Energy usage for snowmaking

A review of the energy use of mobile snowmaking at Swedish ski resorts

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Summary

The interest for cross-country skiing has increased significantly as an outcome of the extensive amounts of snow during the last two cold winters of 2009 and 2010. The increasing popularity for the sport of skiing is obvious among ski clubs and associations making attractiveness of the sport clear. Snow is required to be able to perform this sport. Despite two good winters, with plenty of natural snow, there is a need for complementary snowmaking. The season for skiing, cross-country as well as down-hill, is getting longer and kicks off in early autumn. When natural snow is lacking the option is to use snowmaking to improve conditions. However, snowmaking is an energy demanding process.

Energi & Kalkylanalys AB working in cooperation with the Swedish Cross-Country Ski Association, the Country Administrative Board of Dalarna, and the Energy Authority TestLab carried out an extensive test of the energy usage of snow guns at Swedish cross-country ski facilities. The project has been run as a part of GREEN – *A borderless energy work*. The objective of the tests have been to investigate how much energy is being used for the making of snowmaking with mobile snow guns. The project also aims at investigating the opportunities of reducing the energy usage at snowmaking.

The test is divided into two parts; one part consists of a theoretical pre-study and the other of measurements and trials. In the pre-study statistics are compiled regarding energy usage from snowmaking at Swedish cross-country ski facilities. The purpose of the pre-study was to gain an insight in the present situation in Sweden. Previous test results from trials with snow guns were also included. The results from the pre-study indicate a wide range of different expenditures of energy. In total, input from 80 responders from 100 approached facilities was compiled. Of the 80 facilities that answered the questionaire approximately 30 of them provided information for energy usage as well as produced volume of snow. The results indicate that approximately 3,5 to 4,3 kWh electricity is consumed per m^3 snowmaking. However, the variations were significant between the answers and ranged from 1 kWh/m^3 snow to 14 kWh/m^3 snow. Results from earlier tests with mobile snow guns conducted in Lech, Austria, were also analyzed.

A substantial part of the project was conducted through practical tests and measurements. The tests were carried out at the ski arena *Lugnet* in Falun, Sweden, to verify the energy usage of the mobile snow guns. The tests were performed at two occasions, during 5 days in total, with a fluctuating ambient temperature. At the first occasion snowmaking was at marginal temperatures (i.e. a ambient temperature of around -2°C to -3°C). At the later occasion the temperature varied between -20°C and -6°C. In total 19 tests were conducted with 9 different snow guns, both lances and fan guns were represented. It was possible to test three snow guns in parallel with the existing survey equipment. Each test measured the snow guns energy usage, electricity effect, water flow, water temperature and pressure. The produced volume of snow from each snow gun was determined by two different methods.

The results regarding capacity as well as energy usage are differentiated between the lances and the fan guns. A lance lacks a fan for spreading the snow, which in turn reduces the

energy consumption compared to a fan gun. If one looks at the energy usage for lances, it took between 0,58 – 0,72 kWh electricity to produce 1 m^3 snow. Equivalent figure for the fan guns was 0,97 – 1,94 kWh/m^3. If instead the snow production capacity (produced volume of snow per hour) is compared - the ratio gets reversed. The snow production capacity for the lances in the test varied between 13 – 22 m^3/hour, while the snow production capacity for the fan guns varies between 15 – 34 m^3/hour. The presented results apply to the specific equipments that were tested under these particular circumstances. Factors such as water pressure and length of the lances does also have an impact; increased pressure and length normally intensify the production.

The purpose of the review was to show the potential for energy savings with the use of “new” compared to “old” snowmaking. The results from the tested equipments show that a “new” snow gun uses around 1,1 kWh electricity/m^3 snow and produce around 20m^3 snow/hour. From the results it has been possible to find out that there is potential for energy saving on local as well as national level. The pre-study showed that a representative snow gun (located in a cross-country ski area somewhere in Sweden) on average uses 3,5 to 4,3 kWh electrical energy/m^3 to make snow. The same snow gun produces, according the study, approximately 7 500 m3 per year.

Looking at energy use, this means that between 25 500 – 32 250 kWh is used during one season. A corresponding new snow gun would produce the same amount of snow (7 500 m3) with 8 250 kWh electricity (based on the mean value of 1,1 kWh/m^3 snow). For a single ski area this would mean an energy saving equal to 17 250 to 24 000 kWh per year, which corresponds to a 70 percent reduction. With a presumed energy price of 1,2 SEK/kWh this results in a cost saving of between 21 000 – 29 000 SEK/year. Looking at all 100 cross-country ski areas in Sweden with snowmaking, this corresponds to an energy saving of 1,7 – 2,4 GWh/year.

Energi & Kylanalys

Preface

First of all the authors would like to thank the Country Administrative Board of Dalarna, Anna Lindström, and the Energy Authority TestLab, Lara Kruse, for believing in us to carry out this review.

We would also like to give a warm thank you to all the staff at Lugnet in Falun, the national director of the ski association Per-Åke Yttergård and Åke Albinsson for their work and sharing of information.

Last, but not least, would we like to thank Kenneth Weber (ETM Kylteknik) and the suppliers of Areco, Vinterteknik, Snowtech and JL Toppteknik for their contribution to make these tests possible.

Jörgen Rogstam & Mattias Dahlberg

Älvsjö, 1 April 2011

Energi & Kylanalys

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1 INTRODUCTION

Energi & Kylanalys have together with the Swedish Ski Association mapped out the energy used for snowmaking with snow guns. The survey has included one theoretical part, where statistics from questionaires regarding energy usage in Sweden have been compiled. The survey has also included a practical part, were the energy use of different models of snow guns has been analyzed through different tests and measurements.

The main part of the funding for this project has come from the Country Administrative Board of Dalarna and through the project of GREEN. The Energy authority Testlab has contributed the remaining financial support.

Steering committee of the project:

Jörgen Rogstam, Project manager	Energi & Kylanalys
Anna Lindström, Project manager GREEN	Länsstyrelsen Dalarna
Per-Åke Yttergård, National director	Skidförbundet
Mattias Dahlberg, Project engineer	Energi & Kylanalys
Lara Kruse, Administrator	Energimyndigheten Testlab
Suppliers:	Areco
	JL Toppteknik
	Vinterteknik
	Snowtech

1.1 Background

The interest for cross-country skiing has increased during the last cold winters with plenty of snow. No one knows if the next winter will offer as beneficial weather for skiing, but the interest for cross-country skiing will most likely prevail.

There is a general desire to make the season for winter sports longer and longer. That the ski slopes will be open from early autumn to the end of April, after Easter, is almost taken for granted – and the same goes for cross-country skiing. When the natural snow is lacking, especially at the beginning and the end of the season, the complement of snowmaking become crucial. There can also be a need for complementing the natural snow with snowmaking during the season. However, to produce snow is an energy- and resource demanding process.

There are around 100 cross-country ski facilities that use snowmaking in Sweden today. What type of equipment that these facilities use for snowmaking is unknown. How much energy that is consumed and the cost for snowmaking is also unspecified. Earlier studies indicate that an average snow gun of older model consume approximately 4-5 kWh el/m^3 snow. A modern snow gun produce, according to our information, approximately 1-2 kWh el/m^3 snow. