeze-proof, self-draining below-grade hydrants must be used, or the risers must be heat taped. This will save hours of recharging time per shut-down which could equate to a few thousand dollars per year in labor savings for each resort, depending on size of the snowmaking staff and number or curtailment events. In this example however, the cost to remove piping, digging and preparing a trench, re-installing the piping, and developing below-grade valve boxes with drainage capability would cost on the order of $20,000 to $50,000 at the base of the mountain for a medium-sized facility So, unless incentives are available for the ski areas to make this investment, it is unlikely for most businesses to spend $50,000 to save $1,000.

Installation, Maintenance, and Operational Challenges

In general, burying pipe is only economical in the base area and sometimes on main feed lines, but not on individual trail branches. Assuming that soil conditions are constant, the cost to bury a small branch line and a larger main line are essentially the same. Since branch lines operate for less hours per year and serve few snowguns, the value to burying these lines is diminished. Pipe burial is best suited to new installations, in areas with deep earth over bedrock.

Soil composition, more specifically the presence of large rocks and/or bedrock has a significant influence on the ability and cost-effectiveness to bury lines. This may be of concern for many of the resorts in this study, since the Canadian Shield (Bouclier canadien) is present throughout the province and may inhibit excavating to below frost line (1.5 – 2m). In ideal areas without protruding bedrock, trenching costs may be $5 to $15 CAD per foot. If bedrock is encountered, costs increase quickly. Total installed costs in ideal circumstances for 6″ to 8″ buried un-coated steel pipe can be about $40 to $45 CAD per foot, or roughly $250,000/mile. It is not uncommon for a medium to large ski area to have several miles of snowmaking piping, so burying existing piping can quickly become a large investment.

Buried steel pipe tends to corrode more quickly than aboveground pipe. Many ski areas now use epoxy-coated steel pipe, which tends to last longer underground, but must be installed very carefully to prevent damage to the epoxy finish. Ductile iron pipe is another corrosion-resistant option. Both epoxy-coated steel and ductile iron pipe can cost up to 50% more per foot of material than steel pipe. Regardless of the material, installation of any type of pipe underground is many times more expensive than the material itself. Both steel pipe alternatives provide slightly lower resistance to flow, enabling greater efficiency and pressures.

Aside from the installation cost, there are also significant operating and maintenance cost risks associated with buried piping. While leaks in above ground piping can be discovered visibly and audibly, leak detection in underground piping has proven difficult. If a leak cannot be easily located, isolated, or repaired during the ski season, mountain operators have few options. Depending on the severity and location of the leak, the snowmaking system may be shut down early or it may continue to operate with losses.

A leak in either the air or water network may result in a decrease in performance for all equipment downstream from the leak and an increase in energy use. The energy cost of compressed air leaks is especially high (discussed in sections 2.1 and 3.3) and could quickly erode and even eclipse any energy and cost savings otherwise resulting from burying pipe. Safety concerns also exist for continuing to operate a leaking system, since a blow-out could injure staff or guests.

Repairing underground pipe also comes at a premium cost. Often, the exact location of the leak is not known. As a result, long lengths of the pipe may need to be excavated to discover and repair the leak. Depending on the depth of the pipe, trench boxes may also need to be used to make repairs, which further complicates the process and increases cost. In short, maintenance of underground pipe is significantly more labor and cost intensive than aboveground pipe, with the added disadvantage of extended repair times.

One final characteristic of underground piping with regards to snowmaking is the water temperature. While aboveground pipes have an inherent risk of freezing, they also function to cool the water prior to nucleation. Depending on the temperature of the water at the base, the amount of above ground pipe, and the outdoor air temperature, the water may already be at sub-freezing temperatures when it passes through the snowgun. This has been measured and witnessed many times by VEIC during our work in the field. Subcooled water typically results in drier snow and/or allows for higher water flow rates (more snow production). Conversely, water supplied through underground pipes will be at the same temperature as the earth (2 – 7°C for the resorts in this study). Warmer water will negatively impact the energy needed to make snow, could impact snow quality, and likely results in higher evaporative losses.

HDPE (Plastic) Pipe

The primary advantage to buried air pipe is that HDPE plastic pipe can be used for compressed air only if buried. HDPE pipe is an excellent choice for air or water at less than 150 PSI. It is very lightweight and inexpensive, does not rust or deteriorate, and with practice can be installed by mountain staff. HDPE plastic pipe installed aboveground will expand and contract due to temperature changes. Expansion and contraction cause the pipe to move around, creating a potential hazard and damaging the walls of the soft plastic.

