Energy Efficiency Opportunities for Ski Industry Snowmaking Processes

Gary Epstein, Energy & Resource Solutions, Inc.
Randal Dixon, Public Service of New Hampshire
Brian McCowan, Energy & Resource Solutions, Inc.

ABSTRACT

Presently, there are three general snowmaking technology types for ski industry facilities. Traditional air/water guns can be highly effective, but require considerable quantities of compressed air and have very high operating costs. Single- and multi-ring fan systems have many advantages in that compressed air use is minimized, but these technologies are costly to install and may not be competitive in all weather conditions. HKD tower systems, representing an enhancement to traditional air/water guns, are more energy efficient, but are costly to operate during certain climatic conditions. In this paper, we will discuss the many factors that govern selection and operation of snowmaking equipment in an effort to improve efficiency and performance. We discuss in detail the advantages, disadvantages, and climatic conditions that favor each technology, and strategies snowmaking operators can implement to dramatically reduce energy consumption while minimizing investment in new equipment. Also included is an explanation of new automatic control systems that monitor climatic conditions and modify air/water mixtures to enhance energy savings and snow quality. Approaches to improving compressed air operations that typically requires thousands of connected horsepower are addressed with the focus on optimized compressed air plant operations from equipment, control, and load reduction perspectives. Finally, we will recommend strategies for improved operation of water pumping networks that deliver water to various snowmaking system output devices.

Introduction

Recreational ski facilities are truly unique in the intensity of their energy use, particularly considering the typically short operating season of the industry. For key reasons, ski facilities must be viewed as industrial facilities. First, they differ from any other commercial sector facility 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, and 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. They are clearly in the business of manufacturing a product (snow) that is desired by consumers at ski facilities. Thus, we view ski facilities as industrial facilities in the recreational ski business.

In the United States and North America, it is important to distinguish between 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. In contrast, Western ski facilities generally receive abundant natural snow that eliminates the necessity for artificial snow throughout the ski season. Thus, the subsequent sections and fundamental discussions for this paper are focused on Eastern slopes or those facilities that are dependent on artificial snowmaking.

Overview of Ski Facility Energy Use

Ski facilities have a number of critical energy and utility end uses that distinguish their operation from those of any other facility type. This section presents a typical end use breakdown for a medium size facility operating in the Northeastern (New England) United States. Table 1 shows the summary end use data, while Figure 1 presents the data in graphical format.

Table 1. Typical Ski Facility End Use Breakdown

Electrical End Use Data	kWh	Percent
Lighting	354,440	3%
Snow Making Compressed Air	5,490,373	53%
Snow Making Pumps	2,090,195	20%
Space Heating	176,565	2%
Ski Lifts	2,061,500	20%
Miscellaneous	217,437	2%
Total	10,390,510	100%

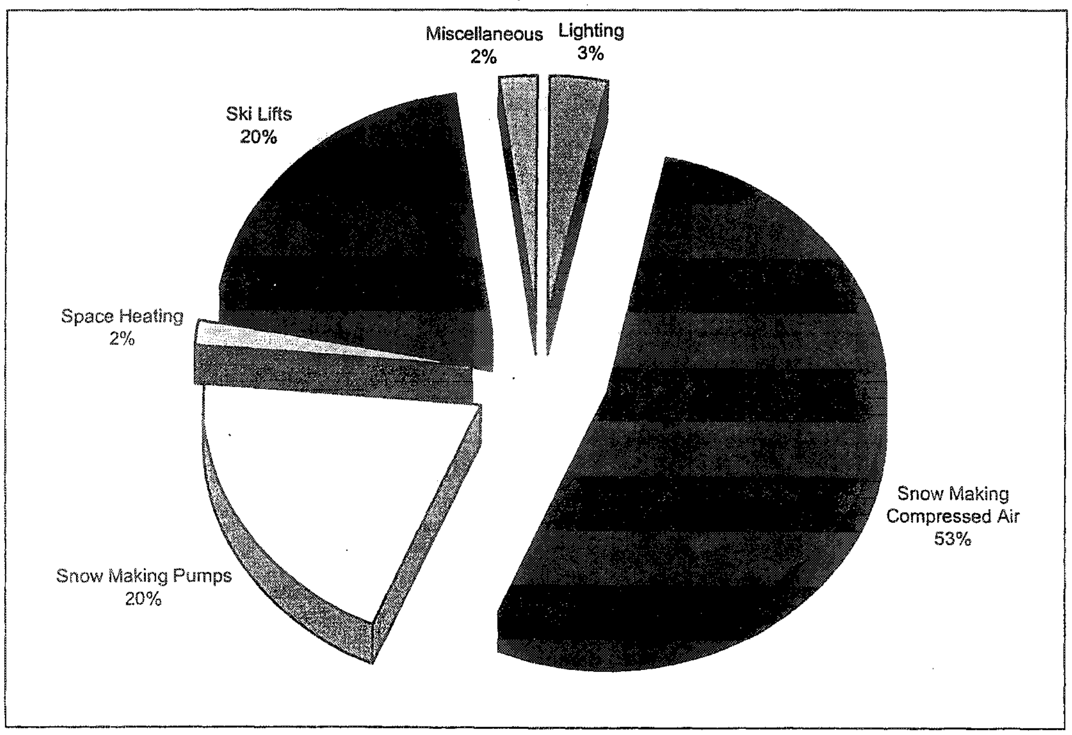

Figure 1. Electrical End Use Breakdown Chart

As clearly demonstrated in the above table and graph data, the dominant end uses are those associated with snowmaking 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. Snowmaking end uses (represented by 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 common to find facilities where air compressors, pumps, and/or lift operations are driven by diesel engines in lieu of electric motors. Traditionally, such facilities saw potential benefits due to lower energy costs. 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 snowmaking nozzles (snow guns) located in numerous locations along ski trails. Thus, the dominant energy end use technologies are air compressors and 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.

Areas for Reducing Energy Use in Snowmaking

There are four fundamental areas to consider for reducing energy use in snowmaking systems that are related to the three basic energy operations involved in all snow production (air delivery, water delivery, and the inherent requirements of the snowmaking equipment). Following is a discussion of each aspect of snowmaking systems that impacts energy consumption. Any snowmaking energy efficiency recommendations must consider the snowmaking equipment, operational control of the system, compressed air operations, and water pumping systems.

Snow Production Equipment

Snowmaking 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 mass of snow. In addition, each equipment category represents differing performance curves under varying climatic conditions, complicating the task of choosing snow delivery technology.

Control of Snow Production Equipment Operation

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 controlling these mixtures are not controlled effectively and considerable energy is wasted.

Compressed Air Systems

Compressed air systems for traditional snowmaking 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.

Water Pumping Systems

Snowmaking operations involve hundreds or thousands of horsepower of 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.

Snowmaking Systems Discussion

Presently, there are four general types of snowmaking technologies and associated equipment. These include traditional air-water guns; single-ring fan systems; multi-ring fan systems; and the HKD tower system. Because of its increasingly widespread use, a commonly used snow inducer technology is also included in the discussion.

Traditional Air-Water Snow Guns

The most common traditional snowmaking system equipment is known as the air/water gun or snow gun as shown in Figure 2.

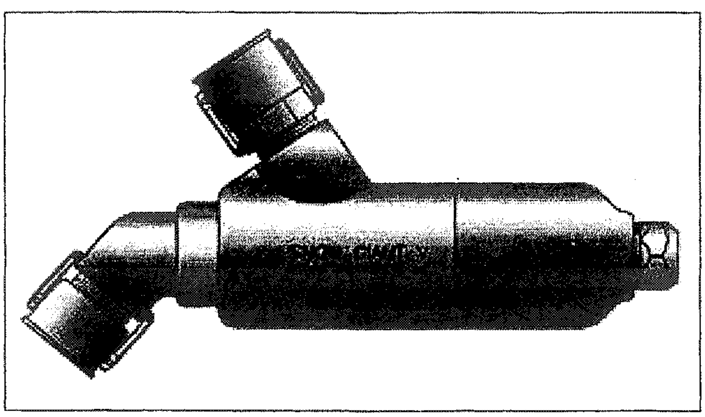

Figure 2. Air/Water Gun

These snow guns are made of a simple nozzle arrangement into which compressed air and high-pressure water are mixed. Inside the mixing chamber, water and compressed air are combined to atomize the water droplets, which are then projected through the spray nozzle of the snow gun. Expansive cooling caused by the compressed air (between 80 and 110 psig) returning to atmospheric pressure as it exits the nozzles causes small ice particles called ice nuclei to be formed. The ice nuclei act as a catalyst to freeze the rest of the droplets when the mixture is adjusted correctly for the ambient conditions. Still, most of the compressed air energy (approximately 98%) is utilized to propel and distribute 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.

Typically, internal mix snow guns are placed in the location on the slope near where snow is required. It is then attached to the water and air hydrants with hoses, the compressed air hydrant and the water hydrant are opened until water flow is observed through the barrel of the gun. The operator then goes into the discharge stream of the snow gun and checks the quality of the snow, adjusting water flow up or down until the desired snow quality is observed. Note that typical snow gun spacing is 150 feet. Units are portable, and can be moved to alternative locations throughout the season, if desired.

There are two commonly used air/water guns: the Ratnik and the Omichron. The Ratnik looks like a long fire nozzle with a 1" opening at the tip. Compressed air is fed from the rear of the gun. Tangent to the gun near the base is a fitting where the high-pressure water enters. Depending on ambient weather conditions and snow characteristics, the relative quantities of air and water delivered to the gun's mixing chamber can vary dramatically. In general, as temperature drops, water flow can be increased (more snow), while compressed air requirements decrease. Compressed air flow varies between 200 and 500 CFM per gun depending on the water flow, which varies from 15 to 70 gpm depending on ambient weather conditions. At the marginal weather conditions of 26°F WB, the Ratnik units will use 450 to 500 CFM but only 15 gpm of water. The Ratniks are fully internal mixing systems.

The Omichron guns are similar except that the shape is a small rectangular box or head. At the front is a slit opening where the discharge air and water mixture exits. High-pressure water is delivered above and below the rear of the slit. Adjustments are similar to the Ratnik. The Omichron system is a semi-internal mixing system. The air/water use ratio of the Omichron system is similar to that of the Ratnik.

Snow gun equipment cost is usually around $1,500 per unit. While the basic gun cost is typically $1,100, it is generally ordered with different sleds and the basic tripod for mounting. Hoses for the water and compressed air from the hydrants are not included in these costs.

Single and Multi-Ring Fan Systems

The single-ring and multi-ring fan systems shown in Figure 3 differ from the air-water type snow gun in that they do not require the large volume of compressed air used by the air/water gun to make snow.

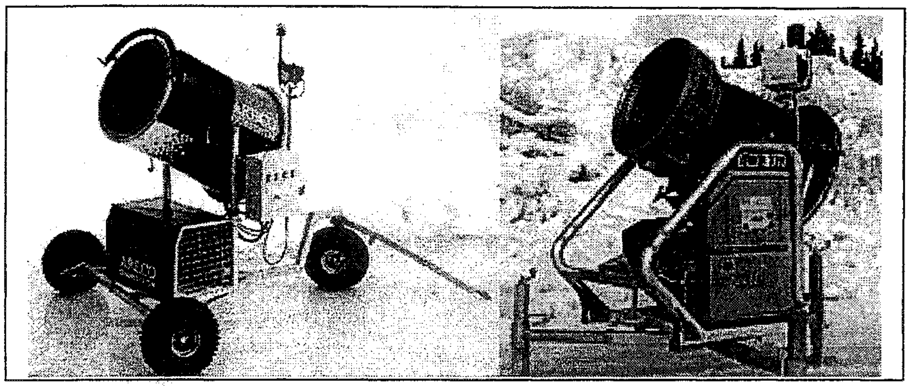

Figure 3. Single Ring Fan Unit (left) and Multi Ring Fan Unit (right)

Single ring fan system. The fan-type snow gun has an array of spray nozzles of varying sizes around the discharge end of a ducted fan with a nucleator. The nucleator is a small air-water snow gun mounted at the bottom of the discharge end of the ducted fan. The amount of compressed air is approximately 25 to 40 CFM for nucleation. In this type of system, the smaller compressed air flows result in a smaller compressor that can usually being installed as part of a fan-type snow gun unit. 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.

The fan type snow units are located on the slope near where the snow is to be made. It is then attached to the water hydrant and an electrical disconnect. The fan motor and on-board compressor (or hill air) are turned on. The water hydrant is then opened until water pressure of between 200 and 400 psi is read on the fan gun pressure gauge. The operator now goes into the snow gun discharge stream and checks the snow quality, adjusting the water flow up or down by turning on or off different combinations of the spray nozzles around the ducted fan until the desired snow quality is observed.

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). Sometimes the fan systems can be permanently mounted on short to medium length poles, adding considerably to the cost.

Multi-ring fan system. Some fan-based snowmaking system manufacturers believe that many nozzles with finer water spray can produce higher quality snow. For instance, the SMI Wizzard fan snowmaking system utilizes five rings of 75 nozzles each to convert water into snow. The 375 heated nozzles are nucleated with a detachable periphery ring with 20 additional nozzles. SMI's nucleator ring is fed by a 5 HP on-board air compressor to provide constant mixing at each nucleator nozzle. Water adjustment is provided with four heated 3-way self-draining ball valves. However, energy performance appears to be essentially similar to the standard fan snowmaking systems.

HKD Tower System

A recently introduced snowmaking technology is the HKD system shown in Figure 4. It is effectively an improved performance air-water gun system. The name derives from the initials of the inventor, Herman K. DuPrey of Seven Springs, PA. The 35-foot towers are permanently mounted at 75-foot increments (half the normal 150 foot spacing of the other technologies) along the prevailing wind side of the trail. At the top of the tower are two 1/8" air holes and two to six water nozzles. Compressed air is provided in the inner core space, while water is provided in the annular space. The water spray passes through the expanding compressed air and creates snow. Because of the height of the tower, these droplets have a similar "hang time" as the fan units. Snow is created without the use of a fan.

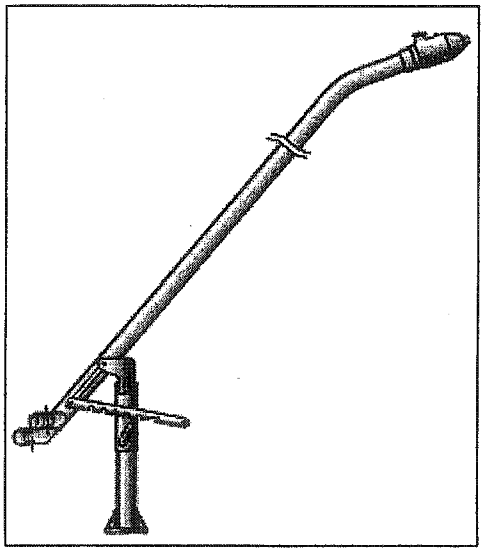

Figure 4. HKD Air/Water Gun

At the marginal conditions, each HKD will use about 15 gpm of water and 50 CFM of compressed air. As the temperature drops, more water flow can be used to increase production (up to 60 gpm depending on nozzle type and quantity). The cost of the unit is $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 since the trail spacing is half that for other systems. These units are not portable, but are permanently fixed in place.

Snow Inducer Technology

Many resorts use a snow inducer called Snomax made by Snomax Technologies Division of York International. Snomax is the commercial name of an active protein that enhances the conversion of water droplets from a snow gun into snow. The protein is derived from a tiny bacterium called Pseudomonas syringae. This naturally occurring bacterium is found in grass, trees, vegetables, cereal crops, and even in the air we breathe. Snomax Technologies grows this bacterium using sterilized fermentation equipment in a controlled environment. Freezing the microorganism yields a protein (pellets) sold as a primary product. A by-product of this process is Snomax, a very active ice-nucleating protein.

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. Most people believe water freezes at 32°F, but 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. Snomax is mixed in water to form a concentrate that is metered into the snowmaking water supply. Every water droplet thrown from the snow gun is then seeded with the Snomax nucleator. This point is important because the key to efficient snowmaking is to freeze as many droplets as possible before they hit the ground.

Source water that has been treated with Snomax contains anywhere from 1,000 to over 100,000 more nucleation sites than untreated source water. This means that every droplet of water has a site for ice crystals to form. Another feature of Snomax is that it functions as a high temperature nucleator, which simply means that it is capable of initiating the freezing process at higher temperatures (than without the nucleator). Studies from the manufacturer have shown that Snomax is effective up to 27°F. Untreated water may not freeze at temperatures above 20°F.

Efficiency and Practical Considerations of the Competing Systems

Each of the discussed approaches for the manufacture of snow has advantages and disadvantages from an energy and practical perspective. Table 2 presents a comparison of the technical merits of each system under prevalent operating conditions. Traditional snow guns are clearly the most energy intensive and can be even more wasteful if they are not controlled effectively (see discussion below on automatic controls). On the positive side, snow guns are the lowest first cost technology. Further, the individual snowmaking guns are readily transported between various locations to optimize snow distribution and to take advantage of current wind conditions.

