Czech University of Life Sciences Prague

Faculty of Economics and Management

Department of Economics

Diploma Thesis

Economic and environmental impacts of artificial snow in the Czech Republic

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Economics and Management

DIPLOMA THESIS ASSIGNMENT

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Economics and Management
Economics and Management

Thesis title

Economic and environmental impacts of artificial snow in the Czech Republic

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Objectives of thesis

The diploma thesis creates a view of the issue of artificial snow in the Czech Republic. This topic is based on the example of 5 Czech ski resorts across the country. The aim of the whole work is an attempt to find a connection between the weather in a particular ski resort and the amount of water subscription for snowmaking and also an attempt to find external costs for this taken water.

Methodology

The diploma thesis is divided into theoretical and practical parts. The first part explains the concepts of snow, artificial snow, the origin of natural and artificial snow, the history of artificial snow, legislation on artificial snow in the Czech Republic, the history of artificial snow in the world, and possible negative impacts of artificial snow on the landscape. Methods as synthesis, deduction, and extraction are used in the first part of the bachelor thesis. The practical part of the diploma thesis works with data on surface water abstractions, with data on weather, and looks for their connections, and determines the external cost of the water taken for artificial snow.

Data on water subscription for the diploma thesis were obtained from individual river basins to which the ski resorts belong and where they have registered subscription points. Weather data were obtained from the Czech Hydrometeorological Institute.

The processed data are put into well-arranged tables and graphs with appropriate explanations and comments.

The proposed extent of the thesis

60 pages

Keywords

artificial snow, water subscription, the environment, external costs, skiarea

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Recommended information sources

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Prague on 31. 03. 2021

Declaration

I declare that I have worked on my diploma thesis titled "Economic and environmental impacts of artificial snow in the Czech Republic" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the diploma thesis, I declare that the thesis does not break any copyrights.

In Prague on 31.3.2021 ____________________________

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I would like to thank doc. Ing. Petr Procházka, MSc., Ph.D. for his valuable comments, supervision and assistance.

Economic and environmental impacts of artificial snow in the Czech Republic

Abstract

The aim of this diploma thesis is to try to find the connection between the amount of water subscription for artificial snow in selected ski areas in the Czech Republic and the weather. Furthermore, the work deals with the topic of costs of electricity used for artificial snow. The work is divided into theoretical and practical parts. The first part explains the concepts of snow, artificial snow, the origin of natural and artificial snow, the history of artificial snow, legislation on artificial snow in the Czech Republic, the history of artificial snow in the world, and possible negative impacts of artificial snow on the landscape. The practical part presents selected ski resorts and then we work with data on water subscription and weather. Furthermore, in the practical part, the mentioned elektricity costs for this abstracted water are sought. Methods as panel data regression, synthesis, deduction, and extraction are used in the diploma thesis. At the end of the diploma thesis is the final evaluation.

Keywords: water subscription, the environment, costs of electricity, skiarea, artificial snow, fan gun, snow lance

Ekonomické a environmentální dopady umělého zasněžování v České republice

Abstrakt

Hlavním cílem diplomové práce je nalezení spojitostí mezi odebranou povrchovou vodou pro účely umělého zasněžování ve 4 vybraných ski areálech v České republice a stavem počasí. Dále se práce zabývá náklady na elektrickou energii pro výrobu technického sněhu. Práce je rozdělena na teoretickou a praktickou část. První část práce vysvětluje pojmy jako sníh, umělý sníh, vysvětluje vznik obou těchto druhů, uvádí stručnou historii výroby umělého sněhu, legislativu umělého zasněžování v České republice a možné negativní vlivy na životní prostředí. Praktická část práce představuje vybrané ski areály a poté pracuje s daty o odběrech povrchové vody a stavu počasí. Dále jsou v praktické části simulovány náklady na elektrickou energii pro jeden vybraný ski areál. V práci je použito panelové regrese a dále syntézy, dedukce a extrakce. Na konci práce je uvedeno hodnocení.

Klíčová slova: odběr vody, životní prostředí, cena elektřiny, ski resort, technický sníh, technické zasněžování, sněhové dělo, sněhová tyč

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CHMI - Czech Hydrometeorological Institute

1 Introduction

Numerous ski resorts in the Czech Republic and around the world employ snowmaking technology. Climate change has forced them to produce artificial snow, since average temperatures in winter months are rising in parallel with a reduction in snowfall.

Artificial snowmaking has certain drawbacks, however. Extending skiing seasons can lead to soil erosion and demands that large amounts of water are extracted from suitable watercourses. Another negative factor is consumption of energy, since snowmaking equipment runs for hundreds of hours during a skiing season.

An important matter in this context constitutes limits on the extraction of surface waters, which are regulated by local authorities. Future debates on applying charges for water extraction would also be appropriate. It is not mandatory for a ski resort in the Czech Republic to pay for water taken from a watercourse. It is quite clear that this may change in the future, though, as dependence on snowmaking will be higher, demanding that the issue is addressed in a timely manner.

In the practical part of the thesis, the author looks for connections between climatic conditions in the selected ski resorts in the Czech Republic and the amount of water utilized for snowmaking through regression of panel data. For this purpose, the author selected the following four ski resorts SKICENTRUM Resort in Deštné v Orlických horách, SKI Aldrov Resort in Vítkovice v Krkonoších, SKI Areál Kvilda Resort and SKI Arena Karlov Rsort. In addition, the consumption of electrical energy is modelled for snowmaking along with its financial burden for a ski resort. The last chapter of the practical part details the rise in temperature at mountain regions and cities in the Czech Republic over the past 56 years. A ski resort located in Harrachov and the capital city of Prague were selected for this purpose.

2 Objectives and Methodology

2.1 Objectives

The main objective of the thesis is to find links between the climatic conditions and the amounts of water taken for snowmaking at four ski resorts in the Czech Republic.
The literature review describes the basic characteristics of natural snow, its formation and the various types that exist. The first portion of the thesis goes on to describe the production of artificial snow and the contemporary technology for this process. The author briefly presents the history of snowmaking in the world. In addition, the first part of the thesis gives an overview of legislation on snowmaking in the Czech Republic. An important part of the literature review comprises discussion of the negative effects of snowmaking on the landscape. The author also briefly focuses on differences in the properties of man-made snow. The main objective of the analytical part is to discern links between weather conditions and the amount of water utilized for snowmaking at the selected ski resorts. Subsequently, the author evaluates differences in the rate of rising temperatures between the Harrachov mountain resort and the capital city of Prague over the last 50 years. The last chapter of the second part of the thesis covers modelling of electricity consumption and related expenditure on the production of artificial snow at a selected ski resort.

2.2 Methodology

The thesis is divided into a literature review and analytical part. All data and information are obtained from books and internet sources. Synthesis, deduction and extraction are applied as methods in the first part of the thesis. The analytical portion is characterized by analysis via panel regression; in particular, the random and fixed-effects methods and also weighted least square method. All the necessary snowmaking data were sourced from the respective local water authorities, while data on weather were provided by the Czech Hydrometeorological Institute. The processed data of particular items are arranged in tables and graphs contained in figures with appropriate explanation and comments.

3 Literature Review

3.1 Basic characteristics of snow

Natural snow is defined as falling or deposited ice particles formed primarily by sublimation (UNESCO/IAHS/WMO 1970). About 5% of all precipitation that falls to the surface of the Earth is snow, of which between 50% and 90% lands in the Arctic region. (Rees, 2006)

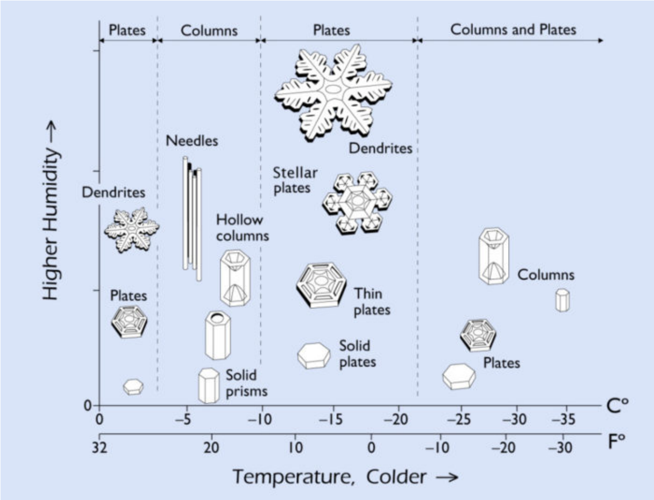
Snow comprises crystals with a complicated symmetrical structure that are dendritic in nature, arising through a process of several stages. The structure of natural snow was first described in 1611 by Johannes Kepler, a German evangelical theologian and scientist, who wrote on the subjects of maths, astrology, astronomy and optics. Snow crystals received greater attention in the late 19th century with the development of photography. (Libbrecht, 2011)

Modern technology makes it possible to replicate natural snow through the process of snowmaking. The equipment generates artificial snow through the crystallization of small droplets of water. Otherwise "fake snow" also exists, which is produced from plastic or polystyrene instead of water. (Fialová, 2014)

3.2 Formation of natural snow

The atmosphere contains microscopic particles of dust and pollen, and these particles act as "condensation cores" during the formation of snowflakes. As water vapour condenses on the particles, an ice crystal is created. The basic shape of the crystal is a flat hexagonal surface, which gradually gets added to as it develops. Its final appearance depends on the external temperature and humidity, as detailed in Figure 1. As water vapour accumulates on the crystal, it impacts droplets of extremely cold water, which is still in a liquid state despite the freezing temperatures (to -12°C). This happens because the surrounding environment does not allow the water to change its state. However, a small change in these conditions is enough for water to freeze immediately. In the event of an ice crystal colliding with a drop of cold water, the water immediately freezes on the crystal. Due to movement in the atmosphere, these collisions of ice crystals and cold water droplets become more intense, resulting in formation of a snowflake. Once of sufficient size, the snowflake begins its descent through the atmosphere towards the ground. If the temperatures of the various layers it passes through are below the freezing point, the snowflake falls to the ground. (meteopress.cz, 2019)

Figure 1: Pattern of formation of a snow crystal



Source: researchgate.net, 2012

3.3 Natural snow: Types and transformation

The basic shapes of snow crystals alter due to thermodynamic processes in the snow as well as exchange in energy and mass between the soil, atmosphere and snow cover. Three essential processes for the transformation of snow exist:

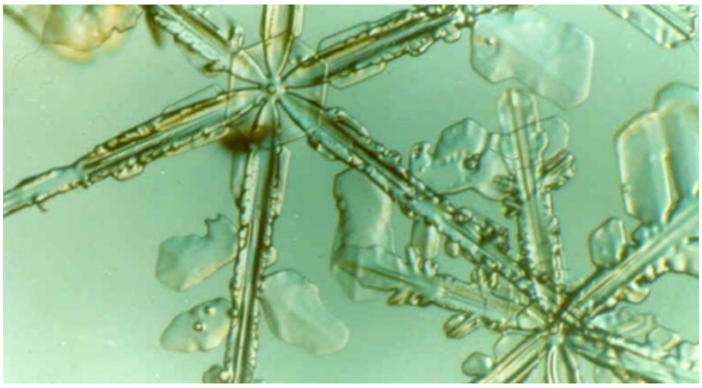
1. Collapse metamorphism
2. Structural metamorphism
3. Melt metamorphism

(ucebnice.horskasluzba.cz, 2010)

3.3.1 Collapse metamorphism

The length of this process primarily depends on the temperature and effect of the wind, taking longer at lower temperatures than, conversely, at higher temperatures, when it is more rapid. The process commences upon the presence of a new snow layer. “Grains” form as the snow crystals lose their tips through thermal and mechanical effects. Pore volume also decreases, permitting the snow cover to settle and strengthen. The period for degradation lasts between one and two weeks at -5°C. Snow physically affected by wind differs in behaviour from snow broken down by settling action, although the shape of the grain may be the same. Slight variances in temperature after snowfall cause a temporary loss in strength. (ucebnice.horskasluzba.cz, 2010)

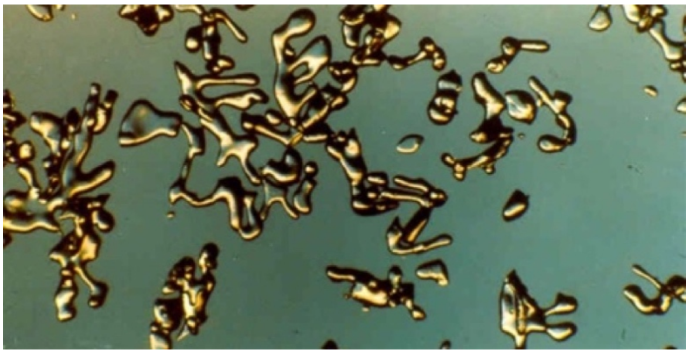
Figure 2: Fresh snow



Source: ucebnice.horskasluzba.cz, 2010

Freshly fallen snow is characterized by a great lack of coherence, because no opportunity for it to cement arises through the actions of the surrounding factors. (ucebnice.horskasluzba.cz, 2010)

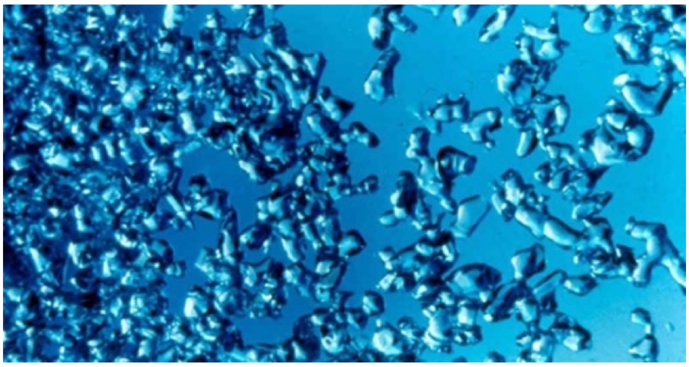
Figure 3: Broken snow



Source: ucebnice.horskasluzba.cz, 2010

Broken remnants of what were once crystals become somewhat compacted due to the effect of the wind, resulting in greater consistency; this metamorphism is usually very rapid. The top layers of the snowpack are almost perfectly interlaced by the action of wind, but no real connection exists with the base layer. (ucebnice.horskasluzba.cz, 2010)

Figure 4: Round-grain snow



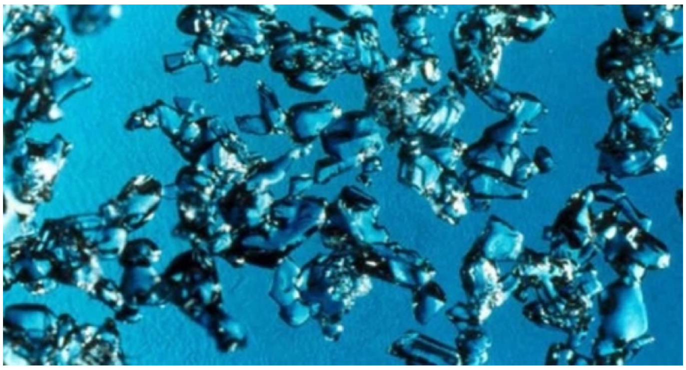
Source: ucebnice.horskasluzba.cz, 2010

During moderate warming, the last branched particles of the crystal melt away gradually, leaving behind a small core referred to as round-grain snow. The shape of the core resembles a small ball of minimal structure, free of lustre and matte white in hue. This comprises the last stage of the collapsing metamorphism. As a result of its capability to interconnect, the snow is lend greater stability. (ucebnice.horskasluzba.cz, 2010)