4.3 Managing Electric Demand

Demand charges can contribute significantly to the total cost of electricity. Demand charges for multiple utility accounts investigated during this study appear to have comprised more than 50% of the total electric bill, due to a temporarily high demand and the ensuing minimum billed demand (PFM). Even when the PFM is not contributing directly to monthly bills, demand charges can still be significant. Snowmaking is an activity that naturally results in a high electric demand. Pumps and compressors, all working at the same time in a loosely controlled scenario can set or exceed a previous annual demand peak in a matter of minutes, with potential financial repercussions to follow. Managing the electric demand of snowmaking operations is therefore a high priority and necessary for cost-effective operation.

Successfully managing electric demand begins by measuring it, and then using that information to make informed decisions. Most snowmaking systems have numerous motors with changing loads. The dynamic nature of these systems results in very large swings in electric demand, which can be hard to control and anticipate. As was discussed at the end of section 4.1, power metering equipment such as eGauge, WattNode, and Shark power meters are relatively inexpensive meters that can be connected to a network so that the power demand can be monitored remotely. These signals can also be fed into a dashboard, so that real-time power monitoring and demand management can become an integrated part of the snowmaking process.

Data provided from any metering package must be interpreted and acted upon to realize any demand savings. The success of a resort’s demand management efforts will largely depend on:

1. The ability to monitor critical circuits and large loads in real-time
2. Knowing/labeling which loads are on which utility account (including non-metered loads)
3. Identifying the demand impact of coincident loads (planned or unplanned)
4. Understanding the load and control characteristics of large power users
5. Defining clear demand targets for each utility account
6. Managing loads to meet the defined demand limit

Demand Management Practices for Small Ski Resorts

Small ski resorts (<20 millions of gallons of water used per year for snowmaking) frequently have one or two electric utility accounts for their snowmaking operations and chairlifts. Small resorts should pay special attention to point #3 above, since running the lifts and snowmaking equipment concurrently will likely set a demand peak. Despite the risk of concurrent loads, consolidating and staggering loads of a similar magnitude on a single utility account is an excellent strategy to minimize the demand cost (refer to section 2.2 for a more detailed description of this opportunity). If coincident loading is a real concern, electrical equipment exists that can be retrofitted to a system to prevent additional loads from connecting when there is already one active.

Regarding point #4, most small resorts operate fan guns with a constant electric load and operate more frequently near the maximum output of their pump. Lowering the electric demand by operating fewer fan guns is an option but will reduce the rate of snow production. If snow makers find that they are running the system at 100% output for a few hours at a time and then shutting down, there may be an opportunity to reduce demand by staging the operation of the fan guns and producing the same amount of snow over a longer period of time.

This practice would be most economical when paired with the use of isolation/zone valves and a VFD on the pump. These two measures will maintain the water pressure and/or reduce overflow, saving energy. Energy savings would be even greater if the pump pressure was set with consideration for the elevation of the snow guns. For example, if the snow guns are in the base area, the pump has essentially no vertical head to overcome and can meet the water pressure needs of the snowguns at a lower pressure output from the pump, resulting in energy savings. A VFD on the water pump, isolation valves, and real-time monitoring can therefore all be tools used by small ski resorts to improve their energy efficiency and manage power demand.

Demand Management Practices for Mid-Sized Ski Resorts

Mid-sized ski resorts (20-40 million of gallons of water used per year for snowmaking) will typically have utility accounts dedicated to snowmaking equipment, with the exception of fan guns, which may be located on chairlift electrical circuits. Points #2, 3, and 5 therefore become more of a concern for mid-sized resorts since demand limits must be managed across multiple accounts, with multiple large power users which may be operating concurrently. For example, how does the use of possible transfer or booster pumps coincide with large main pumps and air compressors, and are these relationships considered when establishing demand limits for each account?

Snowmaking systems at mid-sized resorts are more expansive and utilize more horsepower than smaller resorts. Nonetheless, the points raised on pump VFD's and zoning in the "small resorts" section above still hold true, so long as the resort can consolidate snowmaking operations to zones and elevation bands. If the typical strategy is to make snow at all elevations across the mountain (for instance an entire trail from top to bottom), a VFD will be of little value since it will always need to overcome the vertical head.

Understanding the load profile and controls of your air compressors (point #4) also becomes more important for mid-sized resorts trying to manage demand and operate efficiently. Mid-sized resorts frequently have more than one air compressor and favor centrifugal or screw-type compressors. When two or more air compressors are used simultaneously, the chance for inefficient operation increases. Controlling multiple air compressors to work simultaneously and achieve the highest system efficiency is achieved via a sequencer (offered by most compressor manufacturers). Sequencers become more important with an increasing number of compressors.

