Snow Making/Mountain Operations Technology Assessment Final Report
NOTE TO SKI AREA PROFESSIONALS:

This publication may help you identify cost-saving opportunities at your ski area that can improve your bottom line through energy efficiency improvements.

The ski industry is an important segment of Vermont’s economy. Ski areas are well positioned to benefit from energy efficiency improvements because of their energy-intensive operations such as snowmaking.

Efficiency Vermont can assist ski areas to realize the types of savings highlighted in this document by providing technical support, design review, economic analysis, financial incentives, and assistance in obtaining financing or arranging leases.

Please call us to discuss your plans for projects.
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1.1 INTRODUCTION

This document presents a concise summary of technical findings, outlining technologies and systems that would be suitable for implementation at Vermont ski industry locations. Various snow making systems and their associated components are discussed in this document, giving insights into the snow making process. In addition to the snow manufacturing process, energy efficiency opportunities are also addressed in this report.

Energy Resources Solutions (ERS) developed this assessment, which featured four primary components. First, a comprehensive literature review was conducted to gain insights into snow making systems, equipment and operational controls. ERS reviewed independent documents, articles and information obtained from web-based sources addressing snow making systems. Second, ERS gathered information through discussions with ski equipment manufacturers and vendors, and with firms involved in the design of ski facilities. Third, ERS reviewed all the data gathered by Efficiency Vermont on the ski industry. Finally, all this information was consolidated and reviewed in order to make programmatic recommendations.

This section (the Executive Summary) provides a brief overview of the steps followed for the assessment and summarizes the resulting findings.

Section 2 of this report outlines the technology research approach adopted by ERS and the key findings from the extensive review of gathered information. This section consists of two components: technical literature findings and manufacturer discussion findings.

Section 3 examines the various process and technology options for making snow at ski facilities. Both standard practice (low-efficiency) and state-of-the-art options are described in detail.

Section 4 identifies opportunities for energy savings based on technology research, current practice in Vermont and corresponding energy-efficiency programs in Vermont. These include technologies or operational strategies and controls that are suitable for incentives, or technical services and guidance that may be instrumental in accelerating the adoption of the latest state-of-the-art efficiency systems for the Vermont ski industry.
1.2 OVERVIEW OF THE PROJECT PROCESS

The assessment process involved four major tasks. Each of these is described below.

**Task 1: Technology assessment, literature research and review**
This task involved comprehensive literature research. All available sources of information on snow making systems, equipment, and new operational controls and techniques were thoroughly reviewed. This task required review of any available independent technical documents, articles, and internet sources of information that address snow making systems and technologies, and the effective operation and control of those systems.

**Task 2: Manufacturer and engineering firm interviews and discussions**
This task included detailed discussions with key manufacturers and vendors of snow making systems. Firms involved in the engineering and design of ski facilities were also interviewed.

**Task 3: Vermont ski industry data review**
This task involved reviewing all the data that Efficiency Vermont has gathered on the ski industry. The focus was on information from projects that were completed and incentivized through the program. None of the key ski industry sites was visited to verify the reviewed data. Rather, the purpose was to gather general facility information.

**Task 4: Comprehensive review of data and information organization**
This task involved consolidation of all the collected information, a review of all the data that was collected through prior tasks, evaluation of current practice behaviors of the ski industry in Vermont, and development of recommendations for the Efficiency Vermont services available to the ski industry.

**Task 5: Snow making technology assessment report development**
This project report was developed by consolidating any written pieces prepared through previous tasks, and writing a summary of all approaches and findings.

1.3 TECHNOLOGY RESEARCH FINDINGS

Available performance information for snow guns ranges from limited to non-existent. Most snow making equipment manufacturers provide some range of CFM requirement for a given range of GPM. In general, the minimum GPM rating corresponds to the maximum CFM rating at some maximum wet bulb temperature limit of the particular unit. The maximum GPM rating corresponds to the minimum CFM rating at some optimum wet bulb temperature, below which performance remains relatively unchanged from that of optimum operating conditions. Though the exact relationship between GPM and CFM for a given wet bulb temperature is typically not documented, most manufacturers suggest that both parameters vary linearly with changes in ambient conditions. As the ambient temperature increases, the GPM rating decreases while the CFM requirement increases.

The specific relationship between ambient temperature and humidity that determines a specific wet bulb temperature also impacts the GPM and CFM requirements of snow guns.
Multiple combinations of ambient temperature (dry bulb) and humidity may yield a single wet bulb temperature. As a result of this relationship, snow gun manufacturers suggest that a given wet bulb temperature will not necessarily correspond to a unique GPM and CFM operating condition. According to manufacturers, CFM requirements vary exponentially with changes in humidity.

Reducing the temperature of snow making water can increase the efficiency of a snow making system by reducing the likelihood of unfrozen droplets falling on the slope. Eliminating unfrozen water droplets from the discharge of a snow gun benefits the snow maker in three ways. First, relatively colder snow making water helps prevent melting of existing surface snow particles. Second, relatively colder snow making water helps eliminate unnecessary pumping of water that is not converted to snow. Finally, a water droplet that is nearer freezing requires less energy in the form of compressed air to be converted to an ice particle. Tests have shown system efficiency losses of 2 to 3 percent for every degree that snow making water is above 32°F.

Snow inducers are chemical additives that typically act as high temperature nucleators within a water stream and increase the temperature at which water droplets begin to form ice particles. The use of snow inducers increases the number of nucleators in the water stream thereby increasing the likelihood that any given droplet will contain a nucleator. Having a sufficient number of nucleators present in the water stream is an important factor in efficient water use and, indirectly, pumping energy use.

1.4 CURRENT PRACTICE IN VERMONT

A majority of snow making operations in Vermont employs electric compressors. While diesel compressors actually outnumber electric compressors, the diesel machines are generally used in a supplemental or backup capacity. Efficiency Vermont data indicates that fewer than half of the water pumps used for snow making are equipped with variable frequency drive (VFD) controls. This data may be inaccurate, however, as our discussions and visits suggested that each group of pumps is outfitted with at least one VFD. In such cases, a single VFD efficiently bridges the gap between the full load operation of any number of pumps and the full load operation of an additional pump. Only 2 out of 7 ski areas studied practice cooling of snow making water.

Traditional air/water snow guns slightly outnumber air/water tower guns. The air/water tower guns experience far more use than the somewhat dated ground based guns. The ground based guns do continue to see limited use at most facilities. Research indicates that air/water/fan guns are virtually non-existent in Vermont with only a handful of units in operation, compared to more than 5,000 air/water snow guns.

Large horsepower DC motors are typically dedicated to relatively long passenger lifts, while relatively smaller horsepower AC motors drive the shorter lifts. Diesel or gas (or both) drive motors are typically operated in a back-up role or utilized during the summer and fall months for mountain biking and foliage tours.
Facility lighting is increasingly being replaced with new fluorescent lamps rather than new incandescent lamps as older incandescent lamps come to the end of their useful life. Lighting controls such as occupancy/motion sensors or timers are used sparingly at the facilities.

Small electric heaters are the most popular method of heating lift houses. Furnaces are controlled by a user-operated thermostat rather than a timer. A small number of lift houses are heated by LP gas heaters, which are also typically controlled by user-operated thermostats. Lodge facilities are commonly heated by LP gas HVAC units and guest accommodations are either heated by a central hot water loop or by individual electric heaters. Whatever the means of heating in guest accommodations or lodge facilities, it is rare to see heating systems controlled by facility management software or occupancy controls in these buildings.

1.5 SUMMARY OF SNOW MAKING/MOUNTAIN SYSTEMS TECHNOLOGIES REVIEW AND ASSESSMENT

Natural snow is formed due to the condensation of atmospheric moisture when its weight exceeds the capacity of the air to keep it afloat. This condensed moisture then falls down as snow, if the air above the ground is cold enough. Often the snow crystals pick up more moisture as they fall, resulting in the myriad shapes for which snow crystals are famous.

Snow formed using machines is also “real” snow. Snow crystals, no matter how they are produced, are simply minute crystals of frozen water. Snow making processes involve water being forced from a pond, reservoir, or river into specialized nozzles, where it collides with pressurized (compressed) air. The compressed air shatters, or “atomizes” the stream of water into minute particles and sprays them into the atmosphere. The decompression of air at the end of the nozzle then freezes the minute water particles into ice particles.

Historically, snow making equipment has utilized the pressure of the distributed water and air to project water droplets high enough in the air to allow an adequate “hang time,” during which the ice crystals could form. Recently developed equipment utilizes towers and/or fans to distribute and project the water droplets high enough above the trail to allow greater air contact time.

Snow making equipment is composed of the actual devices that mix compressed air and water to nucleate snow crystals and direct snow to the dedicated areas. In addition to these devices, snow making involves thousands of horsepower of air compressors and water pumping equipment. A detailed description of snow making equipment is presented in the following sections.

Table 1-1 provides an overview of technologies used in making snow and corresponding energy-efficiency measures that can be implemented to improve the system performance and reduce operating costs.
Table 1-1
Ski Facility Equipment Overview & Energy Savings Opportunities

<table>
<thead>
<tr>
<th>Ski Facility Equipment</th>
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<tbody>
<tr>
<td>Snow making equipment:</td>
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<tr>
<td>Internal mix air/water gun</td>
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<tr>
<td>External mix air/water tower gun</td>
</tr>
<tr>
<td>Air/water fan gun</td>
</tr>
<tr>
<td>Airless tower gun</td>
</tr>
<tr>
<td>Compressed air system</td>
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<tr>
<td>Water pumping system</td>
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<tr>
<td>Lift systems</td>
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</tbody>
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<table>
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<tr>
<th>Factors Affecting Snow Making</th>
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<tbody>
<tr>
<td>Ambient conditions</td>
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<tr>
<td>Snow inducers/additives</td>
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<tr>
<td>Water temperature</td>
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<table>
<thead>
<tr>
<th>Ski Facility - Energy-Efficiency Opportunities</th>
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<tbody>
<tr>
<td>Snow Making Equipment</td>
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<tr>
<td>Automated snow making systems</td>
</tr>
<tr>
<td>Appropriate equipment selection</td>
</tr>
<tr>
<td>Weather based snowmaking strategy</td>
</tr>
</tbody>
</table>

| Compressed Air System                         |
| Efficient air compressor selection           |
| Minimizing compressed air leaks              |
| Optimum compressed air storage capacity      |
| Compressed air load reduction approach using VFDs |

| Water Pumping System                          |
| Construction of water reservoirs             |
| Elimination of water leaks                   |
| Avoid water re-circulation                   |
| Modulating water flow using VFDs             |

| Lift Systems                                 |
| Harmonic filtering for lifts                 |
| Peak shaving strategies for lifts            |
| Selection of energy-efficient motors        |
| Use of regenerative drives                   |
| Use of direct drives                         |
| Energy-efficient lighting system for lift houses |
| Energy-efficient heating system for lift houses |
1.6 OPPORTUNITIES FOR ENERGY SAVINGS

There are four basic strategies for reducing snow making system energy use related to the three major areas of ski facility energy use. Because they typically use the most energy, compressed air generation and delivery systems present the most obvious opportunities for performance improvements. Such improvements might include efficient compressor selection, sequencing controls and leak repair. Though they account for comparatively less energy consumption, opportunities such as distribution network leak repair, elimination of recirculation, installation of variable frequency drive flow modulation, and system optimizing controls also present energy conservation opportunities for water pumping systems. Lift drives are typically another significant energy consumer at ski facilities and offer some unique energy conservation measures, such as top drive lift systems, efficient motor selection, and energy-efficient space lighting and heating equipment and controls. The fourth and final major opportunity for conservation relates to snow making equipment such as guns and system controls. Ski areas in Vermont can save significantly on energy costs with optimal equipment selection and control, system automation, snow making water cooling, and the use of snow inducers.
2.1 INTRODUCTION

Recreational ski facilities are unique in the intensity of their energy use, especially considering the typically short operating season of the industry. For two key reasons, ski facilities must be viewed as industrial facilities. First, they differ from other commercial sector facilities in the diversity and intensity of their energy end uses. Most commercial facilities are dominated by a few basic end uses, such as lighting, HVAC, domestic hot water, refrigeration, or office equipment. While ski facilities do have these end uses, the dominant uses tend to focus on the manufacture of snow and the transport of facility patrons to upper slope areas. Second, ski areas are clearly in the business of manufacturing a product (snow) that is desired by consumers at ski facilities. Thus, ski facilities are classified as industrial facilities in the recreational ski business.

In the United States and North America, it is important to distinguish between the Eastern and Western area ski facilities. Eastern ski facilities have an energy use profile that is dominated by equipment and tasks used for the objective of making snow to support facility operation. Large ski facilities in Vermont (greater than 100 skiable acres) for example, boast an average of 78 percent snow making capacity. In contrast, Western ski facilities generally receive abundant natural snow that eliminates the necessity for artificial snow throughout the ski season. However, ski facilities in the Western United States do have snowmaking needs, though to a lesser degree, due to the increasing demand for early season openings.

While subsequent sections and fundamental discussions for this report are focused on Vermont facilities that depend on snow making, systems employed in Western States and in Europe and steps pursued to improve performance are also addressed here because of their general applicability to snow making efficiency.

2.2 TECHNOLOGY LITERATURE FINDINGS

This section describes the findings and all the information gathered based on review of technical documents, articles, and internet sources of information that address snow making systems.