3.3.2 Structural metamorphism

This type of transformation gives rise to new crystals in the snow cover. The rate of the process increases in parallel with difference in temperature. It takes place more slowly than the collapse in metamorphism, though, usually within a period of two to four weeks. This metamorphism results in cavities, thereby forming crystals cup-like in appearance that are termed running snow. The formation of these cup-shaped crystals is due to sublimation. (ucebnice.horskasluzba.cz, 2010)

Figure 5: Prism-grain snow



Source: ucebnice.horskasluzba.cz, 2010

At low temperatures below freezing point, a new type begins to develop from former collapsed crystals. This transformation produces prismatic ice grains, which are comparable to crystalline sugar. (ucebnice.horskasluzba.cz, 2010)

Figure 6: Cup-shaped crystals

Source: ucebnice.horskasluzba.cz, 2010

These are produced under the snow surface and in an enclosed space during long-lasting, deep frosts below -10°C. The emerging crystals are cup-shaped and hollow. This fragile, lightweight form is incapable of coping with the initial or heightened load and an imminent risk of collapse exists. This form of snow is critical in terms of avalanche. (ucebnice.horskasluzba.cz, 2010)

Figure 7: Surface rime

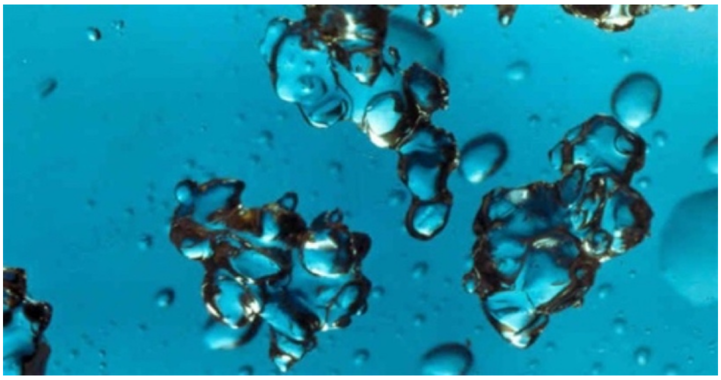
Source: ucebnice.horskasluzba.cz, 2010

New crystals can form on the snow surface of shaded slopes, particularly during long cold periods. They emerge due to humidity. (ucebnice.horskasluzba.cz, 2010)

3.3.3 Melt metamorphism

A process mainly caused by the sun, it occurs when warm air and rain raise the temperature of the snow cover to 0°C, resulting in thawing of the corners and edges of crystals. Crystals become rounded in shape, are more densely packed together and are coated in liquid. Snow loses its consistency as the cavities fill with water. As the amount of moisture rises, any free water flows out and the strength rapidly decreases. Large, round crystals form during the stage of melt metamorphism. Melt metamorphism is independent of the season, although it is a characteristic of springtime. (ucebnice.horskasluzba.cz, 2010)

Figure 8: Firn



Source: ucebnice.horskasluzba.cz, 2010

The melting and freezing phrases alternate several times, during which coarse-grain snow is formed (with a core diameter greater than 1 mm). During a very intense period of melting, it continues to form deeper in the snowpack, resulting in highly incoherent, wet snow under a hard layer. Melt metamorphism is a relatively easy process to explain, and its action is simple to detect and assess. It can take place in a short period of time and cause considerable displacement, evidenced as lumps, corrugated impressions or waves. (ucebnice.horskasluzba.cz, 2010)

Figure 9: Ice layer

Source: novinky.cz, 2016

A layer of ice or in combination with firn of different extents of thickness, occurring in any depth of the snowpack. The depth and thickness of the layer depend on prior weather patterns. (ucebnice.horskasluzba.cz, 2010)

3.4 Artificial snowmaking

“A snowmaking machine utilizes a mixture of compressed air and water vapour. The machine is operated by quickly expelling air and water vapour to cause a rapid expansion in volume through the existence of significant difference in pressure between the tank of the machine and the atmosphere. The energy needed to expand the compressed air and water vapour is derived from these gases, lowering their temperature. The cooling effect leads to the freezing of water vapour into a solid that resembles snow. A snowmaking machine is a practical example of the First Law of Thermodynamics at work. Rapid expulsion of the mixture of compressed air and water vapour at high pressure (typically ca 20 atm) ensures that the process is adiabatic; i.e. no heat is transferred from or lost to the surroundings during the rapid expansion. For the adiabatic process, q = 0. Thus, by the First Law, change in the internal energy of the gases is equal to the work performed by the gases as they expand." (Karukstis, 2003)

Figure 10: Formula for the First Law of Thermodynamics

$$\begin{aligned} \Delta E &= q + w \\ \Delta E &= w \qquad (\text{since } q = 0). \end{aligned}$$

Requirements for the quality of snow, slope maintenance and length of the skiing season are constantly on the rise. As a consequence, the number of snowmaking machines has increased, along with the necessary infrastructure. This includes equipment for distributing air and water across the given area of land, measuring appliances for controlling and optimizing snowmaking conditions, a machine room and sources of water (reservoirs, streams and so on).

Modern technology allows for two methods of artificial snowmaking – monoliquid (low pressure) and biliquid (high pressure). The former of the two uses only water, which is sprayed at the pressure of 10-65 bar. Biliquid technology employs an additional air component to the water, whereby two different principles are possible:

1. Both components are mixed together in a mixing chamber at the pressure of 6-12 bar, prior to being expelled into the air, resulting in the formation of ice crystals.
2. Alternatively, air separately pressurized (15-65 bar) is released into the environment, where it is supplemented by a stream of water, bringing about formation of ice crystals.

Another technological solution exists, however, it is very demanding in power consumption. It essentially involves making ice by cooling water with a type of freon to the temperature of -25 °C, then crushing it with a metal roller and scraping it off afterwards. While this process is totally independent of the given climatic conditions, it is only used occasionally; e.g. when making snow in indoor ski parks. (Paccard, 2010)

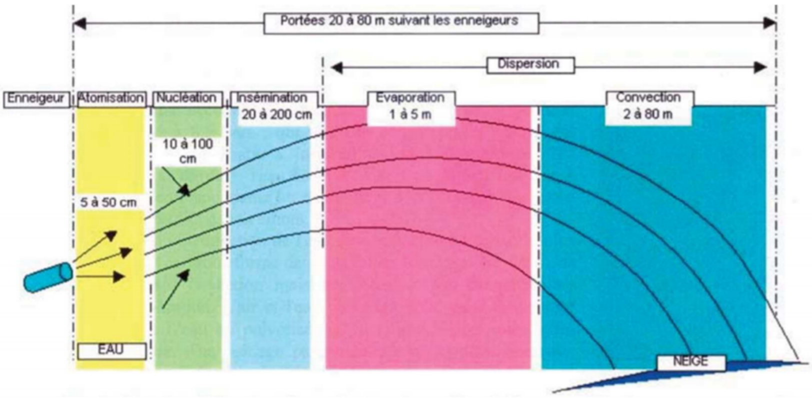
Water that is being transformed into snow goes through five different stages:

1. The first is called atomization (fragmentation), where water is sprayed through nozzles to create droplets of size 0.2–0.8 mm. The smaller the droplets, the easier the procedure of crystallization.

2. The second stage is nucleation. This process runs concurrently with atomization and results in a mix of water and air. The atomized droplets create cores for subsequent crystallization.
3. In the third stage – “insemination” – the condition of the uniform droplets is somewhat impaired, causing “congelation” (congealing).
4. During the fourth stage of “evapotranspiration”, the drops are dispersed in the air and their outer surface evaporates. This evaporation leads to decrease in the temperature of the droplet, thereby reducing the extent of congelation. This is the point at which the impact of climatic conditions make on snowmaking, since the drier the air, the quicker and better the droplets congeal (congelation).
5. The fifth stage is called convection and describes the process of heat exchange between the droplets and surrounding air. Again, snow production is more effective in cold air.

The very last process called “maturing” happens after the droplet falls on the ground. This is when the inner part of the condensed core also freezes.

Figure 11: Five stages of water in the snowmaking process
Stages from left: Atomization, nucleation, insemination, evapotranspiration, convection



Source: Badré, 2009

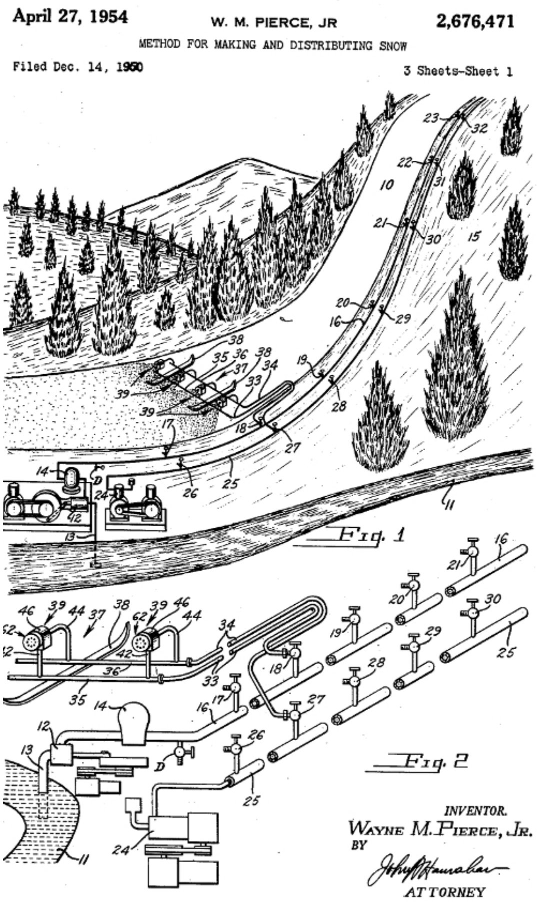
As this process implies, meteorological conditions are a significant factor in artificial snowmaking. The two most important factors are air temperature and air humidity. (Paccard, 2010)

3.5 History of artificial snowmaking

Artificial snow originated in North America, initially produced at Mohawk Mountain Ski Area in Connecticut in 1947. This snow was made by crushing ice into small pieces. This process was very time consuming and costly, and failed to achieve the desired result. During the 1940s, other attempts were made to produce artificial snow in Canada and the US, some of them happening purely by accident. The Tropean brothers from Boston created it by chance while using a watering system to treat trees by spraying them against frost (Paccard, 2010)

The temperature of the air lowered and instead of water, snow fell onto the trees. Another example was Canadian researcher, Ray Ringer, who developed the first snowmaking machine by accident rather than design in the 1940 s. Ringer was investigating the formation of rime (a form of ice) on jet engines. Ringer and his colleagues sprayed water into a chilled wind tunnel in front of a jet engine, but instead of forming a layer of ice as anticipated, the cooled water froze mid-air and snow crystals flew out from the back of the jet. They chose not to pursue their findings commercially, but Wayne Pierce and his team (at Tey Manufacturing, Connecticut, US) were inspired to design such a device (see the patent on the right). The first DIY snow gun was born out of a paint spray compressor, nozzle and garden hose. Wayne Pierce was the first to obtain a patent on artificial snowmaking and the distribution of units. (Pierce, 1954)

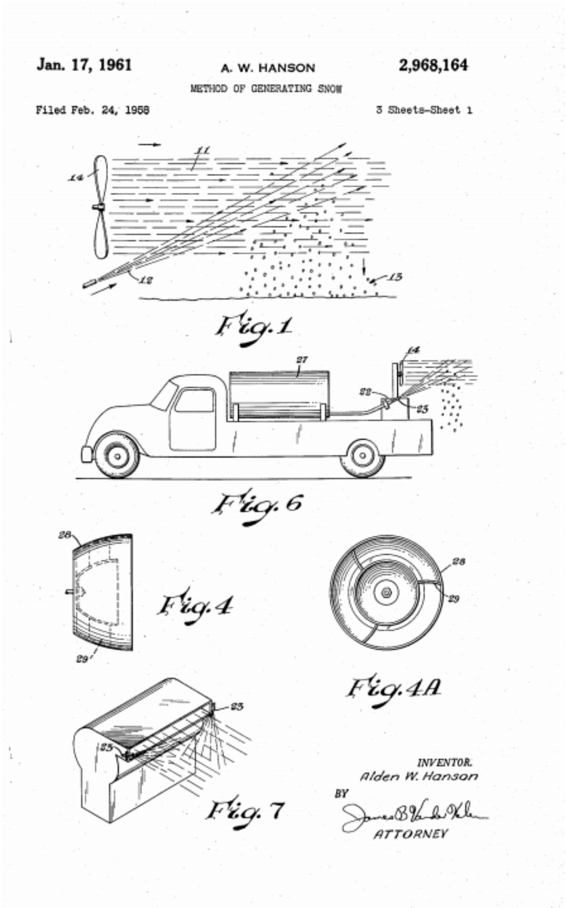
Figure 12: Snowmaking device by Wayne Pierce



Source: Pierce, 1954

Early machines by Tey were noisy and expensive to operate. Another issue was that water froze in the pipes if pumped too slowly. In 1961, Alden Hanson was issued a patent for a design comprising a fan, particulate water and a nucleating agent (dirt particles), which was quieter, cheaper to use and produced far more snow than previous systems. The Hanson design is considered the pioneer patent for all fan snowmaking machines. (Hanson, 1961)

Figure 13: Alden Hanson´s fan snowmaking machine



Source: Hanson, 1961

The primary motivation for developing snowmaking systems is to reduce dependence on climatic conditions. Artificial snowmaking systems first appeared on slopes in the United States, later spreading to Canada in the 1960s. In the following decade, such machines were introduced in Europe, mainly the Alps and Scandinavia. (Hahn, 2004)

Attempts to make artificial snow in Europe initially took place in 1963 in Champ de Feu, eastern France, where four machines were employed on a ski slope 550 metres long for three years. Another French ski centre with five units was Haut-Folin in Burgundy. Artificial snow was also introduced in Germany, Italy and Austria. (Zezula, 2011)

3.6 Technical snowmaking systems

Today, three types of machine are used to produce artificial snow – snow guns, lances and a recent innovation called a Snowfactory. As an example, TechnoAlpin, an Austrian company, is highlighted herein to aid discussion on contemporary technology. A leading firm in the sector, it is based in Bolzano, Italy, and was set up in 1990. Prior to this date its two founders, Walter Rieder and Georg Eisath, spent 10 years investigating various ways at making snow. In 1983, after several winters with minimal snowfall, the two constructed the first prototype of a snow gun, which they continued to improved until 1990, when the two started the company. The enterprise now employs over 750 people at 16 different sites in 13 countries around the world. TechnoAlpin is the official partner of the International Ski Federation (FIS) and was involved in the 2018 Olympic Winter Games in Korea. (technoalpin.com, 2018)

3.6.1 Fan guns

Figure 14: Fan gun

Source: technoalpin.com, 2018

3.6.2 Snow lances

Figure 15: Snow lance

Source: technoalpin.com, 2018

3.6.3 Snowfactory

Figure 16: Snowfactory

Source: inthesnow.com, 2017

Table 1: Comparison of snowmaking facilities

	Energy consumption	Snow production	Water consumption	Range
Fan gun	22 kW/h	1,536 m^3/d	6.8 l/s	50 m
Snow lance	4.01 kW/h	624 m^3/d	2.76 l/s	30 m
Snowfactory	184 kW/h	207 m^3/d	6 l/s	250 m

Source: technoalpin.com, data processed by the author

3.7 Current situation

In the last ten years, the numbers of ski resorts using artificial snow have risen. According to Rixen (2011), in the 1980 s, up to 60% of American ski centres employed artificial snow, unlike Switzerland, where the proportion was below 20%. Nowadays in the US, around 70% of ski areas in the western part utilize artificial snow, compared to over 95% in the south-east and 100% in the mid-west. Meanwhile, the share in Switzerland has gone up to just 40 %. Germany uses even less, at around 20%, yet the figures elsewhere are higher – in France it exceeds 30%, in Austria around 75% and in Italy up to 100%.