The primary need for a sequencer is due to the different control methods utilized by different types of compressors. Centrifugal compressors produce significant amounts of air and are highly energy efficient when producing near their full rated output. However, their turndown ratio is quite small, which results in air blowing off at the compressor if it can not be used on the hill. A modulating screw compressor chokes off the air intake of the compressor to reduce output, which also decreases the compressor efficiency but avoids blowing off. A VFD controlled screw compressor will vary the speed to match the demand and is the most efficient at lower output ranges. Understanding the nature of your compressor controls will help you determine whether you can achieve energy savings and demand reduction with your current equipment via operational strategies, or if a sequencer or new compressor is needed to realize the savings.

One final note regarding operational strategies for compressed air systems: If the air compressor is blowing off or is throttled down (for a modulating screw machine), check and see if there are fan guns running at the same time and if air/water guns could be used instead. In principle, the air that is blowing off (or choked off) represents real work already being done and wasted by the compressor, which could become useful work if used to make snow. If fan guns are in use while this is happening and there is the option to use an air/water gun, then snow could be made without an increase in compressor or pumping power, but instead would save all the fan gun energy. This strategy is admittedly only possible where air, water, and power are co-located.

Demand Management Practices for Large Ski Resorts

All the points raised in the small and mid-sized resort demand management sections are also true for large ski resorts (>40 millions of gallons of water used per year for snowmaking). The size, complexity, multitude of utility accounts and rate structures, and use (or lack) of controls means that large resorts stand to profit more significantly from constant monitoring and execution of a demand management plan. Having a metering system in place will provide operators and managers with the data they need to develop a demand management strategy and verify that their actions are indeed saving energy and reducing demand.

Ultimately, managing the electric demand is just one task that snowmaking operators and managers must consider. There are no fully automatic demand control systems for snowmaking systems, since such a system would need to prioritize demand control over snow production, quality, and system reliability, which could be disastrous. For this reason, demand management is and will likely continue to be a manual, operator centric activity. A comprehensive understanding of the snowmaking equipment, a detailed action plan, and a convenient, reliable power monitoring system are therefore critical tools needed to successfully manage demand.

In addition to managing the actual electric demand, resorts can also manage the electric demand *cost*. Power factor correction, rate selection, and load consolidation can all reduce monthly demand costs without having to little impact if any to snowmaking operations. For a full review of these cost saving measures and strategies, please refer to section 2.2.

5.0 Recommendations and Conclusions

The following conclusions and recommendations apply to the 10 ski areas that were a part of this study, but in most cases will also apply to the other Québec ski areas that were not part of the study:

Automation:

- Every member ski area should track energy use and total water flow. You can't control costs if you can't measure them.
- Member ski areas with more than one high-pressure pump should install control systems for their central snowmaking plant to monitor pumps, compressors, flows, and pressures.
- Every new fan snowgun bought by a member ski area should come with automation.
- When installing new snowguns, fixed, tower-mounted snowguns with self-draining hoses are the best choice for labor savings now and automation in the future.
- Large-scale air/water snowgun automation is cost-prohibitive at smaller ski areas.
- Large ski areas with long snowmaking seasons are the most likely to benefit from full automation.

Pipe Burial:

- Pipe burial is best suited to base areas and main water lines with plenty of earth above bedrock and is not necessary for snowgun automation.
- If pipe is to be buried, epoxy-coated steel or ductile iron pipe should be used for water, and HDPE (plastic) pipe should be used for compressed air.

Snow Guns:

- Nozzle replacements - If the nozzles the tower guns haven't been replaced recently, they should be evaluated by comparing the orifices against the original specifications and replaced if worn. Replacement of worn nozzles will result in a relatively quick payback in energy, snow quality, and production time. Examples of guns that would benefit from this measure include HKD Impulse, SV-10, Method, Phaser, SV-15, Focus, Spectrum, Genesis, Millennium, Standard, and LX4400.
- Nucleator replacements - Replace the nucleators on hybrid mixing and internal mixing type towers to reduce the compressed air consumption up to 30%. Examples of guns that would benefit from this measure include HKD Impulse, Ranger, SV-10, Method, Phaser, and SV-15. Some operations also choose to replace the S-Valve with the newer R-valve at the same time as nozzle and nucleator upgrades to reduce maintenance.

Compressors:

- Measure and fix compressed air leaks – ski areas often have miles of aging compressed air piping that is continuously exposed to the elements. It is not uncommon for leakage rates to be as high as 20%. Tracking and repairing compressed air leaks should be a priority each summer.
- Optimize the staging of compressors and controls – implement strategies to lead with your most efficient compressor, and stage on additional steps, compressors, or modulation to minimize energy consumption and compressor blow-off.