2.2.1 OVERVIEW OF SKI FACILITY ENERGY USE

Energy consumption at ski facilities generally consists of several significant end uses that distinguish ski area operations from those of other facility types. This section presents a typical end use analysis for a medium-sized facility operating in the Northeastern United States. Table 2-1 shows the summary end-use data that is presented graphically in Figure 2-1 below.
Table 2-1
Typical Ski Facility Energy Use

<table>
<thead>
<tr>
<th>Electrical End Use Data</th>
<th>kWh</th>
<th>Percent</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressed Air</td>
<td>5,490,373</td>
<td>53%</td>
<td>$411,778</td>
</tr>
<tr>
<td>Water Pumping</td>
<td>2,090,195</td>
<td>20%</td>
<td>$156,765</td>
</tr>
<tr>
<td>Lift Drives</td>
<td>2,061,500</td>
<td>20%</td>
<td>$154,613</td>
</tr>
<tr>
<td>Lighting</td>
<td>354,440</td>
<td>3%</td>
<td>$26,583</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>217,437</td>
<td>2%</td>
<td>$16,308</td>
</tr>
<tr>
<td>Space Heating</td>
<td>176,565</td>
<td>2%</td>
<td>$13,242</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10,390,510</strong></td>
<td><strong>100%</strong></td>
<td><strong>$779,288</strong></td>
</tr>
</tbody>
</table>

Source: ACEEE 2001 Summer Study on Energy Efficiency in Industry

The table and graph above indicate that the dominant end uses are those associated with snow making and operation of ski area lifts. Facility lighting, HVAC (electric resistance space heating), and miscellaneous uses represent only 7 percent of overall facility energy consumption. Snow making end uses (comprised of both compressed air and water pumping) represent almost three quarters of overall facility energy use, with lift motors representing another 20 percent.

While the prototypical facility presented in the above graphs is based on all-electric end uses, many ski facilities alternatively depend on non-electric energy sources for their operation. For example, it is not uncommon to find facilities where air compressors, pumps, and/or lift operations are driven by diesel engines in lieu of electric motors. ERS is only aware of one diesel pump being used at a Vermont Ski Area at this time. Diesel engines for lifts typically are used only as back-up to remove guests from lifts during power outages. Traditionally, facilities saw potential benefits due to lower energy costs in diesel-driven equipment. In addition, the ability to lease systems (such as compressors and drives) in lieu of purchase had advantages. For facilities using only electric power, custom electric rates made electricity the more cost-effective operational choice.

The manufacture of snow is usually dependent on considerable volumes of compressed air coupled with large flows of water delivered to snow making nozzles (snow guns) located in numerous locations along ski trails. Thus, the dominant energy end use technologies are air compressors and water pumps. It is common to find thousands of horsepower of air compressors and pumps at any given ski facility. Alternative systems that frequently have
better energy characteristics depend on considerably smaller compressors, coupled with modest-sized fans to distribute the snow. The fan systems, however, do have some performance limitations and the base equipment costs can be considerably more than the compressed air-dominated systems.

2.2.2 AREAS FOR REDUCING ENERGY USE IN SNOW MAKING

There are four general strategies for reducing system energy use related to the three major areas of facility energy consumption. Compressed air generation and delivery systems present the most apparent opportunities for performance improvement because they typically use the most energy. Water pumping systems present similarly obvious opportunities for reduction in energy use, though they account for comparatively lower energy consumption. The third and final major area of facility energy consumption that presents obvious savings potential is lift drive systems.

The most common area identified for energy savings is the selection of snow making equipment. The typically large quantity and relatively low cost of snow making guns makes addressing their performance an attractive option for facility personnel. Compressed air system equipment selection and control can offer significant energy savings at similarly significant capital cost. Water pumping equipment selection and control present a similar savings and cost relationship. Finally, automated controls for snow making equipment can provide additional compressed air and pumping energy savings at an additional cost.

Snow making equipment is composed of the actual devices that mix compressed air and water to nucleate snow crystals and direct snow to the desired areas. Some systems are inherently more efficient than others, using less air or overall energy to produce a given volume of snow. In addition, each equipment category represents differing performance curves under varying climatic conditions, complicating the task of choosing snow delivery technology.

Compressed air systems for traditional snow making operations generally require thousands of horsepower of air compressors. Considerable energy savings can be readily achieved through typical compressed air efficiency measures addressing plant efficiency, air system control, and air loss minimization strategies.

Snow making involves hundreds of thousands of horsepower for water pumping. Considerable savings can be achieved through efficient pump selection, pump system and water flow control, and modifications to pumping operations that involve inefficient pumped recirculation back to system reservoirs.

Considerable compressed air and water pumping energy and resource savings can be achieved through proper and effective optimizing control of the air and water mixture that is directed to snow production equipment. It is typical that valves governing these mixtures are not controlled effectively, and considerable energy is wasted by compressing more air and pumping more water than may be necessary.
2.3 MANUFACTURER DISCUSSION FINDINGS

Available performance information for snow guns ranges from limited to non-existent. Most snow making equipment manufacturers provide some range of CFM requirement for a given range of GPM. In general, the minimum GPM rating corresponds to the maximum CFM rating at some maximum wet bulb temperature limit of the particular unit. The maximum GPM rating corresponds to the minimum CFM rating at some optimum wet bulb temperature, below which performance remains relatively unchanged from that of optimum operating conditions.

The exact combination of GPM and CFM for a given wet bulb temperature within the documented operating range is typically not provided. According to Snowmakers, Incorporated (SMI), GPM and CFM both vary linearly with changes in ambient temperature. As the ambient temperature increases, the GPM rating decreases while the CFM requirement increases. This relationship may not be true of traditional or tower air/water guns or even for all air/water/fan guns.

The specific combination of factors governing a given wet bulb temperature also affects GPM and CFM ratings. Since wet bulb temperature is a combination of dry bulb temperature and humidity, multiple combinations of dry bulb temperature and humidity can yield the identical wet bulb temperature. According to SMI, a given wet bulb temperature does not necessarily correspond to a unique GPM and CFM combination. According to SMI, CFM requirements increase exponentially with increases in humidity for a given wet bulb temperature. Conversely, CFM requirements decrease exponentially with decreases in humidity for a given wet bulb temperature. For example, ambient conditions at 41°F dry bulb and 10% relative humidity yield a wet bulb temperature of 28°F. However, ambient conditions at 34°F dry bulb and 50% relative humidity also yield a wet bulb temperature of 28°F.

Ratnik Industries provides a general comparison of the approximate energy use ratings of two basic types of snow guns. The comparison is taken at a widely accepted optimum wet bulb temperature of 19°F. The comparison makes no reference to water temperature or pressure. The comparison suggests that a traditional air/water gun mounted on a tower converts 0.8 GPM of water to snow per kW, a medium sized air/water/fan gun mounted on a tower converts 2.6 GPM of water to snow per kW, and a low energy air/water gun mounted on a tower converts 4.9 GPM of water to snow per kW.

Finally, Ratnik provides a general material cost analysis of snow making systems. Ratnik estimates that snow guns and hoses account for only 10% of the material cost of a snow making system. Air compressors account for 50%, pipes and fittings account for 20%, hydrants, regulators, and valves account for 5%, water pumps account for 10%, and system engineering accounts for 5% of the material cost of a snow making system.
3.1 INTRODUCTION

This section presents a detailed discussion of the various process and technology options researched for making snow at ski facilities. Although many of the snow making equipment options and technologies are discussed in this section, the primary focus is on that which is most applicable to the Vermont climate and market. This section also discusses the energy-efficient options for various processes and equipment involved in snow making.

3.2 OVERVIEW OF SNOW MAKING PROCESSES & COMPONENTS

In nature, water evaporates from the ground, lakes, rivers and the oceans. This atmospheric moisture condenses and falls to the ground when its weight exceeds the capacity of the air to keep it aloft. When the air above the ground is cold enough, it falls to the earth in the form of snow. Often the snow crystals accumulate moisture as they fall, resulting in the myriad shapes for which snow crystals are famous. Machine made snow is still “real” snow. Snow crystals, no matter how they are produced, are simply minute crystals of frozen water. Snow making machines bypass evaporation. Snowmakers force water from a pond, reservoir, or river into specialized nozzles where it collides with pressurized air. The compressed air shatters or “atomizes” the stream of water into minute particles and sprays them into the atmosphere. The decompression of air at the exit of the nozzle then freezes the minute water particles into ice crystals. Because the droplets of water do not have as much time to freeze before they hit the ground as they do in nature, snowmakers must carefully design and operate their systems to produce snow.

Snow making equipment is composed of the actual devices that mix compressed air and water to nucleate snow crystals and direct snow to the designated areas. In addition to these devices, snow making involves thousands of horsepower of air compressors and water pumping equipment. A detailed description of snow making equipment is presented in the following sections.

3.3 SNOW MAKING EQUIPMENT

Currently, there are four general categories of snow making equipment. These categories are: internal mix air/water guns; external mix air/water tower guns; “air-less” tower guns; and internal mix air/water/fan guns. In addition to describing the various snow making equipment categories, this section also discusses the factors affecting the snow making process. The total system efficiency and performance characteristics are also discussed.
3.3.1 INTERNAL MIX AIR/WATER GUN

Figure 3-1 presents a typical internal mix air/water gun. The internal mix air/water snow gun is constructed of a simple nozzle arrangement into which compressed air and pressurized water are mixed. Cold water (generally between 35°F and 45°F) pumped from a remote water source enters the mixing chamber at the top of the gun. Compressed air entering the rear of the gun atomizes the stream of cold water. Atomization occurs when the compressed air stream penetrates and shatters the bulk water stream into tiny droplets of water, giving the water a much larger ratio of surface area to volume, allowing expansive and evaporative cooling effects to nucleate the water droplets.

The compressed air exiting the gun creates the means of spraying the finely atomized water droplets onto the slope. Compressed air generally enters the gun between 80 and 110 PSIG and quickly returns to atmospheric pressure upon exiting the gun. The rapid expansion of the stream of air exiting the gun causes expansive cooling of the air, which causes small ice particles to form on impurities and foreign substances in the water droplets. These nucleation sites act as catalysts to freeze the remaining water droplets when the mixture is adjusted correctly for ambient weather conditions. The volume of compressed air used dictates the extent to which the water stream is atomized, which in turn dictates the number of nucleation sites in the water stream. The volume of compressed air required depends on the ambient conditions. During times of relatively low snow making temperatures, the expansive cooling effect of compressed air exiting the gun is capable of freezing large droplets of water, thereby reducing the need for atomization and compressed air. During times of relatively high snow making temperatures, the expansive cooling effect is weaker. In this case, smaller water droplets are required for adequate nucleation thereby increasing the need for atomization and compressed air.

The cold water steam enters the mixing chamber slightly downstream of the point of entry of the compressed air. Depending on the ambient air temperature and the desired snow characteristics, the relative quantities of air and water delivered to the mixing chamber can vary dramatically. In general, as the ambient air temperature drops, water flow can be increased, resulting in increased snow production and a reduced compressed air/water ratio, i.e., improved system efficiency. For a typical internal mix air/water gun, water flows can range from 15 GPM per gun during mild winter temperatures to 70 GPM per gun in cold temperatures. The flow of water depends primarily on ambient temperature but also on the volume of compressed air available.

Our investigations have shown that snow production capacity at the majority of Vermont ski areas is constrained by compressed air capacity. In general, ski areas can produce only as much snow as the compressed air system can effectively atomize. The amount of water that the compressed air system can sufficiently atomize depends on both the ambient air temperature and the cold water temperature. For a constant cold water temperature, the ability of a given volume of compressed air to sufficiently atomize a stream of water increases as the ambient air temperature decreases. The converse is also true. The result of this relationship is a snow making system whose production is limited by its compressed air capacity. This constraint encourages snow makers to operate air compressors at full capacity.
and vary water flow based primarily on ambient air temperature and, to a lesser extent, water temperature. Such a system operates at optimal energy efficiency when both of these two conditions are constantly monitored, and water flow is constantly adjusted to correspond with those conditions.

Figure 3-1
Internal Mix Air/Water Gun

Still, snow making equipment manufacturers suggest that approximately 98% of compressed air energy is dedicated to propelling and distributing the mixture of water droplets and ice nuclei in the air so that convective and evaporative cooling can freeze the mixture into snow, which can then be delivered to appropriate areas of the ski trail.

The relative popularity of internal mix air/water guns can be attributed to several factors, which vary between snow makers. These three major reasons for the widespread use of this type of snow gun have been expressed to ERS by some Vermont snow makers as well as industry experts:

- precise control of snow coverage (throw);
- relative weather independence; and
- lower capital cost.

Typically, internal mix air/water snow guns are mounted on mobile sleds located on slope surfaces alongside trails. In the case of a ground-mounted internal mix air/water gun, the close proximity of the gun to the ground allows for simple manipulation of the “throw” of the gun. The ability to quickly and easily maneuver a snow gun is paramount to optimal snow distribution and slope coverage. Because of the mobile sled mounting, snow makers find manipulation of these ground-mounted air/water guns particularly useful for covering trails. Perhaps more importantly, a ground-mounted gun is impacted less by potentially detrimental wind conditions. In the case of a tower-mounted gun, a snow maker can occasionally take advantage of wind velocity to aid in distribution. More often, however, wind velocity creates a drifting effect that causes snow to blow away, sometimes being thrown completely beyond the desired location. Ground-mounted air/water guns dramatically reduce vulnerability to drifting effects caused by high winds.
Because internal mix air/water snow guns rely on a significant amount of compressed air, they are capable of operating somewhat independent of the ambient air temperature. No type of snow gun operates in all weather conditions, but within the temperature range generally accepted as adequate for snow making (26°F or colder) internal mix air/water guns can produce quality snow across the entire range of temperatures. The primary concerns of a snowmaker are the production of snow and the quality of trail coverage. The energy efficiency of a particular snow gun system is typically a secondary or tertiary concern. Extensive field use has shown that internal mix air/water guns consistently, if inefficiently, produce quality snow throughout the snow making season in spite of slight temperature variations.