Table 2. Comparison of Snow Making Technologies

Snow Making Technology	Low* Temp.	Marginal** Temp.	Windy Conditions	Equipment Mobility	Purchase/ Install Cost	Requires On Slope Electric	Requires Piped Compressed Air	Comments
Traditional Air/Water Gun	Good	Poor	Good	Excellent	$	No	Yes	portable skid mount
Compact Fan Gun	Fair	Good	Good	Good	$$$	Yes	No***	can be move on snowcat blade
Single Ring Fan Gun	Fair	Good	Fair	Fair	$$$	Yes	No***	usually trailer towed
Multi-Ring Fan Gun	Fair	Good	Fair	Fair	$$$$	Yes	No***	usually trailer towed
Air/Water Tower (HKD)	Good	Fair	Poor	N/A	$$	No	Yes	permanent tower mount

* Low Temperature is generally 16F WB and below.
** Marginal Tempertaures are close to freezing, approximately 26-30F WB.
*** Most fan guns include an onboard compressor, but some models can be ordered to use piped compressed air

The fan systems have the advantage of being far less energy intensive during early season (higher temperature) weather conditions than snow gun systems (which are dependent on large central compressed air plants and distribution networks). The fan systems use less energy than the traditional guns since compressed air is not used to blow snow a distance from the gun. The fan systems utilize small on-board compressors (approximately 5 HP) for initial nucleation of snow through the nozzles, and then use fans for distribution. Fan systems only require water piping and electric power distribution. On the negative side, fan systems are relatively expensive. Many ski facilities are unwilling to pay the high cost of conversion to these systems. Further, they are more difficult to transport to alternative locations. Manufacturers claim these should be placed to take advantage of prevailing winds. However, wind conditions can change continuously on mountain terrain.

The HKD tower systems also represent a considerable increase in efficiency when contrasted with conventional snow guns. The nozzles are mounted at the top of 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. Further, since the HKD towers are permanently fixed in location, 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 not as changeable.

System Efficiency and Performance as a Function of Weather

The efficiency and system performance of the compressed air snow guns (traditional and HKD) 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 lb. of snow). As ambient temperatures decrease, air requirements for snowmaking drop considerably. At temperatures of approximately 10°F, only 25 to 50 percent of marginal condition airflow is required.

The guns used in HKD tower systems have virtually the same relationship with climatic conditions. However, with the increased hang-time, compressed air requirements are significantly less than those for ground-based guns when operating at colder temperatures.
In contrast, fan systems operate more efficiently than air/water guns at marginal (higher) temperatures. Therefore, 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.

Automatic Control

As stated, the efficiency of traditional 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 gross management of compressed air plant output can be done with plant controls, real modulation to achieve the efficiency gains must be done by controlling the air and water valves near each snow gun. There are two reasons for modulating the flow valves. First, control of the valves is necessary to adjust snow quality. Second, it reduces energy use. If the air valves are set for flow volumes consistent with marginal conditions, but the ambient temperatures are significantly lower, snow quality may still be good, but the excess air will just blow through the nozzle to the environment. There are automatic control systems that facilitate control, and flows are modulated to optimize snow quality and efficiency. Such systems are becoming increasingly evident in Europe, but are not common in the US. In consideration of the high costs to operate the large snowmaking system air plants, an effective manual or an automatic control strategy should be mandatory.

Modifying the Snowmaking Strategy

With all types of snowmaking delivery equipment, it is much more expensive to produce snow during marginal weather conditions. This fact is particularly true of traditional and HKD air/water gun systems, which use dramatically increased amounts of compressed air during warmer conditions. Some ski areas have successfully decreased their overall snowmaking costs by investing in additional guns as well as increasing pump and compressor capacity as needed. This investment in increased capacity allows the staff to make increased amounts of snow when the conditions are ideal, while minimizing the amount of time that snow is made during marginal conditions. Often this approach can be more effective than replacing existing equipment with newer, marginally more efficient equipment.

Selection of Equipment

Decisions regarding which snowmaking 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. As a consequence of the large capital investments required for the fan equipment, most facilities are unwilling to do a comprehensive conversion to such systems. Rather, when funds are available, they choose to add such equipment to focused areas of their facility. Ultimately, decisions regarding systems to install must be based on whether the project is new development or a retrofit, snowmaking locations, capital availability, and operating costs.