3.8 Artificial snow in the Czech Republic

Nationally, the use of artificial snow became more common from the year 2000 onwards. The amount of slopes with artificial snow differs from one ski centre to another. For example, in the Krkonoše Mountains, more than ten ski areas employ artificial snow on 100% of their slopes, while for another at least three quarters of their area is given over to it. Ski centres in other parts of the country tend to vary between 50% and 70% in usage, but some do not apply it at all. (Novický et al., 2009)

3.9 Legislation on artificial snowmaking in the Czech Republic

Limits on the use of water sources for snowmaking are laid down in the Act on Water No. 254/2001 Coll. The Act stipulates the protection of surface water, economical use of water resources and minimization of the adverse effects of drawing water for snowmaking purposes. The purpose is also to protect aquatic ecosystems and terrestrial ecosystems that depend directly on the former, in the interests of sustainable utilization of water sources. Those employing surface water are obliged to oversee protection of it and ensure conditions do not degrade. (Punčochář, 2004)

Any general management of surface water does not require authorization or approval from a water authority for drawing on the same for personal use, providing that no compromises are made in water quality and protection, the natural environment is not affected and drainage remains unimpaired. The competence of the water authority also covers regulating the management of waters in the interests of the public. (Punčochář, 2004)

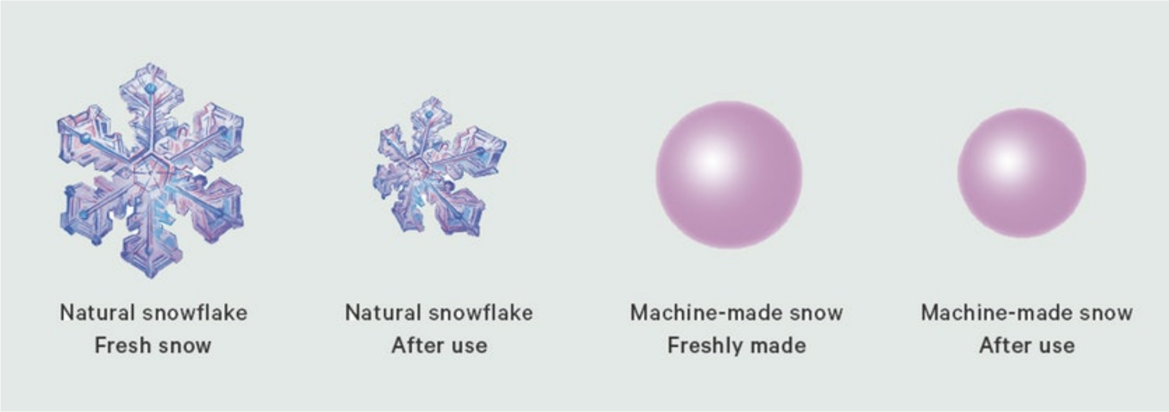
Any utilization of surface water for snowmaking purposes requires authorization from the water authority, which is issued for a limited period of time. Such authorization sets out the purpose of the collection, the scope and the conditions of the same. (Punčochář, 2004)

Water planning strategy is provided by the state for the purpose of defining public interests in protecting water sources as a component of the environment. The Act stipulates a minimum residual flow of surface water in watercourses in order to preserve its various ecological functions (Punčochář, 2004). The Czech Environmental Inspection body supervises compliance with the established limits. In the 2017-2018 season, 19% of ski resorts exceeded the given thresholds. The highest fine ever issued by the Czech Environmental Inspection body in the history of the nation was imposed in 2015 on the ski resort of Portáška, Pec pod Sněžkou, in the Krkonoše Mountains. (irozhlas.cz, 2019)

3.10 Characteristics of natural and artificial snow

The physical and chemical characteristics of natural snow and technical snow vary in many aspects. The fundamental difference lies the shape of the snow grains. Artificial snow is made by freezing droplets outdoors to form spherical structures. Natural snow, in contrast, comprises a dendritic structure, since flakes are created by gradual build-up from the core outwards. The density of both types of snow also varies greatly. For natural snow, density ranges from 100 to 400 kg/m3; in contrast, the figures for artificial snow are 400 to 490 kg/m3, mainly due to the greater proportion of air particles in natural snow. (Kocková, 2008)

Figure 17: Structural difference that exists between natural and artificial snow.



Source: cosmosmagazine.com, 2018

Thermal conductivity is also associated with the density of snow. The effect it exerts could jeopardise soil and vegetation under the snowpack if both are subject to low temperatures due to high density of the snow cover. (Stockli, Rixen, 2003) The soil layer on a ski slope may freeze to below -10ºC when being covered with artificial snow, which is unusual as the temperature rarely drops below freezing point under normal circumstances. (Wipf et al., 2005)

Another characteristic of artificial snow is that it melts very slowly at the end of the skiing season, partly due to compaction by heavy machinery. (Kocková, 2008)

The values of pH for both types also differ, since natural snow develops from rain water, while the artificial variety is produced from surface water, which contains a wealth of ions and minerals so it is more alkaline. (Kocková, 2008)

3.11 Environmental impact of artificial snowmaking

The construction of ski resorts involves extensive landscaping, as well as changes in conditions affecting soil, water and vegetation. Operating such sites brings in a large number of visitors, contributing to noise and light pollution. (Rixen and Rolando, 2013)

Ski resorts are now heavily influenced by climate change, forcing them to respond more frequently to the issue through various measures. Due to decrease in the amount of natural snow, artificial snowmaking is a more frequent occurrence in ski resorts, with the aim of increasing the range of services and comfort available to visitors. (Flousek, 2016)

The snowmaking process itself is accompanied by high consumption of water and electricity. 200-500 l of water and 5-9 kWh of electrical energy are required to produce 1 m3 of artificial snow, which for a snow layer of 30 cm requires ca 600,000 – 1,500,000 l of water and 5,000 – 27,000 kWh per 1 ha. (Rixen et al., 2011) According to the applicable Act No. 254/2001 Coll. on water, no fees are charged in the Czech Republic for taking surface water to make artificial snow by snow guns.

Climate change has led to a decline in the number of days ski resorts can produce artificial snow. Despite the fact that snowmaking equipment is constantly being upgraded, some foreign resorts are forced to use additives for snowmaking in high temperatures. Additives change conditions, by increasing the eutrophication of the soil and watercourse or reducing diversity in plant communities. (Rixen, 2003) The use of any chemicals to make artificial snow is prohibited by law in the territory of the Czech Republic.

3.11.1 Influence on the hydrosphere

The first way to supply a site with water for snowmaking is to collect surface water or groundwater. This method is also likely to have the greatest environmental impact. Today, the period at which flow rate in watercourses is at its lowest coincides with the most intense demand for snowmaking. Although the cumulative total of flow rates may not be dramatic for larger river basins, drawing on local water sources can have serious consequences for the ecosystem of the river. (de Jong, 2007)

Fuksa (2016) highlights the danger of organisms freezing through the action of tapping surface water during the period of reduced flow rates in watercourses.

Snowmaking systems constitute a major intervention in the natural world, whereby water supply equipment and pumping and compressor stations are established. The problem starts to occur in the early stage of laying the distribution system, as the necessary excavations run down the slope, resulting in more rapid run-off from the area. (Flousek, 2016)

According to research by the Swiss Institute for Snow and Avalanche Research, such run-off at the end of the skiing season from a slope with artificial snow is up to 30% higher than usual. (de Jong, 2007)

Another way to facilitate artificial snowmaking is to collect water from retention reservoirs. Sites gather water in these reservoirs when it is sufficient and then use it in a period of scarcity. This allows them to draw on water during periods of reduced flow in watercourses, typically at the turn of November and December. (Paccard, 2010) To fill these reservoirs, sites utilize surface water and rain water, or even mains water, although this is rare. Such reservoirs can also serve for irrigation unless they are exhausted during the skiing season for snowmaking purposes. Of course, building such reservoirs also has a negative effect on the landscape, the most significant of which is change to it. In order to build a retention reservoir, intervention is necessary. Such reservoirs are in use in resorts based in the Czech Republic, such as those along the mountains of Černá hora or Klínovec. (Andrle, 2012)

Figure 18: Retention reservoir, Benecko Ski Resort

Source: idnes.cz, 2020

The third way to source water for snowmaking is utilize mains water. This method is unusual, but does occur. The greatest risk is that there will be a shortage of drinking water for the population as a consequence of using it for snowmaking. This happened in 2007, for example, in Les Gets, in the Haute-Savoie Region. Under such circumstances, the operator is obliged to stop snowmaking and prioritize the supply of drinking water. (Paccard, 2010)

3.11.2 Impact on soil and vegetation

Up to twice as much water ends up on the ski slope from artificial snow as opposed to the natural variety. (Kocková, 2008) According to Kammer (2002), plant damage can occur due to lack of oxygen, which cannot permeate through the thicker snow cover it creates and layers of ice.

Such snow starts melting a few weeks later, too, after the skiing season is over, approximately by 2-4 weeks. Since the snowpack lasts longer, the growing season for plants is reduced or affected. An imbalance occurs through increase in the number of late-flowering plants, with related decline in early flowering species. (Kocková 2008)

4 Practical Part

4.1 Selection of ski resorts

For the purpose of the thesis, four ski resorts were selected throughout the Czech Republic. To this end, the decision was taken to investigate ski resorts located in different mountain ranges to ensure variation in snow and weather conditions were gauged during the skiing season. All of the selected ski resorts only draw upon surface water for snowmaking purposes, and none have a retention reservoir.

4.2 Characteristics of the ski resorts

4.2.1 SKICENTRUM Resort in Deštné v Orlických horách

The municipality Deštné v Orlických horách is situated at an elevation of 650 metres in the valley of the River Bělá and the stream of Deštenský potok. The ski resort contains 6 ski slopes with a total length of 4.5 kilometres. In terms of difficulty, there are 2 tracks marked black, 1 marked red and 3 marked blue. Snowboarders can take advantage of a decent snow-park with numerous obstacles and jumps. A two-seater chair lift and 7 other ski lifts provide transportation. Evening skiing is a very popular activity at the site. Deštná also includes ski hire facilities, ski and snowboard schools and catering facilities. (české-sjezdovky.cz, 2020)

4.2.2 SKI Aldrov Resort in Vítkovice v Krkonoších

The Vítkovice v Krkonoších Municipality is located at an elevation of 683 metres. The Aldrov ski resort is situated at 733 metres above sea level and operates a total of 4 ski slopes. Transport facilities for three tracks comprise four-seater chair lifts, referred to as "The Presidential Express"; so-called because former president Václav Klaus was in attendance when it was formally opened. The total length of the tracks is over 3 kilometres. (české-sjezdovky.cz, 2020)

4.2.3 SKI Areál Kvilda Resort

The Kvilda Ski Resort is a complex that lies in the municipality of Kvilda, not far from the well-known Zadov-Churáňov resort, in the central part of the Šumava Mountains.

Its location and elevation makes it perfect for families with young children or beginners. The resort is located in the village of Kvilda and boasts sufficient parking facilities and restaurants. There are a total of 3 public ski lifts and 2 more ski lifts reserved for a ski school (SKI Kvilda), run by the owner. Sufficient accommodation for guests exists directly in Kvilda or in the nearby municipalities of Borová Lada, Filipova Huť, Modrava and Horská Kvilda.
(české-sjezdovky.cz, 2020)

4.2.4 Ski Aréna Karlov Resort

This complex is located in the municipality of Malá Morávka, Moravia, specifically in the district of Karlov pod Pradědem. With over 12 km of interconnected ski slopes of all difficulty levels, it is the largest ski resort in Moravia. A single ski pass enables visitors to access all 14 local ski slopes. The area has a lighting system for illumination of ca 5.3 km of ski slopes, facilitating the greatest extent of evening skiing in Moravia. The complex also contains tracks for cross-country skiers. (ceskehory.cz, 2020)

4.3 Water extraction for snowmaking at the ski resorts

Data on surface water extraction were provided by the respective local water authorities overseeing the points of extraction; each point of supply was registered by the ski resort and approved formally. More specifically, this involves water authorities managing the river basins of the River Vltava (Horní Vltava Branch) for SKI Kvilda, the River Odra (Opava Branch) for Ski Arena Karlov, the River Elbe (Pardubice Branch) for SKICENTRUM Deštné v Orlických horách and, again, the River Elbe (Jablonec nad Nisou Branch) for Vítkovice v Krkonoších. Together with the data mentioned above, the authorities provided statistics on the number of hours of snowmaking undertaken at each ski resort.

4.4 Weather data

Historical data on weather at the selected ski resorts were provided by the Czech Hydrometeorological Institute (CHMI). As with data on water extraction and the number of hours of snowmaking, the same constitutes monthly information. The following data are used in the thesis: average monthly air temperature, monthly aggregate of fresh snow in height and maximum height of snow cover.

The data from the CHMI were in accordance with Act 123/1998 Coll., such that average, maximum and minimum figures were calculated upon a precondition that no more than 5 values were missing in a given month nor that values were missing for a maximum of three consecutive days. The sum is calculated provided that all measured data are available for the respective time period.

4.5 SKICENTRUM Resort in Deštné v Orlických horách

This ski resort located in the mountains of Orlické hory draws water for its snowmaking operations from the watercourse of Bělá at river kilometre 34.055. The decision to authorise the extraction of surface water was issued by the Municipal Court in Dobruška on 10 January 2012 with the date of effect until 31 January 2022. The maximum authorised amount to be taken is 60 litres per second / 200,000 sqm per year. The ski resort draws water directly from the watercourse and only in the period of November to February.

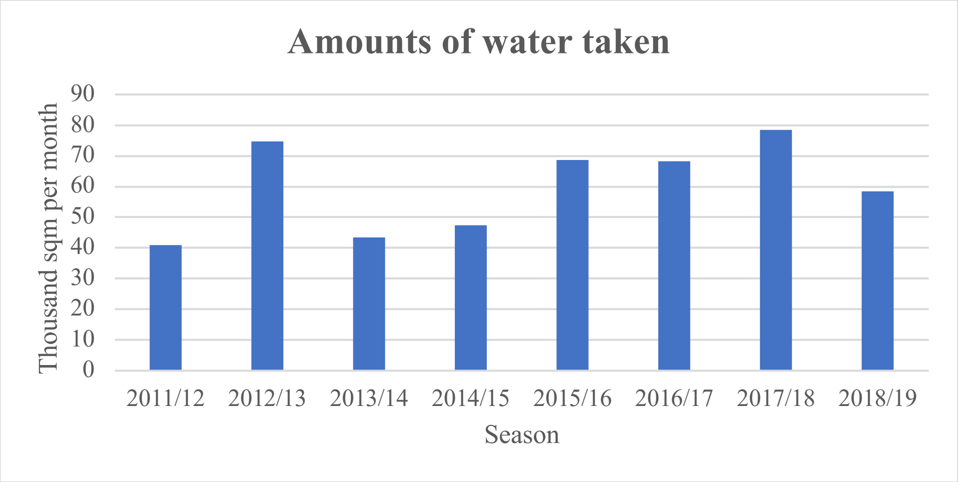
Table 2 shows monthly amount of snowmaking water taken in 2011–2019. The largest amount of water (78,380 sqm) was taken by the ski resort during the ski season of 2017/2018. The least amount (40,830 sqm) was taken during the ski season of 2011/2012. On average, the ski resort took 60,001 sqm per ski season; in all of the years under review, the SKICENTRUM Resort in Resort Deštné v Orlických horách respected the limit set by the decision to authorise the extraction of surface water.