Capital cost is another major consideration regarding the purchase and operation of internal mix air/water snow guns. The purchase cost of an internal mix gun can be as little as 1/5th of the cost of external mix guns and are capable of a greater volume of snow production. Though the operating costs associated with internal mix guns far exceed those of external mix guns, the potential snow making hours available with internal mix guns are also far greater than with external mix guns. As discussed above, the ability to produce snow in a relatively wide range of operating conditions is perhaps the greatest concern of the snowmaker.

### 3.3.2 EXTERNAL MIX AIR/WATER TOWER GUN SYSTEM

A relatively recent development in air/water gun technology is the external mix air/water tower snow gun. The external mix tower gun offers a modified air/water design that improves system efficiency. A typical external mix air/water tower gun is shown in Figure 3-2.

The external mix air/water tower gun represents a significant efficiency improvement over the traditional land mounted internal mix air/water gun. The 8 to 35 foot towers are permanently mounted at 75 to 100-foot increments (significantly less than the normal 150 foot spacing of the other technologies) along the prevailing wind side of the trail. The external mix head located at the top of the tower consists of between two and four air nozzles and between four and eight water nozzles. Compressed air is provided in the inner core space, while water is provided in the annular space. As the water spray passes through expanding compressed air stream, it experiences expansive cooling allowing the tiny water droplets to form nucleation sites. The height of the tower creates “hang time” for the nucleated droplets to experience convective cooling as they descend to the surface, allowing them to freeze before reaching the slope. The relative efficiency of the tower mounted air/water gun is based on the reduced compressed air requirement. The specially designed water nozzles on the external mix head provide sufficient atomization of the water without injecting compressed air into the stream. The combination of the expansive and convective cooling effects experienced by the water spray provides sufficient freezing of water droplets. The distribution of the spray is provided in two ways. High pressure water exiting the specially designed water nozzles at a high velocity and the falling and drifting effect created by the height of the tower sufficiently distributes the spray.
The high-pressure water requirement of external mix air/water tower guns is difficult for some ski areas to satisfy at upper mountain elevations. This is unfortunate because the relatively low temperatures at upper mountain elevations are typically ideal operating conditions for tower-mounted guns. Temperatures at middle mountain elevations, where sufficient pump head is available, while less than ideal, are generally adequate for operating a tower gun. However, we have seen a number of installations run from top to bottom on trails. In some instances, the pumping difficulty can be overcome by the addition of a booster pump. While moderate ambient temperatures at lower mountain elevations inhibit the use of external mix tower guns, elevated water pressure contributes to their success at these locations. In a typical arrangement, minimum water pressure requirements of external mix tower guns are met by pumps located at lower mountain elevations, if not at the base. To reconcile the pressure losses realized at the summit, base pumps generate excess pressure, or “head,” which benefits towers located at lower elevations, including those at base elevations. The pressure generated by base pumps is often as much as 200% of the gun requirements.

According to manufacturers, at marginal conditions, some external mix air/water tower guns will use as little as 15 GPM of water and 50 CFM of compressed air. As the temperature decreases, greater volume of water can be used to increase production (up to 60 GPM, depending on nozzle type and quantity). Our investigations have shown that typical guns at Vermont ski areas use between 50 and 100 CFM compressed air and between 50 and 95 GPM of water. The cost of these units is about $3,500. Additional costs include mounting and two 12-foot hoses. Depending on the soil type, mounting is estimated to cost between $500 and $2,000 per tower. Twice the number of towers are needed with this type of gun, since the trail spacing is half that for other systems. These units are usually not portable, and typically are fixed permanently in place. Tower guns can be sled-mounted, or can be moved to alternate sites if secondary pole bases are cemented in place and an additional adjusting
bracket is installed for each tower. Snowmakers can then move the tower to the second base midway through the season.

### 3.3.3 AIR/WATER FAN GUN SYSTEM

Air/water fan gun systems can be subdivided into single-ring and multi-ring air/water/fan systems. These systems do not require large volumes of compressed air. As a result, a small onboard compressor for nucleation is provided with a large fan for distribution. Single-ring and multi-ring air/water/fan systems are discussed below in greater depth.

#### 3.3.3.1. Single-Ring Air/Water/Fan System

The air/water/fan snow gun features an array of spray nozzles of varying sizes located along the circumference of the discharge end of a ducted fan and a small air/water gun mounted at the bottom of the discharge end of the ducted fan. The volume of compressed air required for nucleation is generally between 25 and 40 CFM. In this type of arrangement, the smaller compressed air requirement necessitates a smaller compressor, typically installed as an integral part of an air/water/fan type snow gun unit. Installing an onboard compressor is not necessary, since the air/water/fan gun also operates effectively when connected to a central compressed air system. The ducted fan produces a large volume of high velocity air that cools, suspends, and distributes the water droplets and the ice nuclei in much the same way that the compressed air does in the traditional air/water gun. Energy savings are possible based on the cost advantage of fan energy over compressor energy.

A typical single-ring air/water/fan gun system is presented in Figure 3-3.

#### Figure 3-3
Typical Single-Ring Air/Water/Fan Gun System

Like the traditional air/water gun, air/water/fan units are located at the particular location that snow making is required. Air/water/fan guns are also connected to local water hydrant in a similar fashion to air/water guns. The air/water/fan guns, however, also require a local electrical connection to power the fan and possibly an onboard compressor. Costs for fan systems can range from $20,000 to over $30,000 depending on the size and optional equipment ordered. Manufacturers of such equipment include SMI, LEMKO, ARECO,
HEDCO, Lake Effect, and Turbo Crystal (fog nozzle). Often fan systems can be permanently mounted on short to medium length poles, enhancing performance in much the same way towers allow air/water guns to operate more efficiently.

### 3.3.3.2. Multi-Ring Air/Water/Fan System

Several fan-based snow making system manufacturers believe that additional nozzles creating a finer water spray are capable of producing higher quality snow than that produced by the single ring models. For instance, the SMI Wizzard system utilizes five rings of 75 nozzles each to convert water into snow. The narrow water streams discharged from the 375 heated nozzles are atomized and nucleated by an additional periphery ring equipped with 20 air nozzles supplied with compressed air by a 5 HP onboard compressor. Water adjustment is provided by four heated 3-way self-draining ball valves. While snow production is increased, energy performance appears to be comparable to the standard fan snow making systems.

A typical multi-ring air/water/fan gun system is presented in Figure 3-4.

![Figure 3-4](image)

Typical Multi-Ring Air/Water/Fan Gun System

### 3.3.4 AIR-LESS TOWER GUN SYSTEM

The air-less tower gun system represents a significant change to the traditional air/water gun. The air-less tower gun eliminates the compressed air requirement for atomization by instead atomizing pre-cooled, high-pressure water with specially designed nozzles. The combination of high-pressure water and specially designed nozzles provides sufficient atomization of the water stream while the distribution of the spray is provided by the high-velocity water droplets exiting the tower. The height of the tower, the relatively low water temperature, and the use of a snow-inducer provides nucleation of the stream of water droplets. The air-less tower gun replaces relatively expensive compressor energy with comparably lower-cost pump energy.
The implementation of air-less tower guns at Vermont ski areas is, thus far, non-existent. Based on our observations and discussions with Vermont ski areas and industry experts, there are no less than four (4) critical obstacles to the widespread use of the air-less tower technology. These are:

- limited functional temperature range;
- significant additional pumping requirements;
- water pre-cooling requirements; and
- snow inducer/additive requirements.

Our investigations have suggested the limited operating temperature range to be the primary obstacle to the widespread implementation of air-less tower guns. The most significant contributor to the limited operating range is the maximum ambient air temperature requirement. According to manufacturer specifications, the maximum start-up temperature of the air-less gun is approximately 19ºF (wet bulb temperature), and the maximum normal operating temperature is approximately 23ºF (wet bulb temperature). Obviously, the maximum normal operating temperature of the air-less gun is several degrees less than that of the standard air/water and air/water tower guns. The lower temperature requirement of the air-less gun shortens the window of snow production and places added emphasis on production efficiency within the window as the potential snow making hours are reduced. The difficulty in relying exclusively on the air-less tower gun system is not only the reduction in total potential snow making hours, but also in the time of day when those potential hours occur.

By all accounts, the majority of snow making in Vermont occurs in the early season, when supplemental snow cover is required to accommodate season opening dates. In November and December alone, more than 40 potential snow making hours are lost when temperatures are between 23ºF and 26ºF, when traditional air/water guns typically begin operation and air-less guns are yet unavailable for operation.

The minimum water pressure requirement of air-less tower guns is also a cause of some difficulty. Most ski facilities currently lack the pumping capacity to provide water at the relatively high pressure (300 PSI) necessary to operate these guns at upper elevations where relatively low temperatures most appropriate for the use of air-less guns are present.

Some experts feel that this can be an insurmountable obstacle, since most ski areas use vertical turbine pumps that generate approximately 100 PSI per stage. Adding 300 PSI of pressure would require three additional bowls for each pump (provided the shafts and bearings could accommodate such an expansion). The concrete reservoirs in which the pumps are suspended would likely lack sufficient depth for additional bowls. This would also increase the horsepower requirement of the pumps significantly, which would necessitate larger motors and electrical services. Of course, operating larger electrical motors would result in increased power demand and energy consumption associated with pumping. However, the amount of energy saved by replacing compressed air energy with relatively less expensive pumping energy more than offsets the additional pumping costs.
Many ski areas also do not currently have the capacity to perform water cooling. Therefore converting to an airless technology will typically require extensive changes in the equipment and the process of making snow.

Air-less technology also requires the use of chemical additives to increase the nucleation temperature of the snow making water. Based on our discussions with Vermont ski areas and industry experts, the cost of additives is the primary obstacle to their widespread use. The effectiveness of these products remains under some scrutiny because of mixed results during performance tests. The purpose of high-temperature nucleating additives is to raise the nucleation temperature of snow making water by introducing “natural particulate” into the water stream to serve as additional nucleation sites. According to the majority of snowmakers and some industry experts, there is little to no difference between the production capacity of a standard system and an identical system using an additive. Based on our investigation, there is no shortage of particulate in common, untreated snow making water, which is generally drawn out of mountain streams, lakes, and reservoirs that are fed by mountain run-off. The mountain run-off typically accumulates sufficient debris as it travels down a mountainside to provide nucleation sites. A detailed discussion of the use and effectiveness of snow making additives is covered later in this report.

### 3.3.5 EFFECT OF AMBIENT CONDITIONS ON SNOW MAKING PROCESS & SYSTEM EFFICIENCY

The primary factors affecting snow making process are dry-bulb temperature, humidity, and water temperature. Since wet-bulb temperature accounts for humidity and the ambient air temperature (dry-bulb temperature), the snow making process usually references only wet-bulb temperature. The effect of water temperature on snow making is discussed in a later section.

Humidity is essentially the amount of water vapor in the atmosphere. Increasing the amount of water vapor in the air can inhibit the rate of cooling of water droplets to nucleation temperatures. Water is cooled by evaporating, releasing energy in the process. The more the air is saturated with water vapor, the slower the cooling process. Thus, efficient snow making requires relatively dry air in addition to cold temperatures.

Wet bulb temperature relates dry bulb temperature to humidity. A water droplet passing through a snow gun is typically at a temperature between 34°F and 44°F. Once the droplet is airborne, its temperature is lowered by expansive cooling, convective cooling, and evaporation. Wet bulb temperature is the equilibrium temperature that the droplet will eventually reach.

The efficiency and system performance of air/water snow guns (internal and external mix) and fan guns (single and multi-ring) can vary dramatically as a function of ambient temperature conditions. The traditional compressed air-based snow guns have marginal performance at about 28°F, the warmest condition at which they are capable of producing snow. At these conditions, the systems are the least energy efficient (CFM per ft³ of snow). As ambient temperatures decrease, air requirements for snow making drop considerably. At
temperatures of approximately 10°F, only 25 to 50 percent of marginal condition airflow is required.

The guns used in external mix tower systems have virtually the same relationship with climatic conditions. However, with the increased water droplet hang-time created by the tower mounting, compressed air requirements of tower guns are significantly less than those of ground-based guns when operating in identical ambient conditions.

In contrast, fan systems operate more efficiently than air/water guns at marginal (higher) temperatures. They have efficiency advantages over other systems during marginal weather conditions, such as those encountered at the beginning of the season. As temperatures drop, they tend to be less effective; their overall capacity drops, and they lose their efficiency advantage over air/water guns.

3.3.6 EFFECT OF SNOW INDUCERS ON SNOW MAKING PROCESS

Snow making is the process of heterogeneous nucleation. The nucleation temperature of snow making water is between 15°F and 20°F because low temperature nucleators are the dominant types of particles in this water. High temperature nucleators will allow water to freeze at higher temperatures.

In order to make snow in the marginal temperature range of 23°F to 27°F, the ice-nucleating site must be a high temperature nucleator to initiate the freezing process at these temperatures. Snow inducers are chemical additives that typically act as high temperature nucleators within a water stream and increase the temperature at which water droplets begin to form ice particles (nucleation temperature). This type of nucleation is referred to as homogenous nucleation. Much like particles found in clouds, these natural proteins provide effective nucleation sites for water molecules to attach and grow from. The use of inducers increases the number of nucleators in the water stream, thereby increasing the likelihood that any given droplet will contain a nucleator. Having a sufficient number of nucleators present in the water stream—whether they are natural impurities in the form of dirt and other mountain debris collected in runoff, or added proteins—is an important factor in efficient water use and, indirectly, pumping energy use.

Given a desired snow quality, the goal of the snowmaker is typically to convert the maximum volume of water into snow without allowing unfrozen water droplets to descend on the slopes. Allowing unfrozen water droplets to descend on the slopes not only lengthens the snow making time required for adequate slope coverage, but also forces pumps to move water that is never converted to snow, i.e., wasteful pumping energy. Over time, wasteful pumping energy can result in a significant cost to the facility. The key to efficient snow making is to freeze as many droplets as possible before they hit the ground or evaporate.

The molecules in water are in continual motion. It is the energy of this motion that determines the temperature of the water and prevents crystallization or freezing. A common misconception is that water freezes at 32°F. In fact, pure distilled water can be “super-cooled” to as low as -40°F before it freezes. For freezing to be initiated, sufficient energy
must be removed from the water to initiate the freezing process. An ice nucleator performs this function by attracting the water molecules and slowing them down. Thus, a nucleator can be simply defined as a foreign particle in the water that starts the freezing process.

Studies have shown that with one widely available snow inducer, water droplets containing the product have anywhere from 1,000 to 100,000 more nucleation sites than untreated source water. Since the inducer is considered a high temperature nucleator, treated water will freeze uniformly up to temperatures of between 26ºF and 26.8ºF. Untreated water may not freeze at temperatures above 20ºF. The inducer is typically mixed in water to form a concentrate that is metered into the snow making water supply via an automated injection system. Every water droplet thrown from the snow gun is then seeded with the nucleator.

Another type of snow inducer is gaining in popularity. This new additive claims to break down the natural cohesive tendencies of water and, in the process, reduce the inherent surface tension and release heat. The manufacturer’s claims indicate that using this inducer, which is a surfactant, allows water to form and flow as a mass of flatter and thinner droplets, each with a greater surface area. As a result, treated droplets will freeze more rapidly and thoroughly as they are blown into the cold air. The manufacturer claims that this inducer can increase water flow by 3%-5% for a given ambient condition, or, for a given water flow condition, increase the maximum snow making temperature by 1º–2ºF.

Furthermore, and perhaps most importantly, because water streams treated with this inducer are more easily atomized, lower air/water ratios are possible. Water that atomizes more readily reduces the amount of compressed air that snow making systems devote to atomization. Reducing the air/water ratio of any snow gun increases production volumes and reduces energy costs.

### 3.3.7 EFFECT OF WATER TEMPERATURE ON SNOW MAKING PROCESS

Water cooling systems cool the water supplied to snow making systems in an effort to increase the chances of water droplets freezing. Reducing the temperature of the water increases the efficiency of the snow making process by reducing the likelihood of unfrozen water droplets descending on the surface. Not only does cooler snow making water prevent melting of existing surface snow particles; it also eliminates unnecessary pumping of water that is not converted to snow. If a water droplet is already near freezing, less energy (less compressed air for atomization) is required to convert that droplet to an ice particle. Cooled water droplets will begin freezing earlier in their descent to the surface, providing additional time at 32 degrees (they are at temperatures below 32ºF before nucleating). Furthermore, warmer water can thaw many smaller ice crystals formed inside the chamber of the snow gun, thereby decreasing the number of nucleants in the plume. Therefore, as a general rule, the cooler the water, the less water is left unfrozen, thereby allowing more of it to become snow. Ratnik Industries and York Snow estimate efficiency losses in snow making at 2 to 3 percent for every degree that the water temperature is above 32ºF.

Water cooling systems have different designs that depend on various elements of the snow making system. Spray cooling systems have lower costs than cooling towers, but water
reservoirs or ponds are required for spray cooling systems. Spray or bubbling systems are also employed to aerate ponds and reservoirs thereby increasing surface heat transfer and preventing freezing. As with any open loop water circulation, careful attention should be given to cooling towers, spray and bubble systems to prevent any clogging or freezing of the system. Cooling towers are an alternative method of water-cooling when a reservoir or pond is not available. Water cooling systems are often necessary for many “air-less” tower guns, which require relatively cold water.

At Aspen Skiing Company (ASC), the Snowmass Mountain ski area uses a cooling tower to reduce the water temperature from 42 to 34°F. Snow can be made earlier in the winter with the cooling tower, so snow making water demands are reduced later in the season. As a result, peak water use is reduced because Snowmass Village and the ski area use the same water supply source. ASC estimates negligible cost and energy savings, but continues to use the cooling tower to be able to make snow earlier in the season and thus open the ski area earlier. Certainly for given ambient conditions, snow guns will operate more efficiently, and thus provide energy and cost savings when the temperature of snow making water can be reduced. Furthermore, snow making can occur at increasingly marginal ambient temperatures when snow making water temperature is reduced. Thus, snow production can occur earlier in the season than previously possible. Based on our investigations, moreover, early season snow production is the primary reason for water cooling. However, for this scenario, it appears that whatever efficiency gains are realized by producing snow with “cold” water are tempered by the inherent inefficiencies associated with producing snow in marginal temperatures.

3.3.8 SNOW MAKING SYSTEM COMPARISON

Each of the snow making technologies discussed has advantages and disadvantages from an energy consumption and production perspective. Table 3-1 presents a comparison of the performance merits of each system under prevalent operating conditions.

<table>
<thead>
<tr>
<th>Snow Making Technology</th>
<th>Conditional Performance</th>
<th>Relative Equipment Cost</th>
<th>Cental Compressed Air</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Temp.</td>
<td>Marginal* Temp.</td>
<td>High Wind</td>
<td>Mobility</td>
</tr>
<tr>
<td>Internal Mix Air/Water Ground Gun</td>
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<td>Good</td>
<td>Excellent</td>
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<tr>
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<td>Poor</td>
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<tr>
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<td>Good</td>
</tr>
<tr>
<td>Single Ring Air/Water Fan Gun</td>
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<td>Poor (+)</td>
<td>Good (-)</td>
<td>Fair</td>
</tr>
<tr>
<td>Multiple Ring Air/Water Fan Gun</td>
<td>Fair (+)</td>
<td>Poor (+)</td>
<td>Good (-)</td>
<td>Fair</td>
</tr>
<tr>
<td>External Mix Water Tower Gun</td>
<td>Excellent</td>
<td>N/A</td>
<td>Poor</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* "Low Temperature" is generally considered 16°F (Wet Bulb) and below.
** "Marginal Temperature" is generally considered 26°F - 30°F (Wet Bulb).
*** Cost comparison does not include the price of supporting infrastructure.
**** Air/Water/Fan guns can operate an onboard compressor or connect to a central compressed air system.

The table above presents the relative performance characteristics of the various snow making technologies with a focus on operating efficiency. The qualitative ratings—poor, fair, good, and excellent—describe the performance of the particular technologies in relation to their range of operating efficiencies. These descriptions do not consider the relative production
capacities of the technologies, but rather suggest the most effective technology in both low and marginal ambient temperatures, and in potentially detrimental wind conditions. With the exception of air-less tower guns, each of the technologies discussed will produce snow of varying quality in marginal temperatures. The exclusion of compressed air for atomization in air-less tower guns effectively eliminates the gun’s ability to produce snow in anything short of ideal ambient conditions. External mix air/water guns rely on a relatively small amount of compressed air (compared to internal mix air/water guns) and thus, are inherently more efficient than traditional internal mix guns but are nonetheless limited in production capacity in unfavorable ambient temperatures.

Fan systems have the advantage of being far less energy intensive during early season (marginal temperature) weather conditions than air/water systems (which are dependent on large central compressed air plants and distribution networks). Fan systems use less energy than the traditional guns since compressed air is not used to distribute the snow cover. Fan systems utilize small on-board compressors (approximately 5-15 HP) for atomization and initial nucleation of snow through the nozzles, and 10-20 HP fans for distribution. Fan systems only require water piping and electric power distribution. The major drawback of air/water/fan guns is their relatively large price tag. Many ski facilities are unwilling (or unable) to pay the high cost of conversion to these systems. Furthermore, the systems are more difficult to transport to various mountain locations. Manufacturers claim these units should be placed to take advantage of prevailing winds. However, wind conditions can change continuously on mountain terrain, necessitating frequent gun adjustments and relocations.

External mix air/water tower systems also represent a considerable increase in efficiency when compared to conventional internal mix snow guns. The nozzles are mounted at the top of 8’ – 35’ towers in order to increase the “hang-time” of the snow crystals, allowing the crystals to partially form on their own, decreasing the dependence on compressed air. They are, however, more expensive to purchase and install than traditional guns. Furthermore, because the external mix towers are permanently installed in predetermined locations, they must be located to take advantage of prevailing wind conditions. As such, many facilities only use these near the facility base or in other protected areas where wind conditions are less variable. Snow guns used in internal mix and external mix systems do not require an external source of power at the snow making gun location, but rather utilize remote compressors and water pumps. Air/water/fan snow guns do, however, require local electrical connections on the slope to power their fans and onboard nucleating compressors. Internal mix air/water and air/water/fan systems offer the highest range of operating temperatures and the greatest control of snow distributions due to their use of compressed air and/or fans. These technologies tend to be best suited for wide and early opening trails where control of snow coverage is essential. External mix systems offer greater energy efficiency but have a limited range of operating temperatures. Another drawback of external mix systems is that snow distribution is greatly affected by prevailing wind conditions. As much as 30 percent extra grooming time may be needed to provide a finished surface when using external mix systems rather than internal mix or air/water/fan systems. External mix systems tend to be best suited for narrow and late opening trails as well as for mid season “touch-ups.”
In practice, tower guns are used to produce high volumes of snow in somewhat predictable weather conditions on high use trails. The use of tower guns generally yields the most energy-efficient and the least labor-intensive method of snow production. The limitation of external mix tower guns lies in the fact that they do not work effectively in relatively warm temperatures, and are essentially not maneuverable.

Fan guns are also very efficient at producing snow in high volumes, in central areas. They are generally employed for blanketing base areas and at circulating points and lift bases. The disadvantages of fan guns include the requirement of a local electrical connection, large size and weight, higher capital cost, and the requirement of constant monitoring. Several Vermont ski facilities have indicated that fan guns can create “nightmare scenarios” rather quickly if freezing is allowed to set in, if the ambient air temperature rises quickly, or if the mounting pole deviates from vertical.

Traditional internal mix air/water guns are an old standby. They typically work well at marginal temperatures when other guns are rendered ineffective. Internal mix guns are also very portable, and have a lower capital cost. The main deterrents from using these traditional guns are the high energy cost associated with compressed air consumption, and the high operator expense associated with continued adjustment.

When selecting snow guns for a new slope or for upgrading an old snow making system, ski areas would do well to consider not only the capital cost. Also important are the cost of supporting structures, such as towers or air compressor systems, and the effectiveness and applicability (including snow making temperature, type of terrain, width of trail, intended opening date, and noise sensitivity) of the given guns as they apply to the proposed location for the guns.
Table 3-2
Considerations for Snow Making Systems

<table>
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<td>Snow making equipment:</td>
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<tr>
<td>Internal mix air/water gun</td>
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<td>External mix air/water tower gun</td>
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<tr>
<td>Air/water fan gun</td>
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<tr>
<td>Airless tower gun</td>
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<td>Compressed air system</td>
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<td>Water pumping system</td>
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<td>Lift systems</td>
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<th>Factors Affecting Snow Making</th>
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<td>Ambient conditions</td>
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<td>Snow inducers/additives</td>
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<td>Water temperature</td>
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<table>
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<th>Ski Facility - Energy-Efficiency Opportunities</th>
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<tbody>
<tr>
<td><strong>Snow Making Equipment</strong></td>
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3.4 AUTOMATED SNOW MAKING SYSTEMS

System control automation can significantly increase the efficiency of snow making systems. Modern automated snow making systems are capable of precisely adjusting air/water mixtures and even gun position based on varying weather conditions. Weather information such as ambient air temperature, wet bulb temperature, humidity, and wind speed and direction is collected from weather stations located throughout the mountain. These weather stations provide important information to snowmakers, allowing them to accurately and more easily modify the snow making systems by using computer controls to quickly respond to changing conditions on the slopes. The improved reaction time for adjusting snow making systems reduces overall energy costs related to pumping excess water or compressing excess air which result from lags in response time during manual operations. According to one design engineer, for internal mix and fan systems, there have been improvements of 30 to 50 percent in efficiency with automatic operations. For external mix systems, the benefit is typically much less since these guns are easy to turn on and off manually and do not require constant adjustment. In addition, weather conditions can change quickly on a mountain, requiring snow making operations to move from one area of the mountain to another. Computers facilitate these operations by allowing the snowmaker to focus on snow making operations while computers manage equipment operation. Increasing facility personnel safety by reducing or eliminating manual adjustments (especially at night) is also an important benefit of snow making automation. Since insurance costs can be significant, this is a benefit worth noting.

Computers also monitor system conditions such as water flow rates, water temperature, airflow rates, and air pressure. Computers often control water pressure to accommodate changing water demands during snow making operations. Also, automated controls for centrifugal compressor systems can measure the system pressure and control multiple compressors to achieve maximum efficiency by load sharing and by automatically starting and stopping units based on system demand.

According to one design engineer, starting and shutting down a manual snow making system can take from one to four hours for startup and from one to three hours for shutdown. Early season snow making often is performed in temperature windows as small as six to eight hours. An automated system can start and stop in a seven to fifteen minute period. The improved response time of an automated snow making system can greatly improve slope quality in the early and late season. Automated systems constantly adjust air/water mixtures and water and air pressures based on the constantly changing ambient conditions on the mountain. On large mountains in particular, ambient conditions can be quite varied at different elevations. Automated systems eliminate the need for often-inefficient “rule-of-thumb” type of adjustments, as well as multiple “sleeve tests” which occupy valuable time during brief snow making windows. According to York Snow, an increase in operating efficiency of up to 60 percent can be achieved by implementing an automated system.

The efficiency of traditional air/water snow gun systems improves as ambient temperatures decrease. In order to benefit from this performance increase, the quantity of air being directed to each snow gun should be modulated. While management of compressed air plant...
output as a whole can be done with plant controls, to achieve efficiency gains in the compressor plant, modulation of compressors is accomplished by controlling the air and water valves supplying each snow gun. Control of the air and water valves provides the means to adjust snow quality. Accurate control of these valves indirectly reduces energy use. Air and water valves set to positions corresponding to weather conditions other than what they are experiencing at the time may provide quality snow at the expense of efficiency. For example, air and water valves set to marginal weather positions are typically "heavy on the air. As the temperature drops, so does the need for compressed air. Excess compressed air will continue to discharge from the snow gun until valve adjustments can be made. There are automatic control systems that modulate flow through valves to optimize snow quality and efficiency. Such systems are becoming increasingly popular in Europe. Because of costs involved, they are not as common in the United States and are rare in the Northeast.

At Aspen Skiing Company, the Snowmass Mountain ski area installed a computerized process control system (PSC) to improve the efficiency of its snow making system. The primary benefit of the system is its ability to adjust water flow according to ambient air temperature. Depending on the ambient air temperature, water can be lost through evaporation if the water flow rate is too low. ASC estimates that 4.5 to 6.3 million gallons of water are saved each season by using the PCS rather than conventional systems.

At least one ski area in Vermont is in the midst of installing an automated zone flooding system. The automated system relies on the fact that the external mix tower guns supplied by the various zones require no adjustments in terms of air/water mixtures. The automated system will serve only to fill and empty the water piping serving the zones.

Currently, most Vermont ski areas monitor detailed weather information to forecast and schedule snow production. Most facilities utilize computer-based pump and compressor control to aid in the snow making process, but also to closely monitor the facility’s peak demand. Based on our discussions with snowmakers at various ski areas in Vermont, maintaining a maximum peak demand is frequently the top priority of facility personnel, followed closely by adequate snow production. Because of the significant cost impact of exceeding a given maximum peak demand, and the attention that must be given a system to maintain such levels, the operating efficiency of a system, at least in terms of constant adjustments to maintain optimum air/water mixtures, is frequently neglected in the name of saving peak.

### 3.5 WEATHER DRIVEN SNOW MAKING STRATEGY

With all types of snow making delivery equipment, it is much more expensive to manufacture snow during periods of marginal weather conditions. This fact is particularly true of traditional and air/water tower gun systems, which use dramatically increased amounts of compressed air during warmer conditions. Air-less tower guns are simply unable to produce snow in marginal ambient conditions. Some ski areas have successfully decreased their overall snow making costs by investing in additional guns as well as by increasing pump and compressor capacity. An investment in increased capacity allows the staff to increase snow production during periods of ideal snow making conditions, while reducing the need to
make snow during marginal conditions. Often, this approach can be more effective than replacing existing equipment with newer, marginally more efficient equipment.

### 3.6 SELECTION OF EQUIPMENT

Decisions regarding which snow making system to use are dependent on a number of conditions. For new facility or trail development where a large compressed air plant associated with a traditional snow gun system is not already present, application of fan systems coupled with traditional equipment for certain locations can be the best choice. Because of the large capital investment required for fan equipment, most facilities are unwilling to conduct a large-scale conversion to such systems. Rather, when funds are available, facility personnel choose to add such equipment to focused areas of the facility. Ultimately, decisions regarding particular systems to install must be based on whether the project is new development or a retrofit, on snow making locations, on capital availability, and on operating costs.

### 3.7 COMPRESSED AIR SYSTEMS AND EFFICIENCY OPPORTUNITIES

Compressed air is a critical component of most snow making systems. Compressed air, once discharged from a snow gun, atomizes water streams into fine droplets that nucleate and form ice crystals during the descent to the slope. For internal mix systems, air compression is the main force atomizing the air/water mixture. With these systems, nucleation depends on the length of time the droplets descend through the air and the expansive cooling effects they encounter. When compressed air at a highly pressurized state suddenly returns to atmospheric pressure, it expands and cools. This process is called expansive cooling. Expansion of the air/water mixture is caused by the pressure release at the nozzle. External mix and air/water/fan systems also rely on these principles to create snow.

Since most snow making systems depend on compressed air for operation, air compression is typically the primary source of energy consumption in snow making operations. According to the Compressed Air Challenge sourcebook “Improving Compressed Air System Performance,” developed for the industry by the U.S. Department of Energy (DOE) Motor Challenge Program at the Lawrence Berkeley National Laboratory, inefficiencies in air compressors can be significant, and system improvements can save as much as 20 to 50 percent in energy consumption.

Air compression systems used in snow making consist of compressors, a distribution network, system controls, and in some cases storage systems and end-use equipment. According to the DOE, older snow making systems used single-stage rotary screw compressors that typically produced approximately four CFM per brake horsepower (BHP). Most of these compressors have been replaced with three-stage centrifugal compressors that produce around 4.8 CFM/BHP.

In 1999, Aspen Mountain had six air compressors for its snow making operations. The system consisted of one new 1,100 HP three-stage centrifugal unit and five older 353 HP
rotary screw compressors. Aspen estimates that it requires approximately 1,000 hours of air compression per ski season. The new 1,100 HP unit served as the main compressor, three of the five older compressors provided auxiliary support, and the remaining two older units had maintenance problems and were rarely used. Aspen Mountain decided to purchase a new air compressor for three reasons. First, two of the rarely used older compressors had defects (damaged cooler, defective bearings, and overheating) that caused maintenance to be costly and continuous. Second, the older compressors had a dramatically lower air volume to horsepower ratio than the new compressor. Aspen Mountain estimated that it would take approximately four of the older compressors to produce the same amount of air as a single 1,100 HP unit. Third, Aspen Mountain wanted an increase in system capacity.

Aspen Mountain estimates approximately 232,800 kWh in electricity savings, 466 kW in non-coincident peak electric demand savings, and 233 kW in coincident peak electric demand savings as a result of the new installation. In addition, Aspen estimates its cost savings for compressor maintenance at $5,000 annually and the implementation cost for the new 1,100 HP compressor at approximately $150,000 (including the costs of the compressor unit, cooling unit, air-cooled after-cooler, and installation).

There are some fundamental limitations related to improving snow making operation efficiency through conversion from one type of snow making equipment to another. These limitations include the relative practicality of alternative systems, high first costs, and overall economics, or return on investment. Once action has been taken to implement improved snow making equipment, the next consideration is to evaluate compressed air operations and water pumping systems.

The typical compressed air plant for snow making operations that use internal mix air/water guns requires between 500 HP for the smallest ski facilities to greater than 10,000 HP for the larger facilities. Air systems are most commonly driven by electric drives, but diesel engine-driven systems are also common.

Such substantial compressed air operations typically represent the largest operating costs for ski facilities, and most facilities actively struggle to secure the best energy rates to reduce costs. Seldom, however, are ski facilities focused on air system energy-efficiency strategies. It is common to find systems with 1,000 horsepower compressors being operated at inefficient part-load conditions rather than according to a more efficient base-load operating strategy. Such poor operation can easily result in tens of thousands of dollars of wasted energy costs annually.

### 3.7.1 EFFICIENT COMPRESSOR SELECTION

Ski facility management is not alone in the industrial community with respect to its selection of relatively inefficient air compressors and major auxiliary equipment. Whenever possible, selection should be based on an accurate understanding of average and peak air requirements, and should also include a plan for overall plant operation. Further, consideration must be guided by the knowledge that lifetime operating costs will far exceed capital costs, even though ski facilities have relatively short operating schedules. The short
operating seasons at ski facilities lend themselves to extended equipment life and the maintenance of energy savings for many years. This point is particularly relevant in light of the frequency of leasing or renting air compressors by ski facilities. Such equipment may reduce cash flow burdens for capital equipment, but may be ill-advised if the operating costs of inefficient equipment are greater than the monthly equipment rental costs.

A network of air compressors should be capable of efficiently supplying peak conditions, and should also be able to operate efficiently when compressed air requirements are reduced. As with the selection of large compressors in any industrial operation where multiple compressors are operating, it is best to have base load compressors with very good performance (low kW per CFM) and peaking compressors that work with reasonable efficiency at part-load conditions. In so many applications throughout the industry, highly effective and efficient reciprocating compressors are not specified, and screw compressors have replaced them as primary compressors, despite their inherently less efficient part-load characteristics. We believe reciprocating compressors have the best performance as base load machines, but it is certainly acceptable to use screw machines if a high performance model is selected. Of course, centrifugal compressors are also well suited for constant demand applications, especially in cases of very high CFM requirements such as those encountered at Vermont ski areas. In fact, for large HP machines operating in relatively cold temperatures, centrifugal compressors can be more efficient than comparable reciprocating machines. For the peaking application compressors, it is especially important to understand the air demand range of the snow making operation. As discussed previously, a properly controlled system will use significantly less air at lower ambient temperatures; therefore, part loads may be less than 50 percent of total compressed air plant capacity. The selected peaking compressors must have capacity for handling the maximum to minimum air demand range, and should have excellent part-load characteristics. Screw systems with integral or retrofit variable frequency drive (VFD) speed control are excellent for such applications. Appropriately staged reciprocating machines or screw compressors with good part-load modulation features are also acceptable choices.

3.7.2 OPTIMIZED COMPRESSOR CONTROL AND OPERATION

Essentially, ERS believes that large compressed air plants such as those at ski facilities should have automatic optimization controls. While the same overall compressor operation strategy can be implemented through manual controls, with thousands of horsepower of air compressor it is imperative that optimum selection of operating compressors be appropriately implemented at all times. In many cases, manual control works well. Eventually, however, a less efficient group of operating compressors can be running for the given load conditions. The proper control system will take data on system load requirements (flow and pressure) and will effectively select compressors that will best serve baseline and peaking needs for that condition.
3.7.3 COMPRESSED AIR LOAD REDUCTION APPROACHES

For compressed air used for snow making, there are two primary means of limiting the air load. One way involves proper control of air going to the snow making guns as a function of ambient temperature conditions. The second approach is also highly significant and involves elimination of significant air system leaks. There are considerable challenges to identifying air system leaks in snow making air lines. There can be as little as a few miles of distribution lines in the smallest of ski facilities, to greater than one hundred miles in large operations. To complicate matters, many of these lines pass underground or through wooded areas and are not readily accessible for leak detection work.

Leaks in any system can be very wasteful of raw materials and energy. Air leaks in air compression systems are especially wasteful because these systems require a great deal of energy to operate. Different air compression systems have different ratings for energy efficiency. A compression system with a leak can waste 20 to 30 percent of the compressor output. Regular inspections should be performed to identify any air leaks in a compression system. Various methods exist to identify leaks, including use of ultrasonic acoustic detectors and pressure gauges at several points in the air distribution system.

Repairing leaks can be difficult if distribution pipes are buried underground. However, the potential savings in energy consumption can quickly offset the costs of repairs and pipe replacements. The case study presented below provides an example of repairs made for above ground and underground pipes and the annual cost savings achieved.

Aspen Mountain was able to quantify the leaks in its compressed air system and estimate the energy and cost savings associated with repairing the leaks. The compressed air system at Aspen Mountain operates six compressors approximately 1,000 hours annually. One compressor is a new 1,100 HP three-stage centrifugal unit, and the remaining five compressors are older 353 HP rotary screw compressors. According to Aspen Mountain personnel, the new compressor can bring the system to pressure in about 30 minutes. When the compressor shuts off, the system returns to zero pressure within two hours.

The amount of air lost from a leak in a compressed air system depends on several factors: the line pressure, the compressed air temperature at the point of the leak, the air temperature at the compressor inlet, and the estimated area of the leak. The leak area is usually estimated as a diameter in inches.

We have found that ultrasonic leak detection protocols for air distribution at ski facilities must be focused on areas where there is the highest probability of identifying leaks. Such high-impact locations include major piping connections near the compressed air plant; valves on the slopes near each snow gun connection; and hose hydrant connections (air line to hose or hose to snow gun). Other areas where leaks are reasonably probable are on the connections between distribution pipe sections. Again, such piping connections may be difficult or impossible to access.

High quality ultrasonic detection systems can be used for monitoring air leaks. While integrity of some hydrant connections on snow guns may be checked at the base of the
slopes, it is more effective to determine performance of the equipment while in its operating location and condition. Ultrasonic leak detection studies can be of limited effectiveness during the summer, since snow guns are usually in storage. Reasonable times for leak assessment may be just prior to the beginning of the ski season (since weather conditions and accessibility may be best), but ski facilities are often busy then and considerable time is required to walk to each snow making location. The best time may be at the end of the ski season, when equipment is in operation, ski facility management has a willingness to accommodate the effort, and monitoring time is reduced due to the ability to rapidly ski between snow gun and valve locations.

Appendix A presents compressed air system maintenance strategies to reduce operating costs.

### 3.8 WATER PUMPING SYSTEMS AND EFFICIENCY OPPORTUNITIES

Lack of water availability for snow making has been an issue that has frequently resulted in the inability of a ski business to grow or expand. There are numerous examples of ski areas that have faced limitations on how much water they could draw from nearby rivers, reservoirs, or wells. Frequently, efforts to convince the community and environmentalists that increased water consumption is acceptable requires years of legal battles, preparation of many environmental impact statements, and continuous negotiations with concerned parties. Results are often disappointing for the ski businesses.

#### 3.8.1 RESERVOIRS

Snow making requires large amounts of water. A common unit of measure in snow making is an acre-ft. An acre-ft is the amount of snow necessary to cover an area of one acre with one foot of snow. The standard volume of water to produce an acre-ft is approximately 179,000 gallons. Many ski areas are capable of converting up to 10,000 gallons of water into snow in about one minute. The large demand for water is often a problem for ski areas due to concerns about natural water supplies. Drawing from natural sources during times of low or reduced flow, such as the winter season, can have negative impacts on wildlife. To protect aquatic habitats, the drain on natural streams and lakes by ski areas could be drastically reduced or eliminated by constructing reservoirs dedicated to snow making operations.