Compressed Air Systems and Efficiency Opportunities

There are some fundamental limitations related to the objective of improving snowmaking operation efficiency through conversion from one type of snowmaking equipment to another. As stated above, these limitations are related to practicality of alternative systems, high first costs, and overall economics or return on investment. Once action has been taken to implement improved snowmaking equipment, the next consideration is to evaluate compressed air operations and water pumping systems. The focus of this section is on the compressed air used for snowmaking.

The typical compressed air plant for snowmaking operations that use air/water guns requires approximately 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 huge air operations generally represent the largest operating costs for ski facilities, and most facilities actively struggle to secure the best energy rates to reduce costs. Seldom, however, have we found that ski facilities are focused on air system energy efficiency strategies. It is common to find systems with thousand-plus horsepower compressors operating in a manner where all of the compressors are at inefficient part-load conditions rather than using a more efficient base-load operating strategy. Such poor operation can easily result in tens of thousands of dollars of wasted energy costs annually. There are many air system efficiency measures that can and should be implemented at ski facilities. Primary among these are the following.

Efficient compressor selection. Ski facility management is frequently unique in the industrial community in their poorly guided selection of air compressors and major auxiliary equipment. 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 the ski facilities have relatively short operating schedules. This point is particularly relevant in light of the regularity 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.

The network of air compressors should be capable of efficiently handling peak conditions, and should also be able to efficiently operate when 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 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. For the peaking application compressors, it is absolutely necessary to understand the air demand range of the snowmaking 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.

Optimized compressor control and operation. This brief discussion is really an extension of the preceding paragraphs. Essentially, we believe that large compressed air plants such as those at ski facilities must 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.

Add cost effective storage capacity. As with all compressed air plants, air storage capacity is significant in its ability to limit operation at less efficient compressor part load conditions. For large air operations like those at ski facilities, selection of storage capacity may not be based on the same rules as those for smaller plants. It can be cost prohibitive and may be ineffective to have as much storage as snowmaking plant CFM would suggest. We recommend a careful consideration of the minimum to maximum air demand range, along with assessment of part-load efficiency within that capacity range. Storage capacity should be selected to optimize system efficiency by limiting a compressor's operation at its lowest efficiency loading regime.

Compressed air load reduction approaches. For compressed air used for snowmaking, there are two primary means to limit the air load. As previously discussed, proper control of air going to the snowmaking guns as a function of ambient temperature conditions is very important. The second approach is also very significant and involves elimination of significant air system leaks. There are considerable challenges to identifying air system leaks in snowmaking 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 through wooded areas or underground and are not readily accessible for leak detection work.

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 Victaulic connections between distribution pipe sections. Again, such piping connection may be difficult or impossible to access.

High quality ultrasonic detection systems must 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 snowmaking 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.

Water Pumping Systems and Efficiency Opportunities

Lack of water availability for snowmaking at ski facilities has been an issue that has frequently resulted in the inability of that business to grow or expand. There are numerous examples of ski areas that had 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 involved parties. Results are often disappointing for ski businesses.

Still, while struggles to increase profitability through facility expansion take considerable effort, there is seldom adequate effort to increase profitability through improved and more efficient pumping system energy management. Design and operation of ski area pumping systems, which frequently require thousands of horsepower, are typically highly wasteful. Some of the key approaches to limit energy use in snowmaking water pumping include the following.

Avoid wasteful recirculation 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 snowmaking pumping systems. Snowmaking 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, 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 snowmaking 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 snowmaking and pumping systems.

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 snowmaking 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 snowmaking 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. Improved flow control is discussed next.

Use variable frequency drives (VFDs) for flow modulation. As just discussed, any modulation of pump output flow (and associated electrical load) is preferable to operation at full output (with recirculation) when snowmaking 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), 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 is dramatic and represent an appropriate measure for snowmaking pump operation.

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 a more efficient full load design condition than it is to have all pumps operating at part load conditions. The stated standard design of snowmaking 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.

Conclusions

This paper has reviewed all of the fundamental aspects of energy systems involved in the manufacture of snow for ski facilities. There are many options to choose from in the effort to optimize production and minimize energy operating costs. Ski facility management must carefully review their snowmaking requirements, current equipment, weather conditions, capital resources, operating budgets, and accurate estimates of operating costs for a variety of systems in order to determine the best snowmaking system options to pursue as they retrofit, enhance, and expand their operations.