Table 2: Amounts of water taken for artificial snowmaking at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019

Water subscription [thousand sqm per month]					
Season	**November**	**December**	**January**	**February**	**Total**
2011/2012	0.00	15.21	16.92	8.71	40.83
2012/2013	3.98	38.59	24.08	8.10	74.75
2013/2014	5.29	22.11	12.71	3.22	43.32
2014/2015	1.90	22.64	14.12	8.63	47.29
2015/2016	9.89	11.83	39.31	7.70	68.74
2016/2017	12.38	39.81	16.06	0.00	68.24
2017/2018	1.24	36.91	31.28	8.95	78.38
2018/2019	15.47	23.65	19.33	0.00	58.46

Source: Povodí Labe (Pardubice Branch), data processed by the author, 2021

Figure 19: Amounts of water taken for artificial snowmaking at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019



Source: Povodí Labe (Pardubice Branch), data processed by the author, 2021

Table 3 shows data on hours of artificial snowmaking operation at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019. During the reference period, the snow guns were operated in December and January to the largest extent.

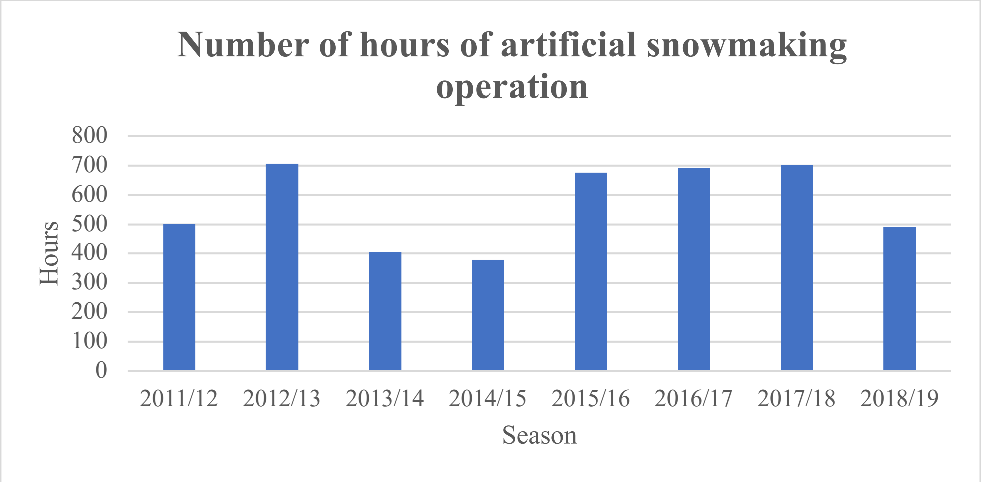
Table 3: Hours of artificial snowmaking operation at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019

Number of hours of artificial snowmaking operation [hours]					
Season	**November**	**December**	**January**	**February**	**Total**
2011/2012	0	228	180	94	502
2012/2013	36	372	223	75	706
2013/2014	49	203	119	35	406
2014/2015	21	199	99	60	379
2015/2016	69	83	438	86	676
2016/2017	137	443	112	0	692
2017/2018	10	305	301	86	702
2018/2019	150	206	135	0	491

Source: Povodí Labe (Pardubice Branch), data processed by the author, 2021

The largest number of hours of operation of snow guns was reached by the ski resort in the ski season of 2012/2013: 706 hours. However, in the 2016/2017 and 2017/2018 seasons, the figures were very similar: 692 hours and 702 hours. On the other hand, in the ski season of 2014/2015, snow guns were operated only 379 hours. On average, snow guns operated 569.25 hours per ski season during the reference period.

Figure 20: Hours of artificial snowmaking operation at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019



Source: Povodí Labe (Pardubice Branch), data processed by the author, 2021

Table 4 contains data on monthly aggregate sums of fresh snow at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019. The largest total sum of fresh snow is shown in the key months of the ski season, i.e., December and January.

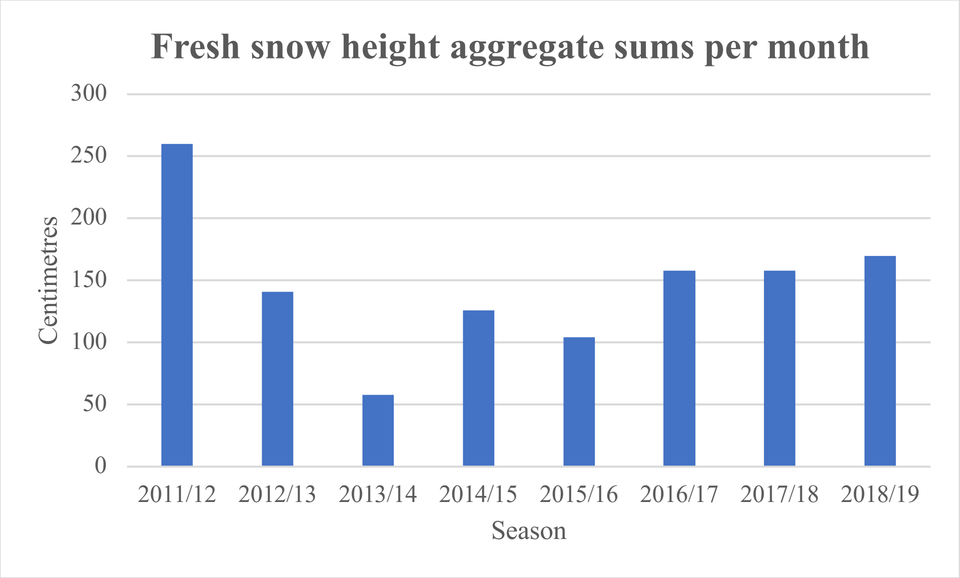
Table 4: Fresh snow height aggregate sums per month at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019

Fresh snow height aggregate sums per month [cm]					
Season	**November**	**December**	**January**	**February**	**Total**
2011/2012	2	56	127	75	260
2012/2013	7	40	47	47	141
2013/2014	18	33	5	2	58
2014/2015	0	17	86	23	126
2015/2016	8	0	54	42	104
2016/2017	21	31	102	4	158
2017/2018	47	48	53	10	158
2018/2019	0	51	111	8	170

Source: Czech Hydrometeorological Institute, data processed by the author, 2021

The maximum sum (a total of 260 cm) of fresh snow cover occurred during the first ski season of 2011/2012, while the least total amount was seen in the season of 2013/2014, when this monitored hydrometeorological figure was only 58 cm. A total of 146.88 cm of natural snow fell on average over the ski season during the reference period.

Figure 21: Fresh snow height aggregate sums per month at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019



Source: Czech Hydrometeorological Institute, data processed by the author, 2021

Table 5 shows data on average daily temperatures at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019.

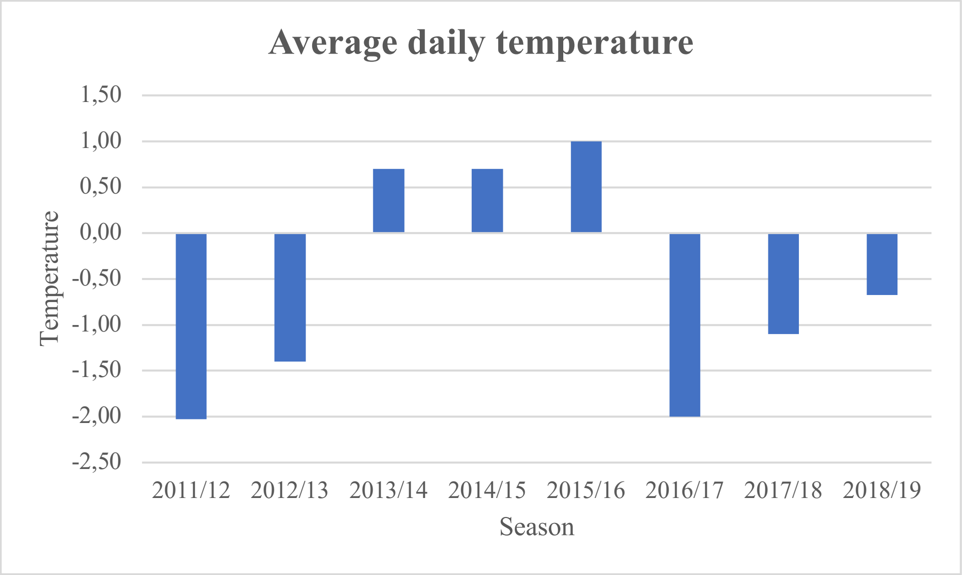
Table 5: Average daily temperatures at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019

Average daily temperatures [°C]					
Season	**November**	**December**	**January**	**February**	**Average**
2011/2012	1.70	-0.20	-2.40	-7.20	-2.03
2012/2013	4.00	-3.10	-3.60	-2.90	-1.40
2013/2014	2.80	-0.30	-0.50	0.80	0.70
2014/2015	5.10	0.00	-1.00	-1.30	0.70
2015/2016	3.70	2.30	-3.40	1.40	1.00
2016/2017	1.00	-2.80	-6.20	0.00	-2.00
2017/2018	2.20	-1.10	-0.10	-5.40	-1.10
2018/2019	3.60	-0.90	-4.60	-0.80	-0.68

Source: Czech Hydrometeorological Institute, data processed by the author, 2021

The warmest ski season was that of 2015/2016 with an average temperature of 1°C. The contrary applies to that of 2011/2012 with an average temperature of –2.03°C. At the month level, the temperatures ranged from –7.20 °C in February, ski season 2011/2012, to 5.10 °C in November, ski season 2014/2015.

Figure 22: Average daily temperatures at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019



Source: Czech Hydrometeorological Institute, data processed by the author, 2021

4.6 SKI Aldrov Resort in Vítkovice v Krkonoších

This ski resort located in the Krkonoše Mountains draws water for its snowmaking operations from the watercourse of Jizerka at river kilometre 12.779. The decision to authorise the extraction of surface water was issued by the Municipal Office of Jilemnice on 24 October 2006 with the date of effect until 20 October 2026. The maximum authorised amount to be taken is 5 litres per second / 6,000 sqm per year. The ski resort draws water directly from the watercourse and only in the period of November to February.

Table 6 shows monthly amounts of snowmaking water taken in the reference period, i.e., 2008–2020. In all of the years under review, the ski resort complied with the limit set by the decision to authorise the extraction of surface water.

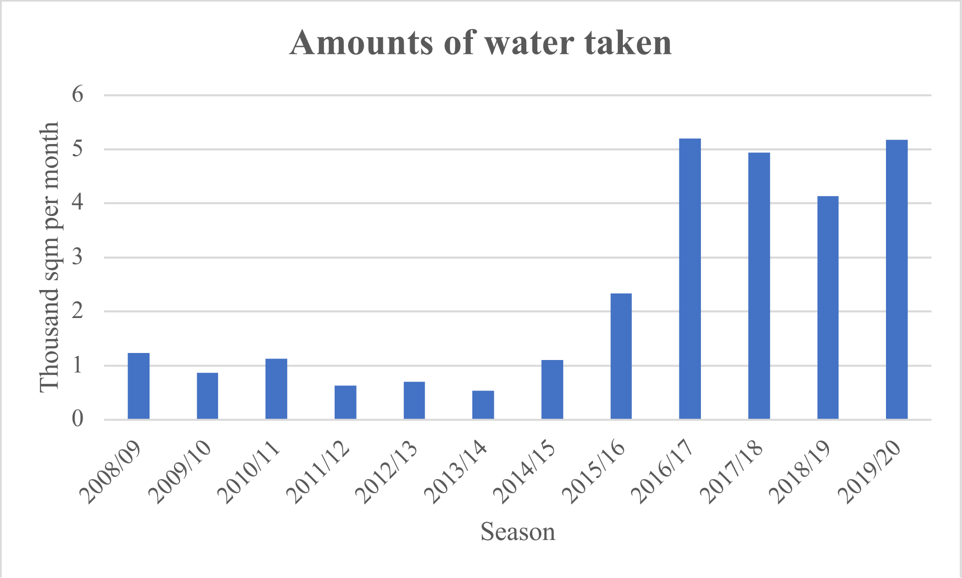
Table 6: Amounts of water taken for artificial snowmaking at the Ski Aldrov Resort in Vítkovice v Krkonoších in 2008–2020

Amounts of water taken [thousand sqm per month]					
Season	**November**	**December**	**January**	**February**	**Total**
2008/2009	0	0.4	0.455	0.385	**1.24**
2009/2010	0	0.285	0.515	0.072	**0.872**
2010/2011	0	0.486	0.457	0.185	**1.128**
2011/2012	0	0.286	0.218	0.125	**0.629**
2012/2013	0	0.249	0.355	0.102	**0.706**
2013/2014	0	0.09	0.295	0.156	**0.541**
2014/2015	0	0.215	0.487	0.398	**1.1**
2015/2016	0	0.435	1.25	0.654	**2.339**
2016/2017	0	0.875	2.35	1.98	**5.205**
2017/2018	0.55	0.96	1.87	1.56	**4.94**
2018/2019	0.89	1.5	0.85	0.9	**4.14**
2019/2020	0.8	3	0.785	0.589	**5.174**

Source: Povodí Labe (Jablonec nad Nisou Branch), data processed by the author, 2021

On average, the Ski Aldrov Resort in Vítkovice v Krkonoších took 2,334.5 sqm of surface water per ski season in 2008–2020. The largest amount was taken in the ski season of 2016/2017, when the quantity of extracted water was 5,205 sqm, while the smallest amount was taken in the ski season of 2013/2014, when the quantity of extracted water totalled 541 sqm. In recent years, a very high trend has been observed for surface water extraction.

Figure 23: Amounts of water taken for artificial snowmaking at the Ski Aldrov Resort in Vítkovice v Krkonoších in 2008–2020



Source: Povodí Labe (Jablonec nad Nisou Branch), data processed by the author, 2021

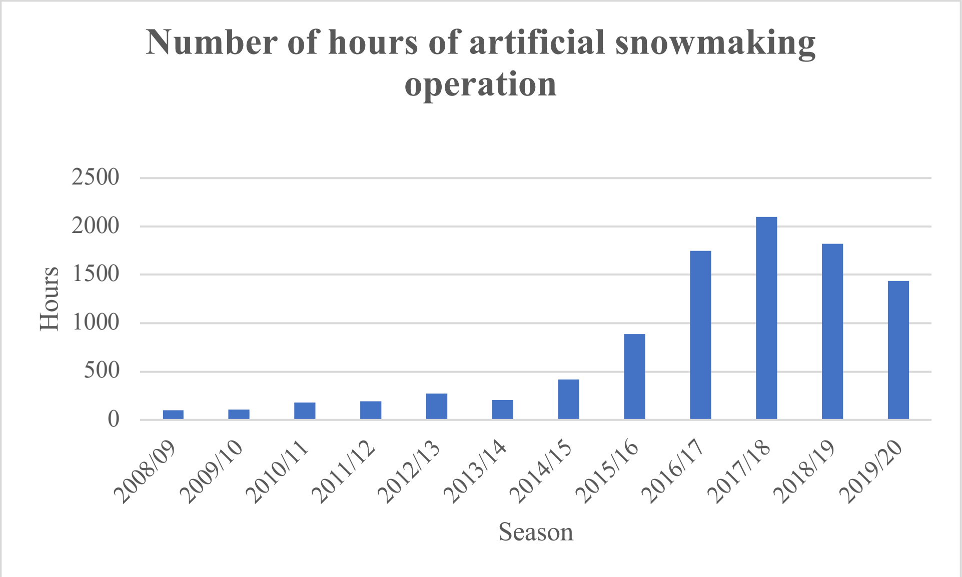
Table 7: Hours of artificial snowmaking operation at the Ski Aldrov in Vítkovice v Krkonoších in 2008–2020

Number of hours of artificial snowmaking operation [hours]					
Season	**November**	**December**	**January**	**February**	**Total**
2008/2009	0	0	56	42	**98**
2009/2010	0	32	52	24	**108**
2010/2011	0	48	90	40	**178**
2011/2012	0	60	84	48	**192**
2012/2013	0	96	136	39	**271**
2013/2014	0	35	112	59	**206**
2014/2015	0	82	185	151	**418**
2015/2016	0	165	475	249	**889**
2016/2017	0	333	744	672	**1749**
2017/2018	294	510	705	588	**2097**
2018/2019	335	564	450	474	**1823**
2019/2020	422	744	156	117	**1439**

Source: Povodí Labe (Jablonec nad Nisou Branch), data processed by the author, 2021

On average, the ski resort operated its snowmaking equipment 789 hours per ski season in the reference period. However, there is a large difference in figures seen at the beginning and at the end of this period. In the 2008/2009 season, snowmaking ran only 98 hours, which is also the minimum observed throughout the period, while at the end of the period it was 14 to 20 times that value. The maximum was reached in the 2017/2018 season: 2,097 hours.