In addition to preserving the aquatic habitat, reservoirs provide operational cost savings. Reservoirs can be located near the elevation of snow making systems so that the vertical distance that water needs to be transported to the system is minimized. Although water must initially be pumped from the water source to the reservoir, this pumping process can occur during the utility’s non-peak hours when the energy charges (non-coincident peak electric demand cost) are lower. Snow production can then occur at the discretion of the snowmaker with minimal utility peak hour charges (coincident peak electric demand cost). Reservoirs located above the elevation of snow making systems can gravity-feed water and eliminate the energy consumption associated with pumping water from the reservoirs to the system.
The Aspen Skiing Company (ASC) reduced its draw on Snowmass Creek by using a 1.5 million gallon reservoir at the Snowmass Mountain ski area. The reservoir cost approximately $110,000. ASC also uses a gravity fed system for the reservoir. ASC estimates that it saves approximately $14,000 per year from reduced electricity costs alone as a result of this project. There are also a number of snow making reservoirs in the state of Vermont. Small reservoirs are generally considered to be less then 25 million gallons in capacity. Larger reservoirs are generally 100 to 250 million gallons in capacity. It can often take an entire year to fill these reservoirs.

3.8.2 REDUCING PRESSURE DROP WITH INCREASED PIPE DIAMETER

Pressure loss in water pipes typically ranges from one (1) to four (4) feet of head per 100 ft of pipe. The maximum pressure loss in that range occurs at the maximum recommended flow rate (GPM). Conversely, the minimum pressure loss occurs at the minimum recommended flow rate. Energy conservation resulting from reduced pump load can be realized with properly sized piping. Of course, pressure losses can be further reduced by further reducing the flow rate through a given pipe diameter. As flow rate is reduced through a pipe, additional piping capacity becomes necessary to accommodate the minimum flow requirement of the particular application. A detailed engineering analysis should be conducted to determine the cost-effectiveness of pressure loss reductions below the typical range of values. Table 3-3 below presents the ASHRAE recommended maximum flow rate (GPM) and the recommended flow rate to (cost effectively) minimize pressure loss for several pipe diameters.

<table>
<thead>
<tr>
<th>Pipe Size (in)</th>
<th>ASHRAE Maximum Flow Rate (GPM)</th>
<th>Recommended Maximum Flow Rate (GPM)</th>
</tr>
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<tbody>
<tr>
<td>4</td>
<td>600</td>
<td>200</td>
</tr>
<tr>
<td>6</td>
<td>1,400</td>
<td>500</td>
</tr>
<tr>
<td>8</td>
<td>2,500</td>
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<td>12</td>
<td>5,200</td>
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<td>14</td>
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<tr>
<td>18</td>
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<td>6,000</td>
</tr>
<tr>
<td>20</td>
<td>13,000</td>
<td>8,000</td>
</tr>
</tbody>
</table>

For applications operating 1,500 hours per year or less, ASHRAE also recommends a maximum water velocity of 15 ft/sec to prevent pipe erosion.

3.8.3 WATER LEAKS

Water piping inadequacies can create leaks in the water distribution system. Piping inadequacies can include corroded or broken underground piping, leaky valves and hydrant connections, or faulty pipe installation. Leaks in the water distribution lines that supply snow
making systems can have several negative impacts on the overall snow making operation. In addition to the wasted water, energy is also wasted when water is pumped through a leaking pipeline to the snow making system. In some cases, leaking water can also come into contact with and melt snow on the slopes. Quantifying the amount of energy wasted and the volume of manmade snow melted by a water leak is difficult and depends on the severity of the leak, the pumping system in use, and the topography of the affected slopes.

During a closed-loop test of the water distribution system at Aspen Mountain, a large leak was discovered between the primary and booster pump houses. The system was losing about 100 gallons of water per minute. The energy savings associated with repairing a leak of this size are obvious. In addition to eliminating the ineffective pumping energy, repairing water leaks will reduce any snow melt that may be caused by running water just below the surface of a slope.

3.8.4 WATER RE-CIRCULATION STRATEGIES

Design of pumping systems that involve pumped recirculation back to the reservoir or supply sump is probably the most wasteful practice that is common in snow making pumping systems. Snow making operations usually involve a network of several pumps, each with the objective of providing service to a certain area of the facility or to a certain elevation. Often, the full capacity of water is not required because snow is not being made in a certain area, because some snow guns are not connected, or because ambient conditions limit the water-to-air ratio, thereby limiting how much water can be directed to snow making equipment. When part-load flow conditions occur, wasteful recirculation designs do not allow reducing the pump output. Rather, the full output (flow and pressure) of the pump is generated, and the excess flow that is not required at the time is recirculated back to the reservoir. This wasteful recirculation practice is frequently the standard pumping design by some engineering firms that develop ski facility snow making and pumping systems. This practice not only wastes electrical energy, but also heats the snow making water by up to 1.5°F per stage of pumping.

When pumps in such systems are operating, they are always at full load. Consequently, there are considerable opportunities for savings. The primary measure that should be implemented involves redesign of the valves on the output side of the pump. When part-load flow to snow making equipment is required, the output of the pump and the associated energy needs should reflect this situation. Therefore, recirculation pumping is not acceptable unless truly needed by the pump for input flow to avoid net positive suction head problems. A properly supplied pump source will limit or eliminate the need to recirculate. As such, a single valve can be used for modulating the flow, in lieu of the wasteful system of two valves that split flow between the snow making equipment and recirculation lines. The throttling of flow allows the pump to at least operate at reduced load when such conditions are required. Of course, throttling itself is an inefficient operation, so not at all an ideal approach for flow modulation. Improved flow control is discussed next.
3.8.5 FLOW MODULATION USING VARIABLE FREQUENCY DRIVES (VFDS)

Any modulation of pump output flow (and associated electrical load) is preferable to operation at full output (with recirculation) when snow making operations require only part-load flows. However, output throttling of pump flows with control valves is inefficient and is associated with higher energy requirements relative to proportional pump flow control strategies. By reducing the speed of the pump, flow can be reduced effectively while dramatically reducing associated input energy requirements. Since ski facility objectives call for full flow whenever possible (to maximize snow production), system designs do not typically have efficient flow modulation equipment. Regardless of the objectives, however, periods with part-load flows represent a substantive percentage of pump operation.

VFDs can result in highly efficient modulation of pump output flow. VFDs modulate flow by reducing electrical frequency to the pump drive and thereby reducing pump speed. Theoretically, energy input requirements are proportional to the cube of the speed (or flow) ratio, so energy use should drop precipitously as pump speed reduces. In practice, however, achievement of that cubic relationship does not occur due to factors such as real pump performance and efficiency when not operating at design conditions. Further, flow reduction potential is limited due to the need to avoid associated output pressure reductions that might inhibit the ability to deliver water to the required area in the ski facility. Still, practical energy savings with VFDs are dramatic and are evidence for this appropriate measure for snow making pump operation.

3.8.6 OPTIMIZATION OF PUMP OPERATION

Pump systems for ski facilities are typically designed so that specific pumps are dedicated to providing flow for certain areas (slopes) or elevations within the ski facility. In the operation of pumping systems, it is frequently most effective and energy efficient to operate those pumps that are most suited for actual flow and pressure conditions. As such, it is often better to have fewer pumps operating at full-load than it is to have all pumps operating at part-load. The stated standard design of snow making pumping systems with piping arrangements that dedicate pumps exclusively to specific regions can be contrary to the most efficient operation. We believe that pump allocation, piping arrangements, and systems controls should be upgraded where possible to facilitate an optimized energy operation. For some facilities, changes to existing piping to achieve pump optimization can be considerable. This approach requires careful consideration of upgrade costs (based on pipe and valve modifications and location(s) of pump houses) and savings potential. Optimization controls for such systems are readily available that allow automatic selection of appropriate pumps based on flow, pressure, and valve operation signals. Of course, operating hours and frequency of pump system loading at certain flows will drive the overall economics of such an optimization strategy.
3.9 LIFT SYSTEMS

A top-drive lift is a lift system with its motor located at the uphill terminal. A top-drive lift pulls from the uphill (loaded) side of the cable. A bottom-drive lift is a lift system with its motor located at the bottom terminal. A bottom-drive lift pulls from the downhill (unloaded) side of the cable. Because it pulls from the loaded side of the cable, a top-drive lift is able to obtain the required cable tension by means of system dynamics alone, whereas a bottom-drive lift requires a higher tension cable to achieve the same effect.

The higher tension cable causes bigger loads on the towers and throughout the system. Because of this difference in system dynamics, estimates indicate that a top-drive lift can achieve 10 to 15 percent more carrying capacity than a bottom-drive using the same equipment. Conversely, to achieve carrying capacity comparable to a top-drive lift would require 10 to 15 percent more power from the driving motor. A bottom-drive system also requires an additional hold-down tower at the bottom of the lift, a larger cable and an increase in torque and horsepower because of the increased tension in the cable, plus stronger structural frames and more concrete in the foundations.

While bottom-drive lifts can be more convenient to install and operate, the additional supporting equipment required could mean a cost of 10 to 20 percent more than a top-drive lift. The larger the lift and the rougher the terrain profile, the more pronounced the potential savings associated with a top-drive lift.

Installation of a top-drive lift depends on the availability of electric power and vehicle access at the top of the lift. It could be expensive to provide power if it is not available near the top of the lift. Furthermore, an operator needs to be at the top of the lift at startup and shutdown, and heavy components may need to be transported to and from the top of the lift during installation and motor maintenance. These factors may require that a road to the top of the lift be built or improved and maintained. Despite these possible drawbacks, a top-drive lift is worth investigating because of the potential cost savings over the life of the lift.

At Arapahoe Basin, a ski lift replacement was planned for the Lenawee Lift. Because of the mid-mountain location of the lift, a bottom-drive lift would be more convenient to access during startup and maintenance than a top-drive lift. However, Arapahoe Basin was interested in comparing the costs and environmental impacts of the two types of lifts.

The design for the new Lenawee Lift called for a bottom-drive lift at a total project cost, including installation, of approximately $1,200,000. As stated above, a top-drive lift is estimated to cost 10 to 20 percent, or in this case $120,000 to $240,000, less than a bottom-drive lift in terms of initial material and equipment costs.

The design for the bottom-drive lift required 238 HP and was supplied 300 HP, whereas a top-drive lift would require 10 to 15 percent less power, as described above.

In addition to the cost savings, the reduced energy consumption would translate into avoided emissions at the electric power plant. Based on average conversions for Colorado utilities, the estimated reduction in carbon dioxide emissions would be 25 to 37 tons per year.
3.9.1 HARMONICS FILTERING

Harmonic distortion is defined as voltage and current frequencies in power systems that are either above or below the normal 60 Hz power provided by utilities in the U.S. For buildings, the most common sources of harmonic distortion are computers, other electronic equipment, and high efficiency electronic ballasts.

For ski areas, the greatest sources of harmonic distortion are large, direct current (DC) drives and alternating current (AC) adjustable speed drives used to power lifts and snow making systems.

Harmonics filters can be installed to eliminate the negative effects of harmonic distortion. In addition to cleaning voltage distortions, harmonics filtering has the added advantage of increasing the power factor. Electric induction motors require a reactive or magnetizing current that does no useful work. This reactive power takes up space in the distribution lines but does not appear on a demand meter. The power factor is the ratio between the active power that a facility uses (measured in kW) and the apparent power that the utility provides (measured in kVA). To ensure that customers are charged for their full power use, many utilities include a power factor charge when the measured power factor is more than 5% of unity. Large DC lift motors in particular tend to have low power factors. For a large DC drive (400 to 1,200 hp) the power factor typically ranges between 0.50 and 0.78. This is partially due to the gearbox ratio, which prevents the DC motor from operating at its rated nameplate speed.

Although harmonics filtering requires a significant capital investment, the payback is reasonable for ski areas with power factor charges imposed by their electric utility. For example, in the case of a Vail, Colorado installation of eight filters cost approximately $500,000 but the payback period in terms of power factor charges alone was only 6 years. Taking into account reduced energy consumption, the payback period was only 4.4 years.

In 1990, Holy Cross Energy began receiving customer complaints about power supply instability caused by harmonic distribution. Vail Resorts and Aspen Skiing Company are Holy Cross’s two largest customers, and their large HP lifts were suspected to be the problem. After studying the problem, Holy Cross executives devised a plan to finance the installation of harmonics filters on Vail and Aspen lifts. The ski areas would repay the implementation cost to Holy Cross with savings from improving power factors. Seven DC lifts on Snowmass Mountain were selected for harmonics filtering. The power factor savings were estimated based on utility bills issued before filter installation. The energy reduction was estimated to be 5 percent and was also derived from utility bills.

Many ski lifts have separate transformers that isolate the effects of the DC drives on the network. Often capacitor banks are all that are required to correct the power factor.

3.9.2 UTILITY BILLING RATE STRUCTURE FOR LIFTS

Electric rates typically consist of a consumption component and a demand component. The consumption charge is proportional to the amount of energy used and is measured in kWh.
The demand charge is proportional to the rate at which energy is used and is measured in kW. It costs the utility more to provide the capability of using power at a faster rate. The monthly bill is based on the maximum demand, or “peak demand,” reading for that month, typically monitored over 5 to 30 minute intervals. For lifts, the peak demand charges for electricity can dwarf consumption charges because lifts must perform at peak capacity for only eight hours per day during the ski season. For the rest of the time, the utility must be able to provide peak capacity while the lifts lie idle.

In addition to consumption (kWh) and demand (kW) charges, some lifts may be charged for electricity based on a rate structure that includes a “coincident peak” charge. At the end of the month, the utility determines when its total system peak occurred during the month and charges customers to monitor their energy use, compare it to total system activity, and shift loads whenever possible to avoid excess charges.

**3.9.3 PEAK SHAVING STRATEGIES FOR LIFTS**

“Peak shaving” refers to actions taken to reduce the maximum demand on a meter over a building cycle (typically one month). Depending on the rate structure for lifts there may be an added incentive to reduce the coincident peak (coincident peak shaving).