Pumps:

- Install Variable Speed Drives (VFD) to control pumps – install VFD's to eliminate the need to bypass or blow off system flow during start-up, gun repositioning, and shutdown.
- Reset pressures – use the VFD's to reset system pressure relative to where snow is being made on the mountain instead of throttling flow with the hydrants.
- Measure water leaks and repair or replace failed pipe - repair the leaks in the snowmaking water piping and evaluate whether a plan to systematically replace piping should be undertaken. It is much easier to reinforce or replace snowmaking piping during the summer, than to repair it during the winter.
- Up-size high pressure-drop runs – measure the pressure drop at hydrants in the system during snowmaking operation at system nodes on the mountain and upsize sections of pipe that show significant frictional pressure drops.
- Hard pipe hose runs that are over 40' in length – long hose runs create high pressure drops that must be overcome by the system pumps, lower pressures at the guns which reduce production, and also create a significant safety issue where the person at the gun can't see the person at the hydrant.

Demand Management

- Install power metering equipment to monitor electric demand in real-time. A stand-alone web interface is generally available/provided, however information from the metering equipment would be most useful when incorporated into a snowmaking dashboard (if possible).
- Itemize large snowmaking loads on utility accounts, investigate control systems, and determine coincident peak implications. Develop a demand management plan with clear goals and actions outlined, according to your specific equipment and operation strategy.

Power Factor Correction:

- Over $77,000 in cost savings identified for study participants due to power factor penalties.
- Power factor penalties are also be assessed on rate G and M accounts, which do not have a specific power factor clause. Penalties on those accounts are occurring in the form of higher electric demand (kVA not kW).
- Cost savings were not calculated for every account that has a power factor <90%. Only 17/142 accounts contribute to the identified savings. High frequency suggests that this problem is widespread, estimate 20% of all resorts' electric accounts have a low power factor.
- Many of the power factor problems seem to appear on chairlift accounts. Power factor improvements would therefore improve system capacity for many cold months of the year.
- Installation of capacitor banks for correct the problem and lead to cost savings. Typical payback time for this improvement is 1-2 years.
- A program to help ski resorts improve their power factors would provide cost relief to the resorts and free-up capacity on the electrical network.

Review and Revision of Electric Rates:

Power factor penalties are assessed on a monthly basis if the kW demand dips below 90% of the recorded kVA. This holds true even if kVA is below the minimum billed demand (PFM). Power factor penalties are designed to recover the cost of additional system capacity obligations that are caused by a poor power factor. If the customer is paying a PFM that exceeds the power factor influenced kVA, then they have already paid for a greater amount of kVA than was needed and should not be subject to a power factor penalty for that month. Numerous accounts reviewed in this study and included in table 6 were paying a power factor penalty during the summer months, while also paying a demand charge (PFM) that was above the 90% kVA rating for that month. Modifying the terms of the power factor penalty to only be applied if the 90% kVA rating exceeds the PFM would reduce the electric cost for customers, while ensuring that Hydro-Québec is still compensated for capacity obligations.

Several member ski areas reported interest in participating in Hydro Québec curtailment programs but cited program conditions as a barrier. Because many member ski areas only make snow in November and December, they are unable to curtail snowmaking in January and February. Being unable to curtail when called can cause them to be disqualified from the program. Even if not disqualified, if many curtailments are called when ski areas are no longer making snow, their average winter curtailment kW may be low, reducing the benefit of participation.

If member ski areas had a way to participate in curtailment programs without being penalized for missing late-winter curtailments, many more ski areas might choose to curtail snowmaking during peaks in November, December, and sometimes January. An example of a curtailment program that has worked well for ski areas is Green Mountain Power's Curtailable Load Rider program[2]. The Curtailable Load Rider simply sets the customer's demand kVA as the maximum monthly kVA incurred during a curtailment call. By lowering demand for curtailments, ski areas in Vermont save significantly on their monthly bills, but more importantly can avoid the ratchet demand charges that would otherwise continue throughout the year. A similar program could help Québec ski areas to participate in demand response. Such a program that reduced the demand used to set ratchet charges would allow ski areas to use year-round service at lower cost and avoid the inconvenience of complete shutdown for the G9 short-term tariff.

Individual ski areas should contact their electric utility account manager to determine if their facility could benefit by changing the snowmaking account to an alternate rate structure. Also, the ski areas in Québec collectively have approximately 120,000 hp of connected load in their snowmaking systems, which represents a significant block of demand kW. If the ASSQ is not currently doing so, it may be a good idea to meet regularly with Hydro-Québec to determine the best way to forge a partnership that can help to verify that members are on the best rate for their situation, or even to create a separate Snowmaking Rate to optimize both the ski areas and Hydro-Québec's needs.

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[2] https://greenmountainpower.com/wp-content/uploads/2019/01/Curtailable-Load-Rider-1-3-19.pdf