Figure 24: Hours of artificial snowmaking operation at the Ski Aldrov in Vítkovice v Krkonoších in 2008–2020



Source: Povodí Labe (Jablonec nad Nisou Branch), data processed by the author, 2021

Table 8 shows fresh snow monthly totals at the Ski Aldrov Resort in Vítkovice v Krkonoších in 2008–2020.

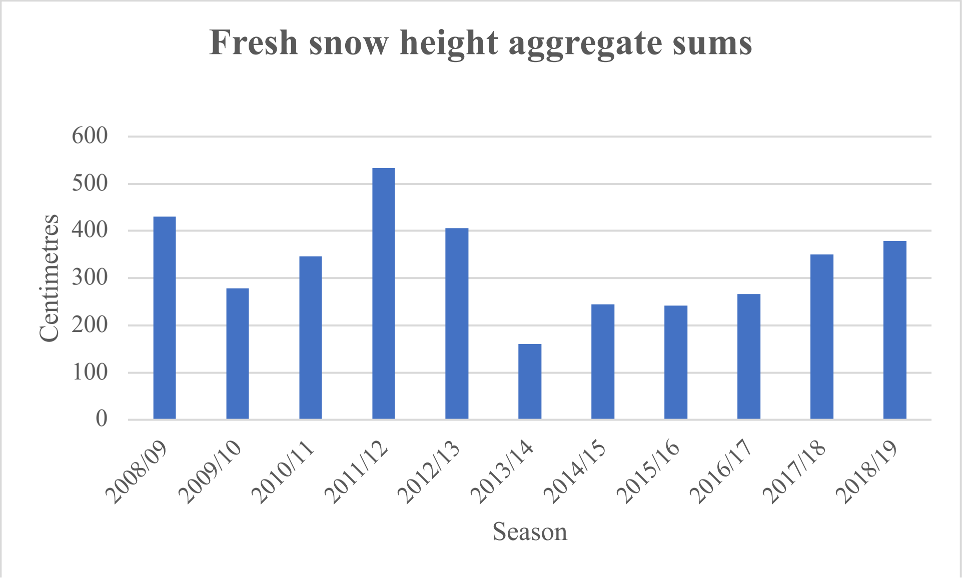
Table 8: Fresh snow height aggregate sums per month at the Ski Aldrov in Vítkovice v Krkonoších in 2008–2020

Fresh snow height aggregate sums per month [cm]					
Season	**November**	**December**	**January**	**February**	**Total**
2008/2009	99	80	86	166	**431**
2009/2010	13	77	140	48	**278**
2010/2011	45	215	72	14	**346**
2011/2012	0	158	268	107	**533**
2012/2013	21	97	145	143	**406**
2013/2014	37	85	26	13	**161**
2014/2015	0	70	139	35	**244**
2015/2016	34	8	107	93	**242**
2016/2017	30	40	176	21	**267**
2017/2018	81	130	124	15	**350**
2018/2019	1	97	252	29	**379**

Source: Czech Hydrometeorological Institute, data processed by the author, 2021

As seen in the table, there is a high decrease in the monthly totals for fresh snow; it particularly applies to the season of 2013/2014, where the total aggregate sum of fresh snow was only 161 cm throughout the season. On the contrary, the maximum amount of snow was seen in the season of 2011/2012 when the figure under monitoring was 533 cm. On average, a total amount of 330.64 cm snow fell at the ski resort per ski season in the reference period.

Figure 25: Fresh snow height aggregate sums per month at the Ski Aldrov in Vítkovice v Krkonoších in 2008–2020



Source: Czech Hydrometeorological Institute, data processed by the author, 2021

Table 9 shows the maximum height of snowpack at the Ski Aldrov Resort in Vítkovice v Krkonoších in 2008–2020. The table clearly shows seasons featuring big amounts of snow; it particularly involves the 2011/2012 and 2018/2019 seasons when the snow cover peak (165 cm) for the reference period was reached during January 2012.

Table 9: The maximum height of snowpack at the Ski Aldrov Resort in Vítkovice v Krkonoších in 2008–2020

Maximum height of snowpack [cm]				
Season	**November**	**December**	**January**	**February**
2008/2009	38	26	44	97
2009/2010	10	35	80	95
2010/2011	23	95	68	50
2011/2012	0	53	165	155
2012/2013	5	42	40	82
2013/2014	25	80	11	14
2014/2015	0	26	52	62
2015/2016	18	8	46	31
2016/2017	6	24	95	70
2017/2018	34	55	63	34
2018/2019	0	35	115	105

Source: Czech Hydrometeorological Institute, data processed by the author, 2021

Table 10 shows data on average daily temperatures at the Ski Aldrov Resort in Vítkovice v Krkonoších in 2008–2019.

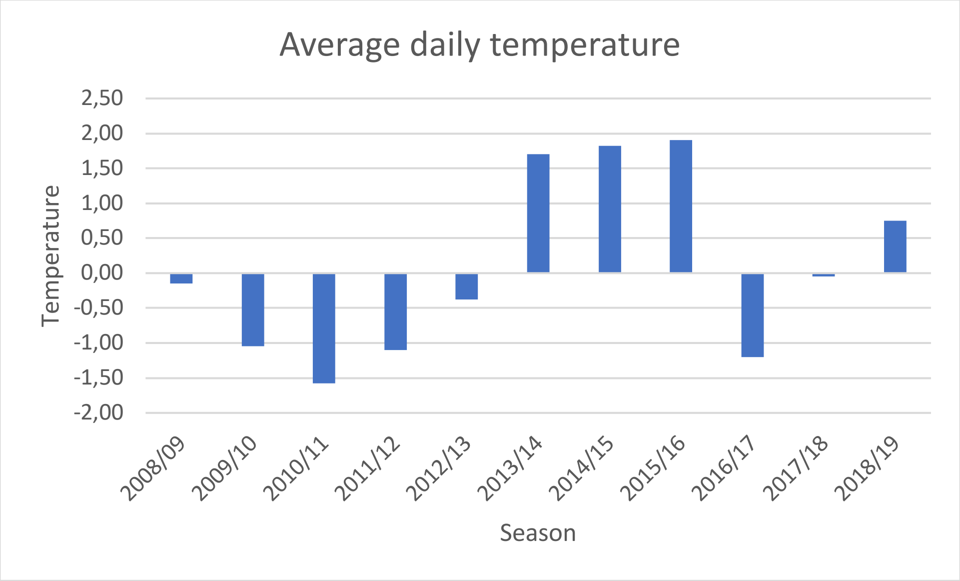
Table 10: Average daily temperatures at the Ski Aldrov Resort in Vítkovice v Krkonoších in 2008–2020

Average daily temperature [°C]					
Season	**November**	**December**	**January**	**February**	**Average**
2008/2009	4.7	0.6	-4.7	-1.2	**-0.15**
2009/2010	5	-1.7	-5.5	-2	**-1.05**
2010/2011	4.7	-5.7	-2.4	-2.9	**-1.58**
2011/2012	2.7	1	-1.8	-6.3	**-1.10**
2012/2013	5	-2.4	-2.4	-1.7	**-0.38**
2013/2014	3.8	0.7	0.2	2.1	**1.70**
2014/2015	6.2	1.1	0.3	-0.3	**1.83**
2015/2016	4.9	3.1	-2.7	2.3	**1.90**
2016/2017	2.2	-1.5	-6.1	0.6	**-1.20**
2017/2018	3.2	-0.5	0.8	-3.7	**-0.05**
2018/2019	4.9	0.4	-2.8	0.5	**0.75**

Source: Czech Hydrometeorological Institute, data processed by the author, 2021

The warmest ski season was recorded for the 2015/2016 season, when the average temperature was 1.90°C throughout. The opposite was seen in the 2010/2011 season, with the average temperature dropping to –1.58°C. The warmest month of each of the ski seasons in the reference period was November, at an average of 4.3°C.

Figure 26: Average daily temperatures at the Ski Aldrov Resort in Vítkovice v Krkonoších in 2008–2020



Source: Czech Hydrometeorological Institute, data processed by the author, 2021

4.7 SKI Areál Kvilda Resort

The SKI Areál Kvilda Resort draws water for its snowmaking operations from the watercourse of Teplá Vltava at river kilometre 424,300, downstream of the River Řasnice. The ski resort extracted water directly from the watercourse and only in the period of November to February in the years under review.

Table 11 shows monthly amounts of snowmaking water taken in 2012–2019.

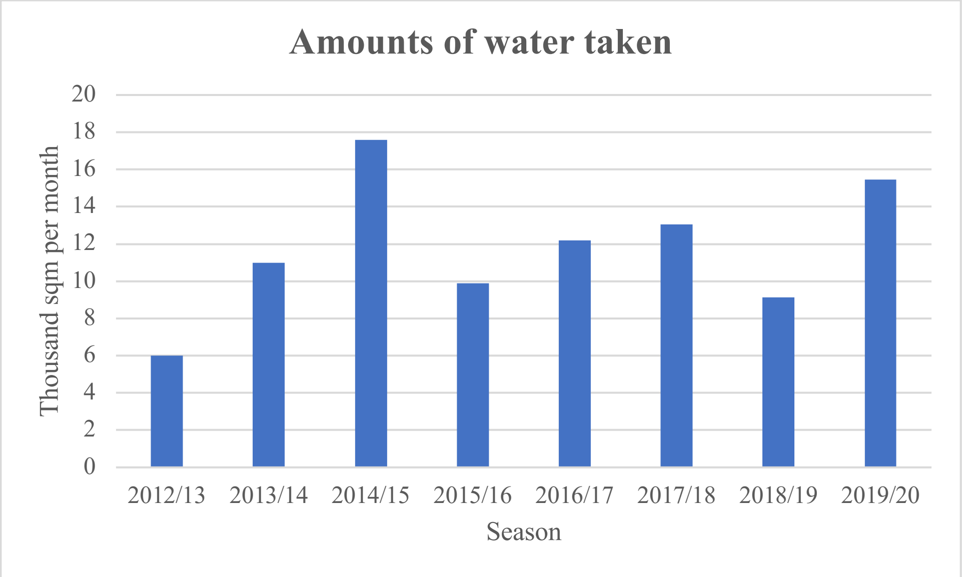
Table 11: Amounts of water taken for artificial snowmaking at the SKI Areál Kvilda Resort in 2012–2019

Amounts of water taken [thousand sqm per month]					
Season	**November**	**December**	**January**	**February**	**Total**
2012/2013	1	2	3	0	**6**
2013/2014	1	5	5	0	**11**
2014/2015	3	8	4.3	2.3	**17.6**
2015/2016	1.8	0.8	4.1	3.2	**9.9**
2016/2017	2.1	4.2	4.38	1.51	**12.19**
2017/2018	5.14	4.55	3.37	0	**13.06**
2018/2019	2.19	4.71	2.23	0	**9.13**

Source: Povodí Vltavy (Horní Vltava Branch), data processed by the author, 2021

During the reference period, the largest amount of water (17.60 sqm) was taken by the ski resort during the ski season of 2014/2015, while the smallest amount was taken in the ski season of 2012/2013, when the quantity of extracted water totalled 6,000 sqm. On average, the ski resort took 11,791 sqm per ski season in all of the years under review.

Figure 27: Amounts of water taken for artificial snowmaking at the SKI Areál Kvilda Resort in 2012–2019



Source: Povodí Vltavy (Horní Vltava Branch), data processed by the author, 2021

Table 12: shows data on hours of artificial snowmaking operation on a monthly basis at the SKI Areál xxx Kvilda Resort in 2012–2019.

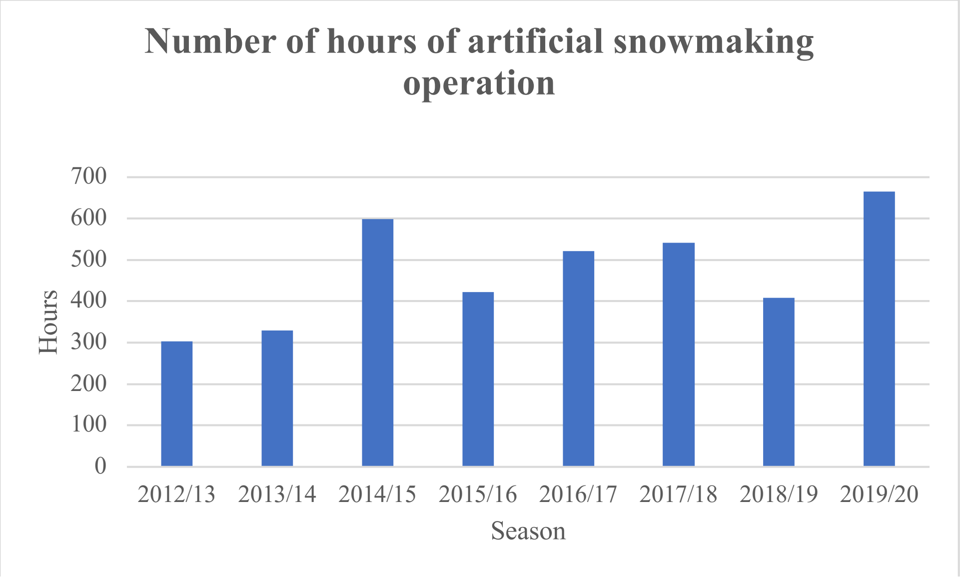
Table 12: Hours of artificial snowmaking operation at the SKI Areál Kvilda Resort in 2012–2019

Number of hours of artificial snowmaking operation [hours]					
Season	**November**	**December**	**January**	**February**	**Total**
2012/2013	68	136	100	0	**304**
2013/2014	30	150	150	0	**330**
2014/2015	100	250	166	83	**599**
2015/2016	84	38	158	142	**422**
2016/2017	92	167	195	67	**521**
2017/2018	211	209	122	0	**542**
2018/2019	111	203	94	0	**408**

Source: Povodí Vltavy (Horní Vltava Branch), data processed by the author, 2021

During the reference period, the snowmaking equipment was operated for an average of 473.88 hours per season. The highest figure for this was in the 2014/2015 season at 599 hours, in contrast to the 2012/2013 season, which witnessed a total of 304 hours.

Figure 28: Hours of artificial snowmaking operation at the SKI Areál Kvilda Resort in 2012–2019



Source: Source: Povodí Vltavy (Horní Vltava Branch), data processed by the author, 2021

Table 13 below contains data on monthly aggregate sums of fresh snow at the SKI Areál Kvilda Resort in 2012–2019.