In the case of lifts, there is little opportunity to reduce the peak demand during ski season because the lifts must operate to transport skiers uphill. Slight demand reduction might be achieved through minor adjustments of existing systems such as lighting or through heater upgrades. However, if there is a coincident peak charge, the ski area has an incentive to ensure that it is not operating electric lift motors when the system peak occurs. Backup diesel engines can be used during these episodes, saving the ski area thousands of dollars in electricity bills. More often, as is the case in Vermont, lifts are monitored for peak load and snow making pumps and compressors are curtailed to avoid establishing new peaks.

To make effective use of backup diesel engines, a ski area needs computers tied to the electric utility, where real time information is available on how the overall power system is operating. It takes experience to recognize when monthly system peaks are building and therefore when the ski area needs to act in order to minimize its own peak. Using backup diesel engines to minimize coincident peak charges is becoming increasingly common in the industry. If diesels are used in non-emergency situations, the ski area should check state and federal air permitting requirements.

Another form of peak shaving is to manage multiple loads on the same meter. During the off-season, ski areas can pay up to five times more per kWh than during ski season because they operate lifts sporadically, kicking in full demand charges but incurring comparatively small consumption charges. If two or more lifts are coupled on one meter, this provides a strong incentive to avoid simultaneous operation of the lifts during the off-season. Likewise, using backup diesel engines instead of primary electric motors in summer can save on electricity costs.
3.9.4 ENERGY EFFICIENT MOTOR SELECTION

Upgrading to “premium-efficiency” motors has the greatest potential in the 1 to 20 HP range for motors that are operated at least 4,000 hours per year. However, neither of these criteria fits the typical lift motor. Lift motors are very large in comparison to those used in other industrial settings and are operated for fewer hours per year. A lift motor represents a large capital investment, with the motor typically being semi-custom designed to meet specific application needs. In fact, motors of more than 200 HP are already considered relatively energy efficient without upgrading to a more efficient grade. However, there are a few energy-efficiency opportunities to consider for new lift systems. These opportunities involve regenerative drives, AC and DC lift motors, and direct-drive motors and are further discussed below.

3.9.4.1. Regenerative Drive Lift Motors

A lift system contains enormous potential energy from pulling such a significant load uphill. When a lift needs to slow down, a regenerative drive converts the potential energy to electrical energy and puts the energy produced back on the power grid. The regenerative cycle is of such short duration and so sporadic that electric utilities do not credit customers for putting energy back on the grid. Furthermore, the energy may need to be filtered before it is returned to the grid because of high harmonic distortion levels. Therefore, regenerative drives are not cost saving devices for a ski area, despite the fact that they conserve total system energy. The main reason that ski areas use regenerative drives on lift motors is the improved control of lift operation that the drives offer. Regenerative drives are becoming more common as their prices fall. According to one industry expert, most new lifts installed since the early 1990s have regenerative drives. In fact, about one third of ski lifts in Colorado have regenerative drives.

3.9.4.2. AC Vs DC Lift Motors

AC motors equipped with VFDs and DC motors with silicon control rectifier (SCR) allows speed control so that the motor is working only as hard as needed to meet the demand load. In many applications, AC motors are considered more efficient. However, in the ski industry, this is true only in certain power ranges typically less than 300 HP. Larger AC motors have three additional drawbacks: regenerative drives have only become available on AC motors relatively recently; they can be more complicated to operate than DC counterparts; and special braking mechanisms are required for safety. If harmonics filtering is needed, which is often the case for larger HP motors (greater than 200 HP), filtering tends to overcorrect the power factors, such that the AC motor has a leading power factor after filtering.

In practice, energy efficiency is seldom involved in the design decision about which type of motor to use. Rather, the cost, the state of technology, and the particular application at hand are the deciding factors affecting decisions about lift motors.
3.9.4.3. Direct Drive Motors

Some direct drive electric motors that could be used in this application would raise the efficiency by as much as 7 percent. However, there are drawbacks to this approach. First, direct drive motors are very expensive. Also, a direct drive motor is difficult to implement for a retrofit project because it is large and may not fit in the existing motor room. Despite the drawbacks, there may be cases where direct drive motors are cost effective, such as for larger lifts in regions where utility rates are relatively high. According to the National Ski Areas Association (NSAA) there are no direct drive lifts in the U.S., but Leitner recently installed a direct drive motor on a lift in Italy.

3.9.5 HEATING AND LIGHTING IN LIFT HOUSES

Although lift motor houses and operator houses are relatively small structures (usually less than 250 square feet), the energy principles still apply to these structures. Lift house heating and lighting represent relatively small electrical loads compared to the lift motors. However, while the performance of a lift motor is fixed with replacement representing a major capital investment, improvement of building performance offers a relatively low cost area of opportunity to reduce demand and consumption costs related to heaters and lighting. The economic and environmental benefits may not be large for a single lift house, but there can be significant cumulative benefits over time if energy conservation principles are applied to routine upgrades of the existing house as well as to the installation of new lifts.

Fuel switches for electrically heated lift houses is often a good idea at the base of the mountain, and installing set-back controllers can be cost effective for electric heat up on the mountain.
4.1 ENERGY EFFICIENCY OPPORTUNITIES FOR VERMONT SKI AREAS

In general, there are four general strategies for reducing system energy use related to the three major areas of facility energy consumption. Compressed air generation and delivery systems present the most obvious opportunities for performance improvement because they typically use the most energy. Water pumping systems present similarly obvious opportunities for reduction in energy use, though comparatively they account for lower energy consumption. Lift drives are typically the next most significant energy consumer at ski facilities and offer some unique potential energy conservation measures. The fourth and final major contributor to facility energy consumption that presents obvious savings potential is the snow making system itself.

4.2 COMPRESSED AIR SYSTEM

As most snow making systems depend on compressed air for operation, air compression is typically a primary source of energy savings in snow making operations. Three opportunities for energy savings associated with compressed air systems at Vermont ski areas are presented below.

4.2.1 EFFICIENT SELECTION

Consideration must be guided by the knowledge that lifetime operating costs will far exceed capital costs, even though the ski facilities have relatively short operating schedules. The short operating seasons at ski facilities lend themselves to extended equipment life and therefore many years of energy savings. This point is particularly relevant in light of the frequency of leasing or renting air compressors by ski facilities. Such equipment may reduce cash flow burdens for capital equipment, but may be ill-advised if the operating costs of inefficient equipment are greater than the monthly equipment rental costs.

As with the selection of large compressors in any industrial operation where multiple compressors are operating, it is best to have base load compressors with very good performance (low kW per CFM) and peaking compressors that work with reasonable efficiency at part-load conditions. In many applications throughout industry, highly effective and efficient reciprocating compressors are not specified, and screw compressors have replaced them as primary compressors, despite their inherently less efficient part-load characteristics. We believe reciprocating compressors have the best performance as base load
machines, but it is certainly acceptable to use screw machines if a high-performance model is selected.

4.2.2 SEQUENCING CONTROLS

Proper compressor control systems will take data on system load requirements (flow and pressure) and will effectively select compressors that will best serve baseline and peaking needs for that condition. While the same overall compressor operation strategy can be implemented through manual controls, with thousands of horsepower of air compressor it is imperative that optimum selection of operating compressors be appropriately implemented at all times.

4.2.3 LEAK REPAIR

Leaks in any system can be very wasteful of raw materials and energy. Air leaks in air compression systems are especially wasteful of energy because these systems require a great deal of energy to operate. Different air compression systems have different ratings for energy efficiency. Regular inspections should be performed to identify any air leaks in a compression system. Various methods exist to identify leaks, including use of ultrasonic acoustic detectors and pressure gauges at several points in the air distribution system. Repairing leaks can be difficult if distribution pipes are buried underground. However, the potential savings in energy consumption can quickly offset the costs of repairs and pipe replacements.

4.3 WATER PUMPING SYSTEMS

Water pumping equipment is typically accountable for up to 30% of energy use at ski facilities in the Northeast and because of some relatively obvious opportunities for energy savings offer significant potential savings. Four (4) opportunities for energy savings associated with water pumping systems at Vermont ski areas are presented below.

4.3.1 LEAK REPAIR

Leaks in the water distribution lines that supply snow making systems can have several negative impacts on the overall snow making operation. In addition to the wasted water, energy is also wasted when water is pumped through a leaking pipeline to the snow making system. In some cases, leaking water can also come into contact with and melt snow on the slopes.

4.3.2 ELIMINATING RECIRCULATION

When part-load flow to snow making equipment is required, the output of the pump and the associated energy needs should reflect this situation. Therefore, recirculation pumping is not
acceptable unless truly needed by the pump for input flow to avoid net positive suction head problems. A properly supplied pump source will limit or eliminate the need to recirculate. As such, a single valve can be used for modulating the flow, in lieu of the wasteful system of two valves that split flow between the snow making equipment and recirculation lines. The throttling of flow allows the pump to at least operate at reduced load when such conditions are required. Of course, throttling itself is an inefficient operation, so that is not the ideal approach for flow modulation.

4.3.3 VARIABLE FREQUENCY DRIVE (VFD) FLOW MODULATION

Any modulation of pump output flow (and associated electrical load) is preferable to operation at full output (with recirculation) when snow making operations require only part-load flows. However, output throttling of pump flows with control valves is inefficient and is associated with higher energy requirements relative to proportional pump flow control strategies. By reducing the speed of the pump, flow can be reduced effectively while dramatically reducing associated input energy requirements. VFDs can result in highly efficient modulation of pump output flow. VFDs modulate flow by reducing electrical frequency to the pump drive, thereby reducing pump speed. Energy savings with VFDs are dramatic evidence for the appropriateness of this measure for snow making pump operation.

4.3.4 SYSTEM OPTIMIZING CONTROL

It is frequently better to have fewer pumps operating at full-load than it is to have all pumps operating at part-load. We believe that pump allocation, piping arrangements, and systems controls should be upgraded where possible to facilitate an optimized, energy-efficient operation. Optimization controls for such systems are available that allow automatic selection of appropriate pumps based on flow, pressure, and valve position.

4.4 LIFT SYSTEMS

An analysis of typical energy consumption behavior of ski facilities in the Northeast indicates that passenger lift systems are generally the third largest consumer and as such present an obvious target for conservation measures. Four (4) opportunities for energy savings associated with passenger lift systems at Vermont ski areas are presented below.

4.4.1 DRIVE LOCATION

A top-drive lift is a lift system with its motor located at the uphill terminal. Because it pulls from the loaded side of the cable, a top-drive lift is able to obtain the required cable tension by means of system dynamics alone, whereas a bottom-drive lift requires a higher tension cable to achieve the same effect. The higher tension cable causes bigger loads on the towers and throughout the system. Because of this difference in system dynamics, estimates indicate that a top-drive lift can achieve 10 to 15 percent more carrying capacity than a bottom-drive lift using the same equipment. Conversely, to achieve carrying capacity comparable to a top-
drive lift would require 10 to 15 percent more power from the driving motor. Installation of a top-drive lift depends on the availability of electric power and vehicle access at the top of the lift. It could be expensive to provide power if it is not available near the top of the lift.

4.4.2 EFFICIENT MOTOR SELECTION

Typical lift motors of more than 200 HP are already considered relatively energy efficient. However, there are a few energy efficiency opportunities to consider for new lift systems. AC motors equipped with VFDs and DC motors with silicon control rectifier (SCR) allows speed control so that the motor is working only as hard as needed to meet the demand load. In many applications, AC motors are considered more efficient. However, in the ski industry, this is true only in certain power ranges, typically less than 300 HP.

Some direct drive electric motors that could be used in this application would raise the efficiency by as much as 7 percent. A direct drive motor is difficult to implement for a retrofit project because it is large and may not fit in the existing motor room. Despite the drawbacks, there may be cases where direct drive motors are cost effective, such as for larger lifts in regions where utility rates are relatively high.

4.4.3 LIFT HOUSE HVAC SELECTION

Programmable thermostats installed in lift houses are viable energy and cost saving measures for Vermont ski areas. Programmable thermostats can control output based on a predetermined occupancy schedule and save heating energy by reducing the space to a minimum safe temperature when no activity is taking place. Fuel switches for electrically heated lift houses are often a good idea at the base of the mountain, and installing set-back controllers can be cost effective for electrical heat up on the mountain.

4.4.4 LIFT HOUSE LIGHTING SELECTION AND CONTROL

Occupancy-based lighting controls and energy-efficient lighting are simple energy saving measures that have seen limited implementation at Vermont ski areas. Automatic lighting controls save energy in much the same way that programmable thermostats conserve heating energy. An occupancy sensor will determine the lighting status dynamically rather than based on a predetermined schedule. Programmable lighting controls are also available but would generally save less energy than would occupancy-based controls. Such controls are viable measures in lift houses, guest accommodations, personnel offices, storage spaces, etc. Essentially, any space with variable occupancy is a candidate for lighting controls. Energy-efficient lighting is another significant opportunity for energy savings. Many Vermont ski areas operate inefficient incandescent lighting that could be replaced with less energy-intensive fluorescent technology. High efficiency T8 and T5 fluorescent lights are effective replacements for older, less efficient T12 fluorescent fixtures. Likewise, compact fluorescent lights can generally replace incandescent lamps, resulting in drastic reductions in energy consumption.
4.5  SNOW MAKING EQUIPMENT SELECTION AND OPERATION

When selecting snow guns for a new slope or for upgrading an old snow making system, it is worthwhile to consider more than just the capital cost of guns. It is also important to think of the cost of supporting structures, such as towers or air compressor systems, and the effectiveness and applicability (including snow making temperature, type of terrain, trail width, intended opening date, and noise sensitivity) of the given guns as these factors apply to the proposed location of the guns. Four opportunities for energy savings associated with snow making equipment at Vermont ski areas are presented below.