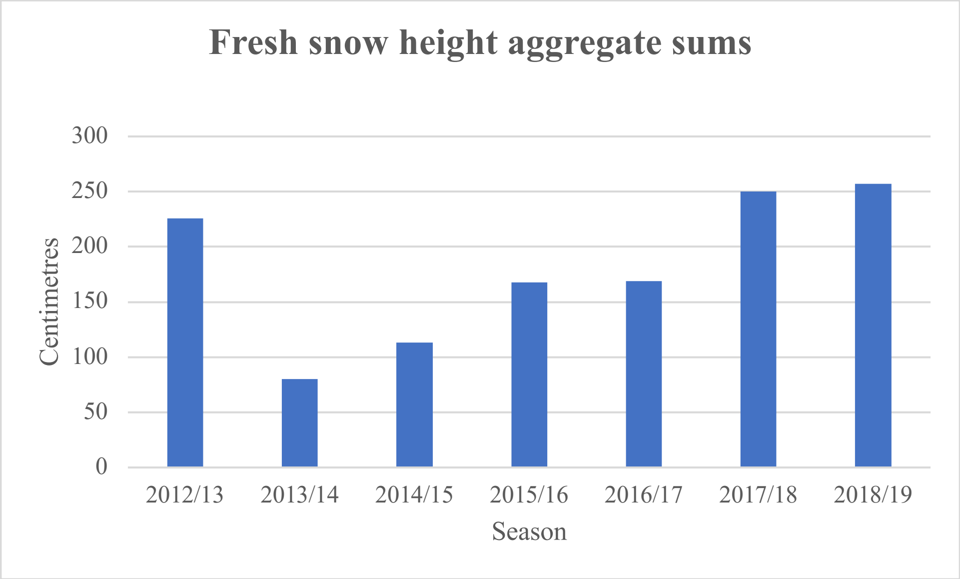
Table 13: Fresh snow height aggregate sums per month at the SKI Areál Kvilda Resort in 2012–2019

Fresh snow height aggregate sums per month [cm]					
Season	**November**	**December**	**January**	**February**	**Total**
2012/2013	6	64	51	105	**226**
2013/2014	24	32	15	9	**80**
2014/2015	0	56	44	13	**113**
2015/2016	12	5	96	55	**168**
2016/2017	27	23	97	22	**169**
2017/2018	40	97	80	33	**250**
2018/2019	25	58	136	38	**257**

Source: Czech Hydrometeorological Institute, data processed by the author, 2021

The largest monthly aggregate value was observed during the 2018/2019 season, with a total of 257 cm of snowfall; during the same period, one month experienced the largest aggregate amount of fresh snow – January 2019 with 136 cm of fresh snowpack. The season with the least amount of fresh snow was early in the reference period, namely the 2013/2014 season with 80 cm of snow.

Figure 29: Fresh snow height aggregate sums per month at the SKI Areál Kvilda Resort in 2012–2019



Source: Source: Czech Hydrometeorological Institute, data processed by the author, 2021

Table 14 shows data on average daily temperatures at the SKI Areál Kvilda Resort in 2012–2019. During the entire reference period, the average daily temperature throughout the ski season was below the freezing point.

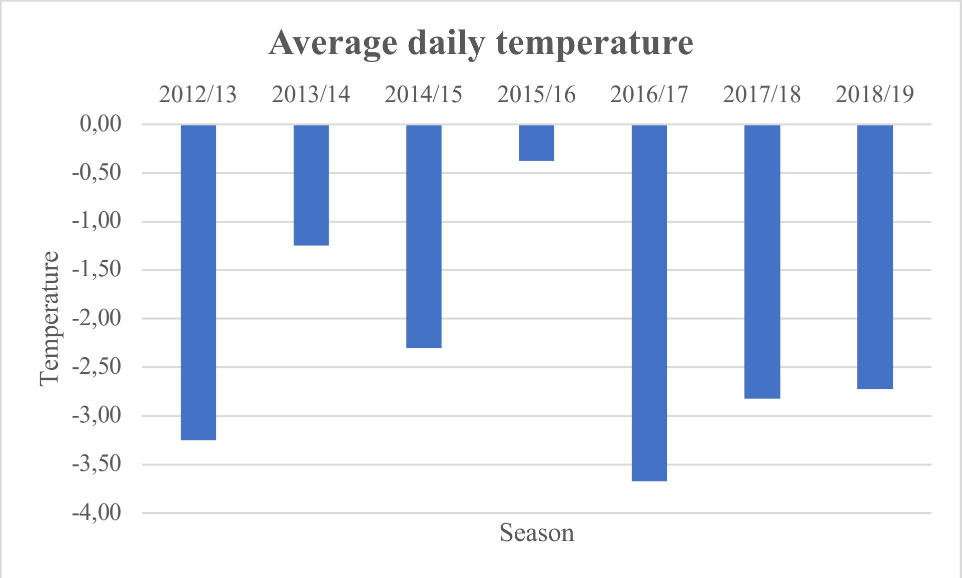
Table 14: Average daily temperatures at the SKI Areál Kvilda Resort in 2012–2019

Average daily temperature [^oC]					
Season	**November**	**December**	**January**	**February**	**Average**
2012/2013	0.5	-3.2	-4.4	-5.9	**-3.25**
2013/2014	0	-2.4	-1.3	-1.3	**-1.25**
2014/2015	1.6	-2.1	-2.5	-6.2	**-2.30**
2015/2016	2.4	1.5	-3.9	-1.5	**-0.38**
2016/2017	-0.6	-3.9	-8.7	-1.5	**-3.68**
2017/2018	0.1	-2.6	-0.8	-8	**-2.83**
2018/2019	-0.3	-1.3	-6.3	-3	**-2.73**

Source: Czech Hydrometeorological Institute, data processed by the author, 2021

The coldest season was that of 2016/2017 with an average temperature of –3.68°C. During this season, the monthly minimum for the entire reference period was also reached, namely –8.7°C, during January 2017. The warmest season was that of 2015/2016 with an average temperature of –0.38°C. The coldest month in the years under review was January with an average temperature of –3.98°C.

Figure 30: Average daily temperatures at the SKI Areál Kvilda Resort in 2012–2019



Source: Czech Hydrometeorological Institute, data processed by the author, 2021

4.8 Ski Arena Karlov Resort

This ski resort draws water for its snowmaking operations from the watercourse of Moravice at river kilometre 93.900. The ski resort nearly always draws water directly from the watercourse during November to February, but in the skiing season of 2016/2017 it also took a small amount of water during October 2016.

Table 15 shows monthly amounts of snowmaking water taken in 2009–2019.

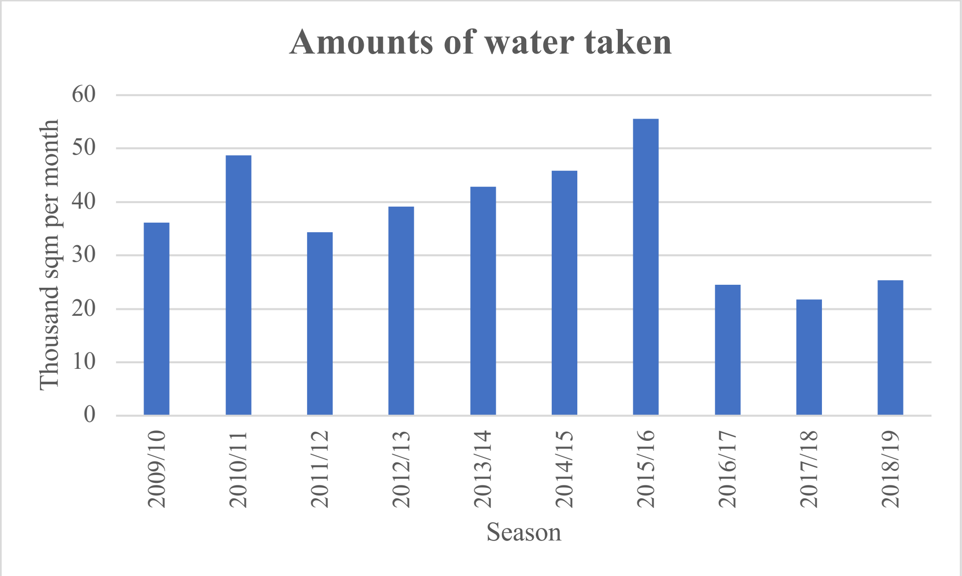
Table 15: Amounts of water taken for artificial snowmaking at the Ski Arena Karlov in 2009–2019

Amounts of water taken [thousand sqm per month]					
Season	**November**	**December**	**January**	**February**	**Total**
2009/2010	0	20	16.2	0	**36.2**
2010/2011	5	22.9	13.6	7.2	**48.7**
2011/2012	4.6	7.8	12.4	9.5	**34.3**
2012/2013	3.4	8.5	16.5	10.7	**39.1**
2013/2014	5	12.2	14.1	11.5	**42.8**
2014/2015	6	13	19.2	7.6	**45.8**
2015/2016	3.8	9.5	22.5	19.8	**55.6**
2016/2017	17.9	3.1	2	1.5	**24.5**
2017/2018	2	9.3	7.4	3.1	**21.8**
2018/2019	3.3	9.8	12	0.2	**25.3**

Source: Povodí Odry (Opava Branch), data processed by the author, 2021

The largest amount of water (55,600 sqm) was taken by the ski resort during the ski season of 2015/2016, while the smallest amount was taken in the ski season of 2017/2018, when the quantity of extracted water totalled 21,800 sqm. On average, the ski resort took 37,410 sqm per ski season in all of the years under review.

Figure 31: Amounts of water taken for artificial snowmaking at the Ski Arena Karlov in 2009–2019



Source: Povodí Odry (Opava Branch), data processed by the author, 2021

Table 16 shows data on hours of artificial snowmaking operation at the Ski Arena Karlov Resort in 2009-2019. During the reference period, the snow guns were operated in December and January to the largest extent.

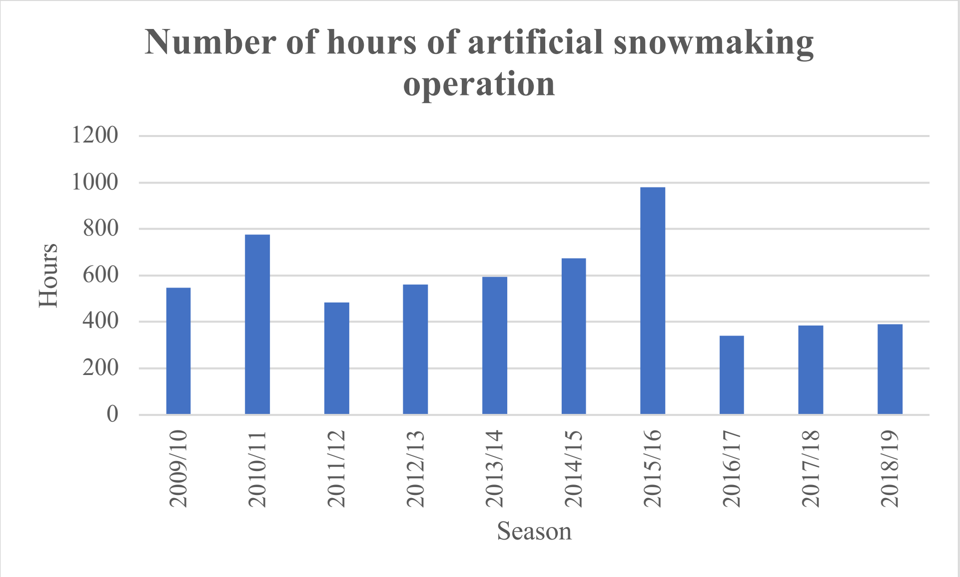
Table 16: Hours of artificial snowmaking operation at the Ski Arena Karlov Resort in 2009– 2019

Number of hours of artificial snowmaking operation [hours]					
Season	**November**	**December**	**January**	**February**	**Total**
2009/2010	0	321	226	0	**547**
2010/2011	131	360	210	75	**776**
2011/2012	71	101	175	138	**485**
2012/2013	30	186	200	145	**561**
2013/2014	80	175	190	150	**595**
2014/2015	95	185	260	133	**673**
2015/2016	65	170	456	288	**979**
2016/2017	192	60	50	40	**342**
2017/2018	33	157	145	51	**386**
2018/2019	59	172	153	7	**391**

Source: Povodí Odry (Opava Branch), data processed by the author, 2021

The snowmaking equipment was used the most during the skiing season of 2015/2016; the same period also accounted for the highest number of hours (456) within a single month in January 2016. The snow guns were operated during the season of 2016/2017 to the least extent (342 hours); during the reference period, the resort used the snow guns for an average of 573.5 hours per skiing season.

Figure 32: Hours of artificial snowmaking operation at the Ski Arena Karlov Resort in 2009– 2019



Source: Povodí Odry (Opava Branch), data processed by the author, 2021

Table 17 contains data on monthly aggregate sums of fresh snow at the Ski Arena Karlov Resort in 2009–2019.

Table 17: Fresh snow height aggregate sums per month at the Ski Arena Karlov Resort in 2009–2019

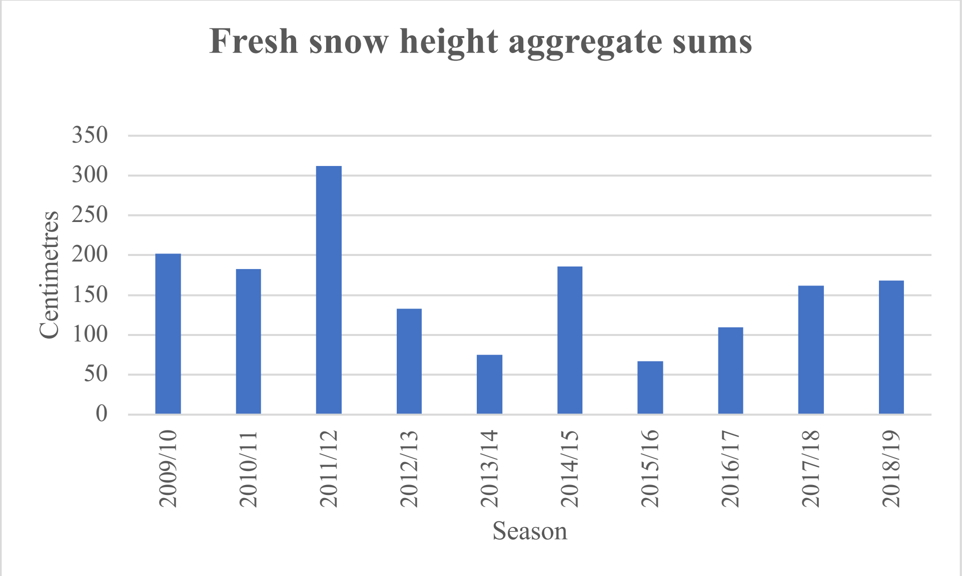
Fresh snow height aggregate sums per month [cm]					
Season	**November**	**December**	**January**	**February**	**Total**
2009/2010	11	32	119	40	**202**
2010/2011	13	117	46	7	**183**
2011/2012	0	70	158	84	**312**
2012/2013	1	24	33	75	**133**
2013/2014	34	36	4	1	**75**
2014/2015	1	37	116	32	**186**
2015/2016	5	0	32	30	**67**
2016/2017	14	21	67	8	**110**
2017/2018	29	46	62	25	**162**
2018/2019	3	49	103	13	**168**

Source: Czech Hydrometeorological Institute, data processed by the author, 2021

The maximum aggregate value for fresh snowpack (a total of 312 cm) was recorded during the season of 2011/2012, while the least was seen in the 2015/2016 season, at only 67 cm.

The month when the largest amounts of snow were witnessed was January – a total of 740 cm within the reference period.

Figure 33: Fresh snow height aggregate sums per month at the Ski Arena Karlov Resort in 2009–2019



Source: Czech Hydrometeorological Institute, data processed by the author, 2021

Table 18 shows data on average daily temperatures at the Ski Arena Karlov Resort in 2009–2019.

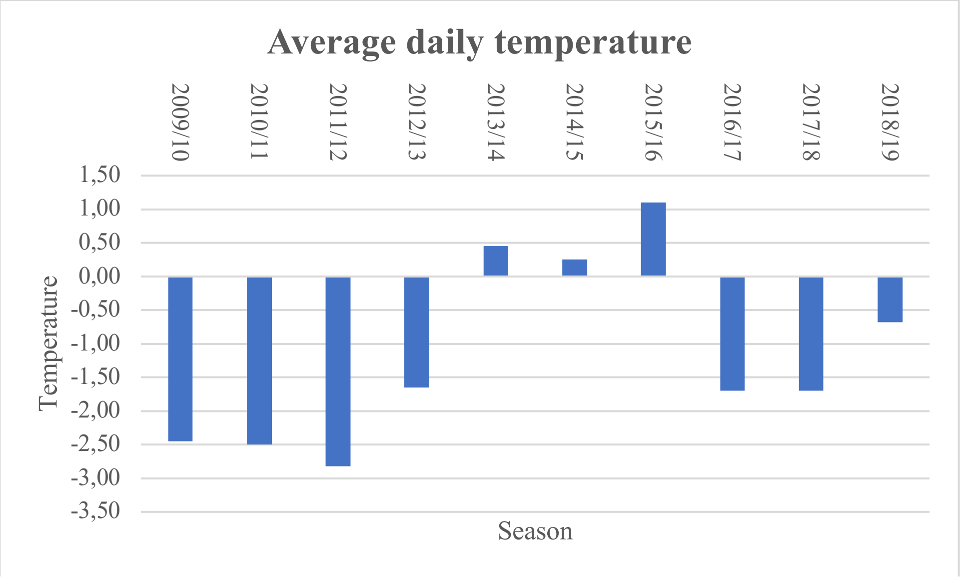
Table 18: Average daily temperatures at the Ski Arena Karlov Resort in 2009–2019

Average daily temperature [ºC]					
Season	**November**	**December**	**January**	**February**	**Average**
2009/2010	3.5	-2.6	-7.4	-3.3	**-2.45**
2010/2011	3.4	-6.4	-3.2	-3.8	**-2.50**
2011/2012	1.1	-1.2	-3.2	-8	**-2.83**
2012/2013	3.8	-3	-3.9	-3.5	**-1.65**
2013/2014	2.5	-0.1	-1.4	0.8	**0.45**
2014/2015	4.6	-0.6	-1.2	-1.8	**0.25**
2015/2016	4.2	2.5	-3.3	1	**1.10**
2016/2017	1.1	-1.5	-6	-0.4	**-1.70**
2017/2018	1.6	-1.4	-0.7	-6.3	**-1.70**
2018/2019	2.8	-1.4	-4.6	0.5	**-0.68**

Source: Czech Hydrometeorological Institute, data processed by the author, 2021

The highest average daytime temperature was observed during the skiing season of 2015/2016, when it reached 1.10°C. The lowest average temperature (–2.83°C) was encountered early in the reference period during the 2011/2012 skiing season, while January was the coldest month with an average daytime temperature of –3.49°C.

Figure 34: Average daily temperatures at the Ski Arena Karlov Resort in 2009–2019



Source: Czech Hydrometeorological Institute, data processed by the author, 2021

4.9 Analysis by panel regression

Panel regression was the preferred approach for analysing the effect of weather on snowmaking operations at the resorts. This specifically involved applying random/fixed effects and the weighted least squares methods. The table below shows the input data.

Table 19: Panel regression: Input data

SKI RESORT	SEASON	WATER	TEMPERATURE	SNOW
1	2011/2012	10.21	-2.03	65.00
1	2012/2013	18.69	-1.40	35.25
1	2013/2014	10.83	0.70	14.50
1	2014/2015	11.82	0.70	31.50
1	2015/2016	17.18	1.00	26.00
1	2016/2017	17.06	-2.00	39.50
1	2017/2018	19.59	-1.10	39.50
1	2018/2019	14.61	-0.68	42.50
2	2009/2010	9.05	-2.45	50.50
2	2010/2011	12.18	-2.50	45.75
2	2011/2012	8.58	-2.83	78.00
2	2012/2013	9.78	-1.65	33.25
2	2013/2014	10.70	0.45	18.75
2	2014/2015	11.45	0.25	46.50
2	2015/2016	13.90	1.10	16.75
2	2016/2017	6.13	-1.70	27.50
2	2017/2018	5.45	-1.70	40.50
2	2018/2019	6.33	-0.68	42.00
3	2012/2013	1.50	-3.25	56.50
3	2013/2014	2.75	-1.25	20.00
3	2014/2015	4.40	-2.30	28.25
3	2015/2016	2.48	-0.38	42.00
3	2016/2017	3.05	-3.68	42.25
3	2017/2018	3.27	-2.83	62.50
3	2018/2019	2.28	-2.73	64.25
4	2008/2009	0.31	-0.15	107.75
4	2009/2010	0.22	-1.05	69.50
4	2010/2011	0.28	-1.58	86.50
4	2011/2012	0.16	-1.10	133.25
4	2012/2013	0.18	-0.38	101.50
4	2013/2014	0.14	1.70	40.25
4	2014/2015	0.28	1.83	61.00
4	2015/2016	0.58	1.90	60.50
4	2016/2017	1.30	-1.20	66.75
4	2017/2018	1.24	-0.05	87.50
4	2018/2019	1.04	0.75	94.75

Source: Czech Hydrometeorological Institute, Branches, data processed by the author

SKI RESORT

1- Deštné v Orlických horách
2- Ski Arena Karlov Resort
3- Ski Kvilda Resort
4- Ski Aldrov Resort

WATER – Average amounts of water taken per month in the skiing season [thousand m3 per month]
TEMPERATURE – Average daily temperatures in the skiing season [°C]
SNOW – Average monthly increment in fresh snow in the skiing season [cm]

The average monthly amount of water extracted for snowmaking during the ski season was selected as a dependant variable, while the average daily temperature and the average monthly increment in fresh snow were designated independent variables.

4.9.1 Random effects

Figure 35: Random effects results

```
Random-effects (GLS), 36 observations
Included 4 cross-sectional units
Time-series length: minimum 7, maximum 11
Dependent variable: WATER

                     coefficient   std. error      z-score     p-
value
  ---------------------------------------------------------------------------
--
  Const.              11.1281      1.85972        5.984   2.18e-09
  TEMPERATURE   −0.316772     0.532864    −0.5945   0.5522
  SNOW              −0.0886615   0.0312777   −2.835    0.0046

Mean dependent var.   6.637694  S.D. dependent var.   6.138727
Residual sum of squares    921.6394   S.E. of regression
5.206442
Log-likelihood         −109.4492  Akaike criterion     224.8984
Schwarz criterion    229.6490    Hannan-Quinn         226.5565
rho                         0.069908   Durbin-Watson        1.694152

'Between' variance = 0.76104
'Within' variance = 5.62505
```

```
mean theta = 0.326124
corr(y,yhat)^2 = 0.331245

Joint test on named regressors -
  Asymptotic test statistic: Chi-square(2) = 8.1024
  with p-value = 0.0174015

Breusch-Pagan test -
  Null hypothesis: Variance of the unit-specific error = 0
  Asymptotic test statistic: Chi-square(1) = 37.1787
  with p-value = 1.07786e-09

Hausman test -
  Null hypothesis: GLS estimates are consistent
  Asymptotic test statistic: Chi-square(2) = 78.1751
  with p-value = 1.05803e-17
```

For the random effect method, the Hausman test value is $p < 0.05$, thus the null hypothesis is rejected. Random effect model is not consistent.

4.9.2 Fixed effects

Figure 36: Fixed effects results

```
Fixed-effects, 36 observations
Included 4 cross-sectional units
Time-series length: minimum 7, maximum 11
Dependent variable: WATER

             coefficient   std. error   t-ratio    p-value
  ----------------------------------------------------------
  Const.          7.43494      1.26324       5.886     1.92e-06 ***
  TEMPERATURE    0.0158516    0.406346     0.03901   0.9691
  SNOW         −0.0146957    0.0258881    −0.5677    0.5745

Mean dependent var.   6.637694   S.D. dependent var.   6.138727
Residual sum of squares    168.7515   S.E. of regression    2.371719
LSDV R-squared       0.872055   Within R-squared     0.017697
LSDV F(5, 30)       40.89518   P-value(F)          1.64e-12
Log-likelihood      −78.89014   Akaike criterion     169.7803
Schwarz criterion    179.2814   Hannan-Quinn        173.0964
rho                 0.069908   Durbin-Watson        1.694152
```

```
Joint test on named regressors -
  Test statistic: F(2, 30) = 0.270233
  with p-value = P(F(2, 30) > 0.270233) = 0.76504

Test for differing group intercepts -
  Null hypothesis: The groups have a common intercept
  Test statistic: F(3, 30) = 42.0325
  with p-value = P(F(3, 30) > 42.0325) = 7.30894e-11
```

The fixed effect model does not show any indication that, for the observed handles and years, a relationship is discerned between water extraction and new snow and average temperature.

The fixed effects model is not appropriate because the values for independent variables are not assume to be fixed.

4.9.3 Weighted least squares method

Figure 37: Weighted least square method results

```
WLS, 36 observations
Included 4 cross-sectional units
Dependent variable: WATER
Weights based on per-unit error variances

               coefficient   std. error   t-ratio   p-value
  ----------------------------------------------------------
  Const.          11.8333      1.54683       7.650    8.32e-09 ***
  TEMPERATURE    −0.578654    0.472788     −1.224     0.2297
  SNOW           −0.115510    0.0242985    −4.754    3.80e-05 ***

Statistics based on the weighted data:

Residual sum of squares    34.66883   S.E. of regression
1.024973
R-squared            0.416284   Adjusted R-squared   0.380907
F(2, 33)            11.76718   P-value(F)          0.000139
Log-likelihood      −50.40359   Akaike criterion     106.8072
Schwarz criterion    111.5577   Hannan-Quinn         108.4652

Statistics based on the original data:
```

Mean dependent var. 6.637694 S.D. dependent var. 6.138727
Residual sum of squares 899.8488 S.E. of regression
5.221891

The weighted least squares method can be applied in the case of heteroscedasticity. Based on weighted least squares method in panel regression, it is possible to interpret the following: when the snow cover increases by 1 unit, then water extraction goes down by 115 m3. R square d is relatively low, meaning that other variables influence water extraction.

4.9.4 Back testing of panel regression

According to the information provided by the staff of the unnamed ski resort, the snowmaking equipment can produce up to 2.5 m3 of technical snow from 1 m^3 of water. Taking the result of the previous panel regression into account, where 115 m^3 water is saved with every centimetre of fresh snow, the capacity exists to produce 287.5 m3 of artificial snow from such an amount of water under ideal conditions, which is equal to the surface area of 2.875 ha for a snow cover height of 1 cm. This subsequently corresponds well with the result of the previous panel regression for a smaller ski resort, such as one of the selected complexes, i.e. SKI Kvilda, which is equal to a ski resort extending over 3 ha of surface area.

4.9.5 Energy savings

The panel regression results make it possible to calculate the potential energy savings if there is enough fresh snow and the snowmaking equipment does not have to be operated. One snow gun is capable of pumping 1 m3 of water in 2.5 minutes. With the 115 m^3 saved, this saves 287.5 minutes of operation per snow gun. Taking the sample of a snow gun referred to in the first chapter of the thesis into account, a unit consuming 22 kW per hour, the resulting saving is 105.42 kW.

4.10 Warming in temperature over the past 56 years

The Harrachov Mountain Resort and the capital city of Prague were selected to illustrate the different rates of warming in the mountains and in a city located in a lower-elevation zone over the past 56 years.

Table 20: Average daily temperatures in Harrachov and Prague in 1964–2019

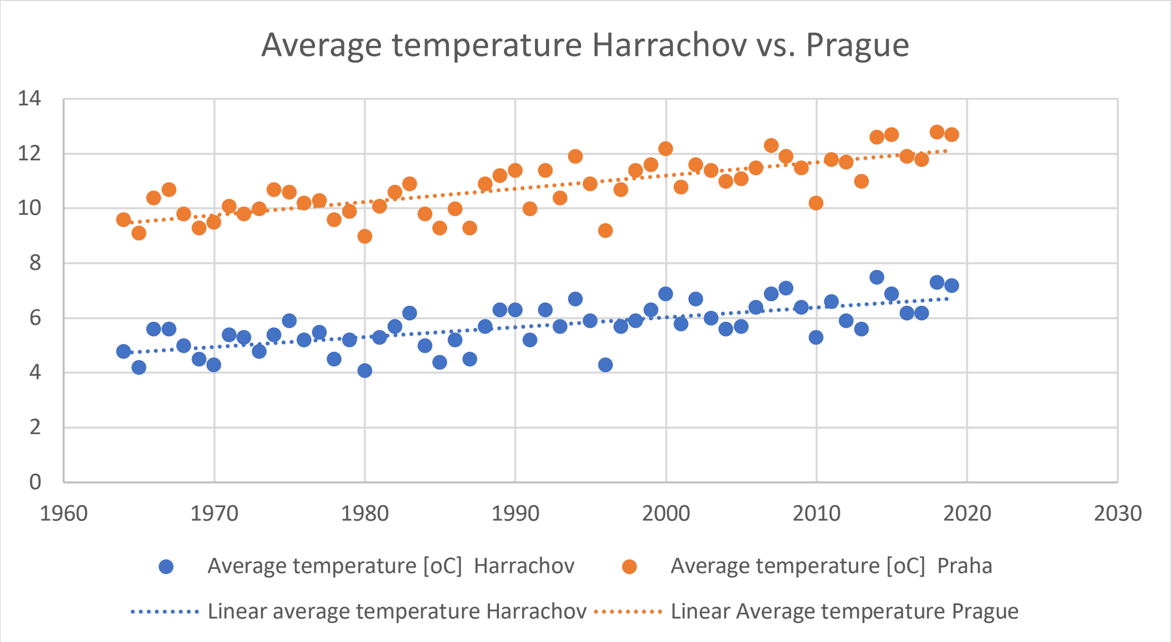
Year	**Average daily temperature [^oC] Harrachov**	**Average daily temperature [^oC] Prague**
1964	4.8	9.6
1965	4.2	9.1
1966	5.6	10.4
1967	5.6	10.7
1968	5	9.8
1969	4.5	9.3
1970	4.3	9.5
1971	5.4	10.1
1972	5.3	9.8
1973	4.8	10
1974	5.4	10.7
1975	5.9	10.6
1976	5.2	10.2
1977	5.5	10.3
1978	4.5	9.6
1979	5.2	9.9
1980	4.1	9
1981	5.3	10.1
1982	5.7	10.6
1983	6.2	10.9
1984	5	9.8
1985	4.4	9.3
1986	5.2	10
1987	4.5	9.3
1988	5.7	10.9
1989	6.3	11.2
1990	6.3	11.4
1991	5.2	10
1992	6.3	11.4
1993	5.7	10.4
1994	6.7	11.9
1995	5.9	10.9
1996	4.3	9.2
1997	5.7	10.7
1998	5.9	11.4
1999	6.3	11.6