4.5.1  EQUIPMENT SELECTION

In practice, tower guns are used to produce high volumes of snow in somewhat predictable weather conditions on high use trails. The use of tower guns provides very energy-efficient operation and the least labor-intensive method of snow production. Based on our visits and discussions with Vermont ski areas, we believe that external mix tower guns supply the majority of snow production in the state. Certainly, some level of production via internal mix ground-guns remains prevalent because of temperature range and maneuverability advantages. Currently the most energy-efficient gun types for both warm and cold temperatures are not used in Vermont. Internal mix air/water/fan guns are regarded as the most efficient marginal temperature gun but are not attractive to facility personnel because of their relatively high cost and large size. Air-less tower guns are easily the most energy-efficient method of cold temperature snow production but are not attractive to facility personnel because of high pressure and low temperature water requirements. The limitation of any “low energy” snow gun is its limited temperature range.

4.5.2  SYSTEM AUTOMATION

Control of the air and water valves provides the means to adjust snow quality. Accurate control of these valves indirectly reduces energy use. Air and water valves set to positions corresponding to weather conditions other than what they are experiencing at the time may provide quality snow at the expense of efficiency. There are automatic control systems that modulate flow through valves to optimize snow quality and efficiency. Computers also monitor system conditions such as water flow rates, water temperature, airflow rates, and air pressure. Computers often control water pressure to accommodate changing water demands during snow making operations. Also, automated controls for centrifugal compressor systems can measure the system pressure and control multiple compressors to achieve maximum efficiency by load sharing and by automatically starting and stopping units based on system demand.

4.5.3  SNOW MAKING WATER COOLING

Not only does cooler snow making water prevent melting of existing surface snow particles, but it also eliminates unnecessary pumping of water that is not converted to snow. For a
given set of ambient conditions, snow guns will operate more efficiently, and thus provide energy and cost savings, when the temperature of snow making water can be reduced. Snow making can also occur at increasingly marginal ambient temperatures when snow making water temperature is reduced. Thus, snow production can occur earlier in the season than previously possible. Based on our investigations, moreover, early season snow production is the primary reason for water cooling. However, for this scenario, it appears that whatever efficiency gains are realized by producing snow with “cold” water are tempered by the inherent inefficiencies associated with producing snow in marginal temperatures.

### 4.5.4 SNOW INDUCERS AND ADDITIVES

The use of snow inducers increases the number of nucleators in the water stream, thereby increasing the likelihood that any given droplet will contain a nucleator. For most Vermont ski areas the likelihood that a droplet of snow making water contains a nucleator is high regardless of the inclusion of snow inducers. When ambient temperatures are relatively low, these naturally occurring impurities are typically sufficient to induce freezing. High temperature nucleating snow inducers can stretch temperature limits to allow snow makers to cover trails at temperatures several degrees higher than with untreated water. Other snow making additives that reduce the inherent surface tension properties of water allow for increased production for the same energy consumption. These additives allow for reduced dependence on compressed air allowing increased water flow with constant air flow. Consequently, for a given volume of snow production, energy requirements are reduced.
appendix a

COMPRESSED AIR SYSTEM MAINTENANCE STRATEGIES
INTRODUCTION

The following are regular maintenance activities as put forth by the Compressed Air Challenge Program of the Department of Energy (DOE).

Like all electro-mechanical equipment, compressed air systems require periodic maintenance to operate at peak efficiency and minimize unscheduled downtime. Inadequate maintenance can have a significant impact on energy consumption via lower compression efficiency, air leakage, or pressure variability. Most problems are minor and can be corrected by simple adjustments, cleaning, part replacement, or elimination of adverse conditions.

All equipment in the compressed air system should be maintained in accordance with manufacturers’ specifications. Manufacturers provide inspection, maintenance, and service schedules that should be followed strictly.

One way to tell if a system is well maintained and operating properly is to periodically baseline the system by tracking power, pressure, flow, and temperature. This baselining will also indicate if the compressor is operating at full capacity, and if the capacity is decreasing over time.

The maintenance schedules provided in this appendix are intended to be used only as a guide. For more exact procedures, always refer to the manufacturer’s manual.

ROUTINE MAINTENANCE FOR LUBRICATED INJECTED (LUBRICANT FLOODED) TYPE ROTARY COMPRESSOR

Periodically / Daily-8 hours maximum
- Monitor all gauges and indicators for normal operation.
- Check lubricant level.
- Check for lubricant leaks.
- Check for unusual noise or vibration.
- Drain water from air/lubricant reservoir.
- Drain control line filter.

Weekly
- Check safety valve operation.
MONTHLY

- Service air filter as needed (daily or weekly if extremely dusty conditions exist).
- Wipe entire unit down, to maintain appearance.
- Check drive motor amps at compressor full capacity and design pressure.
- Check operation of all controls.

6 MONTHS OR EVERY 1,000 HOURS

- Take lubricant sample.
- Change lubricant filter.

PERIODICALLY/YEARLY

- Go over unit and check all bolts for tightness.
- Change air/lubricant separator.
- Change air filter.
- Lubricate motors per manufacturer’s instructions.
- Check safety shutdown system. Contact Authorized serviceperson.

ROUTINE MAINTENANCE FOR LUBRICATED FREE (OIL-LESS) TYPE ROTARY COMPRESSOR

DAILY

Following a routine start, observe the various control panel displays and local gauges to check that normal readings are being displayed. Previous records are very helpful in determining the normalcy of the measurements. These observations should be made during all expected modes of operation (i.e. full-load, no-load, different line pressures, different cooling water temperatures, etc).

AFTER INITIAL 50 HOURS OF OPERATION

Upon completion of the first 50 hours of operation, a few maintenance requirements are needed to rid the system of any foreign materials which may have accumulated during assembly.

- Change the lubricant filter element.
- Clean the control line filter element
- Check/replace the sump breather filter element.
Every 3,000 Hours of Operation

The following items should be checked every 3,000 hours of operation, although service conditions such as relative cleanliness of the process air or quality cooling water may necessitate shorter inspection intervals.

- Check/Change oil charge and filter element.
- Check/Change air filter element.
- Check/Change sump breather filter element.
- Check/Clean control line filter element.
- Check/Clean condensate drain valve.
- Check condition of shaft coupling element and tightness of fasteners.
- Measure and record vibration signatures on compressor, gearbox, and motor (optional).

NOTE: Please refer to the motor manufacturer’s documentation for recommended maintenance. Keep in mind that the specific type and quantity of lubricating grease for the motor bearings is crucial.

Every 15,000 Hours of Operation

In addition to those items covered in the 3000-hour maintenance interval, the following items must also be checked every 15,000 hours of operation, depending upon conditions of service.

- Operate/Test all safety devices.
- Check/Clean heat exchangers.
- Check/Clean blowdown valve.
- Check operation of balancing switch/valve assembly.
- Check/Clean water regulating valve.
- Check/Clean check valve.
- Check/Clean galvanized interstage pipe work.
- Check condition of isolation mounts under compressor unit and motor.
- Check/Clean strainer and check valve included in oil pump suction line, inside oil sump.
- Check compressor unit internal clearances.
ROUTINE MAINTENANCE FOR CENTRIFUGAL AIR COMPRESSOR

**Daily**
- Record operating air inlet, interstage and discharge pressures, and temperatures.
- Record cooling water inlet and outlet pressures and temperatures.
- Record lubricant pressure and temperatures.
- Record all vibration levels.
- Check air inlet filter differential pressure.
- Check proper operation of drains traps.
- Drain control air filter.
- Check for leaks, air, water, and lubricants. Repair and clean as necessary.
- Check lubricant sump level and adjust as necessary.
- Check drive motor for smooth operation and record amperes.

**Every 3 Months**
- Check lubricant filter differential pressure. Replace element as necessary.
- Check lubricant sump venting system. Replace filter elements as necessary.
- Check operation of capacity control system.
- Check operation of surge control system.
- Check main drive motor amperes at full load operation.
- Check automatic drain traps and strainers. Clean and/or replace as necessary.

**6 Months**
- Check air inlet filter and replace element as necessary.
- Take oil sample for analysis. Replace lubricant as necessary.

**Annually**
- Inspect intercooler, aftercooler, and lubricant cooler. Clean and/or replace as necessary.
- Inspect main drive motor for loose mounting bolts, frayed or worn electrical cables, accumulated dirt. Follow manufacturer’s recommendations, including lubrication.
- Inspect main drive coupling for alignment.
ROUTINE MAINTENANCE FOR AIR COOLED RECIPROCATING COMPRESSOR

Every 8 hours (or Daily)
- Maintain lubricant levels between high and low level marks on the bayonet gauge.
- Drain receiver tank, drop legs, and traps in the distribution system.
- Give compressor and overall visual inspection and be sure guards are in place.
- Check for any unusual noise or vibration.
- Check lubricant pressure on pressure lubricating units. Maintain 18 to 20 PSIG when compressor is at operating pressure and temperature. High pressure rated compressors should maintain 22 to 25 PSIG of lubricating pressure.
- Check for lubricant leaks.

Every 40 Hours (or Weekly)
- Be certain pressure relief valves are working.
- Clean the cooling surfaces of the intercooler and compressor.
- Check the compressor for air leaks.
- Check the compressed air distribution system of leaks.
- Inspect lubricant for contamination & change if necessary.
- Clean or replace the air intake filter. Check more often under humid or dusty conditions.

Every 160 Hours (or Monthly)
- Check belt tension.

Every 500 hours (or Every 3 Months)
- Change lubricant (more frequently in harsher conditions).
- Check lubricant filter on pressure lubricated units (more frequently in harsher conditions).
- Torque pulley clamp screw or jam-nut.

Every 1,000 hours (or Every 6 Months)
- When synthetic lubricant is used, lubricant change intervals may be extended to every 1000 hours or every 6 months, whichever occurs first (change more frequently in harsher conditions)
- Inspect compressor valves for leaks and/or carbon build-up. The lubricant sump strainer screen inside the crankcase of the pressure-lubricated models should be thoroughly cleaned with a safety solvent during every lubricant change. If excessive sludge build-up exists inside the crankcase, clean the inside of the crankcase as well as the screen. Never use a flammable or toxic solvent for cleaning. Always use a safety solvent and follow the directions provided.

Every 2,000 hours (or every 12 Months)
- Inspect the pressure switch diaphragm and contact. Inspect the contact points in the motor starter.

**ROUTINE MAINTENANCE FOR WATER-COOLED DOUBLE-ACTING RECIPROCATING COMPRESSOR**

**Every 8 hours (or Daily)**
- Check compressor lubricant level in crankcase and cylinder lubricator and, if necessary, add to level indicated by sight gauge.
- Check cylinder lubrication feed rate and adjust as necessary.
- Check lubrication pressure and adjust as necessary to meet specified operating pressure.
- Check cylinder jacket cooling water temperatures.
- Check capacity control operation. Observe discharge pressure gauge for proper LOAD and UNLOAD pressures.
- Drain control line strainer.
- Check operation of automatic condensate drain trap (intercooler and aftercooler).
- Drain condensate from discharge piping as applicable (drop-legs and receiver).
- Check intercooler pressure on multi-stage machines, and refer to manufacturer’s manual if pressure is not as specified.

**Every 360 Hours (or Monthly)**
- Check piston rod packing for leaks and for blow-by. Replace if necessary.
- Inspect lubricant scrapper rings for leaks. Replace if necessary.
- Inspect air-intake filter. Clean or replace if necessary.
- Drain lubricant strainer/filter sediment.
- Lubricate un-loader mechanism per manufacturer’s manual.
- Check motor amps at compressor full capacity and pressure.

**Semi-Annually or every 3,000 Hours**
- Perform valve inspection.
- Inspect cylinder or cylinder liner, through valve port, for scoring.
- Change crankcase lubricant if required.
- Clean crankcase breather (if provided).
- Change lubricant filter element.
- Remove and clean control air filter/strainer element.
- Check all safety devices for proper operation.
- Perform piston ring inspection on non-lubricated design. Replace per manufacturer’s manual.

**Annually or every 6000 Hours**

- Remove and clean crankcase lubricant strainer.
- Check foundation bolts for tightness. Adjust as necessary.
- Perform piston ring inspection. Replace as necessary per manufacturer’s manual.
- Inspect compressor valves for leaks and/or carbon build-up. The lubricant sump strainer screen inside the crankcase of the pressure-lubricated models should be thoroughly cleaned with a safety solvent during every lubricant change. If excessive sludge build-up exists inside the crankcase, clean the inside of the crankcase as well as the screen. Never use a flammable or toxic solvent for cleaning. Always use a safety solvent and follow the directions provided.

**Every 2,000 hours (or Every 12 Months)**

- Inspect the pressure switch diaphragm and contact. Inspect the contact points in the motor starter.

**DRYER MAINTENANCE**

**Every 500 Hours**

- Check the air inlet temperature. The dryer operates much more efficiently at temperatures below 100°F. The after-cooler is designed to deliver air to the dryer at less than 100°F. If the temperature is higher, the after-cooler needs to be cleaned.

**OTHER RECOMMENDED SYSTEM MAINTENANCE**

**Every 3 Months**

- Clean debris from all drain traps, making sure that auto-drain traps are not stuck in the open or closed position.
- Check to see that condensate is being properly drained to a container for disposal as hazardous waste.
- Adjust timer controlled drains to accurately drain all condensate without any extra running time.
- Check and clean end-use filters and combination filter/ regulators.
- Check flexible delivery hoses, replacing them when cracking begins and before leaks develop.
- Check and refill end-use lubricators. Proper tool operation and longevity depends on proper lubrication.

**Annually**
- Perform simple leak survey looking for large audible leaks.

**Every 2 Years**
- Perform an ultrasonic leak survey, tagging and repairing all leaks.