2000	6.9	12.2
2001	5.8	10.8
2002	6.7	11.6
2003	6	11.4
2004	5.6	11
2005	5.7	11.1
2006	6.4	11.5
2007	6.9	12.3
2008	7.1	11.9
2009	6.4	11.5
2010	5.3	10.2
2011	6.6	11.8
2012	5.9	11.7
2013	5.6	11
2014	7.5	12.6
2015	6.9	12.7
2016	6.2	11.9
2017	6.2	11.8
2018	7.3	12.8
2019	7.2	12.7

Source: Czech Hydrometeorological Institute, data processed by the author, 2021

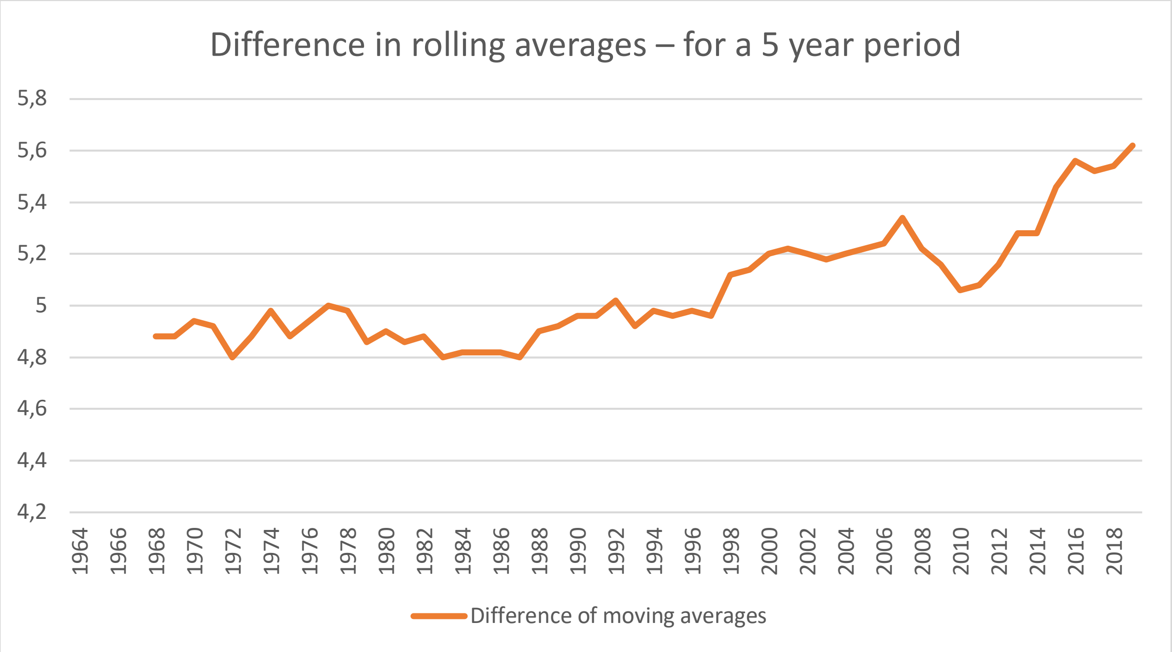
The graph below shows the average temperature at both selected locations along with a linear function of average curve with. This is followed by graphs showing rolling average differences, using successively a period of 5 years and one of 10 years.

Figure 38: Average yearly temperature with linear function



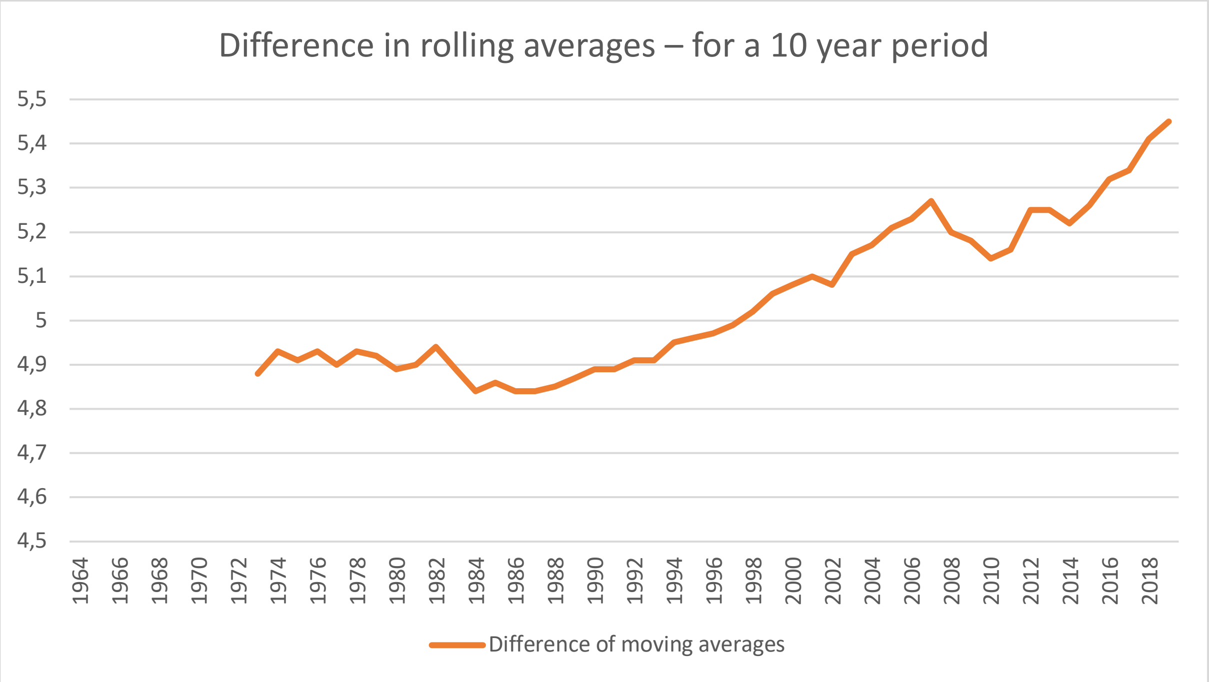
Source: Czech Hydrometeorological Institute, data processed by the author, 2021

Figure 39: Difference in rolling averages for Harrachov and Prague – for a 5 year period



Source: Czech Hydrometeorological Institute, data processed by the author, 2021

Figure 40: Difference in rolling averages for Harrachov and Prague – for a 10 year period



Source: Czech Hydrometeorological Institute, data processed by the author, 2021

The graph mentioned above, which shows the difference in the rolling average annual temperatures in Harrachov and Prague within the 10-year period chosen, clearly shows a rise that differentiates the temperatures. The graph implies that the rate of warming in these two places differs. The tendency in the graph is clearly one of increase, albeit with fluctuation; the first case extends from 1982 to 1984, while the second major swing occurred in 2007 to 2010. These marked decreases in tendency are due to marked changes in average temperature in the years monitored.

4.11 Electricity utilized for snowmaking

The SKICENTRUM Resort in Deštná v Orlických horách was selected to evaluate the costs of electricity consumption for snowmaking.

According to the information available, resorts similar in scope to this one never need to draw upon maximum capacity for snowmaking; instead around 20–30 pieces of equipment are employed at a time. The snow lance to snow gun ratio is 10:1. The following model of external artificial snowmaking costs is based on this information.

Table 21: Hours of artificial snowmaking operation per ski season at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019

Season	**Number of hours of artificial snowmaking operation [hours]**
2011/2012	502
2012/2013	706
2013/2014	406
2014/2015	379
2015/2016	676
2016/2017	692
2017/2018	702
2018/2019	491

Source: Povodí Labe (Pardubice Branch), data processed by the author, 2021

Table 22: Hourly electricity consumption for each piece of artificial snowmaking technology

Device	**Energy consumption [kW per h]**
Snow gun	22
Snow lance	4.01

Source: technoalpin.com, data processed by the author

The model applies a price of 3.60 CZK per kWh for the SKICENTRUM Resort in Deštná v Orlických horách, which corresponds to the situation in 2021. Under circumstances of 30 snowmaking devices running simultaneously, of which 27 were snow lances and 3 were snow guns, the combined hourly consumption of electricity is 174.27 kW. At the given price, the cost for electricity per hour of snowmaking is 627.37 CZK.

The following table details electricity consumption for each skiing season.

Table 23: Amounts of electricity taken for artificial snowmaking at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019

Season	**Energy consumption [kW per h]**
2011/2012	87,484
2012/2013	123,035
2013/2014	70,754
2014/2015	66,048
2015/2016	117,807
2016/2017	120,595
2017/2018	122,338
2018/2019	85,567

Table 24: Cost of electricity taken for artificial snowmaking at the SKICENTRUM Resort in Deštné v Orlických horách in 2011–2019

Season	**Cost of electricity taken for artificial snowmaking [CZK]**
2011/2012	314,941
2012/2013	442,925
2013/2014	254,713
2014/2015	237,774
2015/2016	424,103
2016/2017	434,141
2017/2018	440,415
2018/2019	308,040

Thus, on average, expenditure on electricity for this purpose at the SKICENTRUM Resort in Deštná v Orlických horách in 2011–2019 equalled 357,131 CZK during the skiing season. In this case, it is only a model of certain conditions based on data from another similarly sized resort in the Czech Republic; specific figures with respect to the cost of snowmaking are not generally disclosed by ski resorts.

4.12 Amounts of water taken based on average monthly temperature

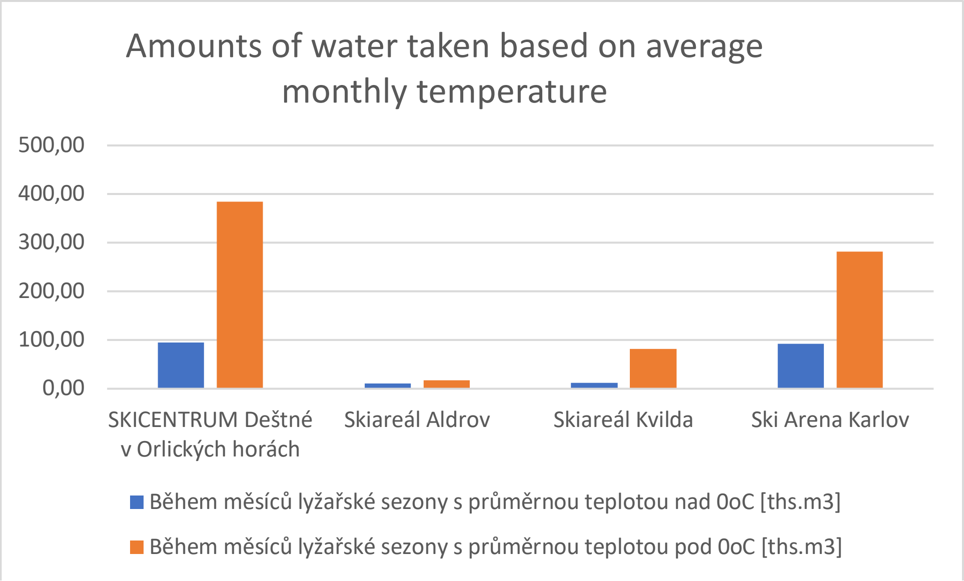
In the selected ski resorts, the amounts of water extracted for snowmaking were examined based on average monthly temperatures. The following table lists the data for each ski resort.

Table 25: Amounts of water taken based on average monthly temperature

	Amounts of water taken	
Ski resort	During the months of the ski season, with an average temperature above 0ºC [thousand sqm]	During the months of the ski season, with an average temperature below 0ºC [thousand sqm]
SKICENTRUM Resort in Deštné v Orlických horách	95.55	384.46
Ski Aldrov Resort	10.71	17.31
Ski Kvilda Resort	12.74	81.59
Ski Arena Karlov Resort	92.00	282.10

The table shows that all the ski resorts peaked in utilization of extracted water in months when the average temperature was below 0°C. Under freezing conditions, the efficiency of snowmaking is significantly greater than otherwise, which is why the ski resorts seek to make the most of the situation.

Figure 41: Amounts of water taken based on average monthly temperature



5 Results

There are several results of this thesis. The panel regression using the weighted least square method demonstrates the dependence of water taken for artificial snow in selected ski resorts on weather. To be more specific, if there is 1cm of snowfall, 115m^3 of water is saved.

Thanks to the rolling averages of the average year temperature of two different places (Harrachov and the capital city Prague) the different pace of warming was proven.

The cost simulation of electrical energy for the production of artificial snow in SKICENTRUM Resort in Deštná in the Orlické Mountains was on average 357,131 CZK per season of the monitored period. The maximum theoretical expenses was 442,925 CZK and minimum 237,774 CZK.

The final chapter confirms the initial hypothesis. The assumption was that ski resorts use bigger part of water for the production of artificial snow during months with lower average temperature.

6 Conclusion

Reviewed literature showed that snowmaking may have negative effects on the environment, one being a threat to species of plants and animals through extending the skiing season. As a result of increased amounts of snow on the slope, there is also a risk of possible soil erosion as the snow melts in the spring. The energy required to produce artificial snow constitutes a significant impact, which is a considerable burden in terms of electricity consumption. Also, a large amount of water is taken from watercourses, which is not subject to any charge in the Czech Republic at present, as merely the quantity is regulated by the respective water authorities. Fortunately, it is forbidden in the Czech Republic to use additives to make artificial snow, so no further negative effects are manifest through this. The author focused in this thesis on discerning the negative effects of snowmaking in the first part of the paper, while the second part investigates links between the state of weather and the amount of water extracted for snowmaking at four ski resorts in the Czech Republic. Attention then turns to associated energy requirements, differences in the rate of heightening temperatures at the Harrachov Mountain Resort and the capital city of Prague over the last 56 years, and analysis is made of the amounts of water extracted in relation to average monthly temperature at the respective ski resorts.

Using the panel regression approach, namely the weighted least squares method, a connection was found between the state of weather in the ski resorts studied, the amount of water taken and the height of fresh snowpack in 2008–2019, all in the form of monthly data per skiing season (November to February). More specifically, 115 m3 water needed for snowmaking is saved with every centimetre of fresh snow. This result was then back-tested and found relevant for a ski resort of approximately 3 ha, which in the present case is equal to the selected ski complex of SKI Kvilda.

For the SKICENTRUM Resort in Deštné v Orlických horách, the modelling of electricity demanded for snowmaking showed an average cost of 357,131.50 CZK per ski season in 2011–2019. The average electricity consumption in the reference period was 99,203 kW.

The Harrachov Mountain Resort and the capital city of Prague were chosen to illustrate the different rates of warming in temperature over the past 56 years. Research shows thatPrague is warming at a faster rate than the mountain resort. This may have implication for snowmaking at czech ski resorts for the future.

In the last chapter, the author analysed the amounts of water taken by individual ski resorts for snowmaking, depending on the average monthly temperature during the skiing season. This analysis clearly shows that the ski resorts take water much more frequently in months with an average temperature below 0ºC compared with situations when the temperature is above 0ºC. In the case of the SKICENTRUM Resort in Deštné v Orlických horách, this difference is four times higher, while for the Ski Kvilda Resort it is even 6.4 times higher. This finding is logical, as in freezing temperatures the efficiency of snow equipment is greater, thus ski resorts seek to produce as much artificial snow as possible at such cold temperatures.

In conclusion, the problem related to snowmaking are most likely going to worsen in the future. Global climate change may shorten the lenght of winter skiing season, thus creating the need for greater volumes of artificial snow and extracted water. Policy makers should carefully acces current policies related to water extraction for snowmaking, since according to literature review snowmaking making may threaten ecosystems.

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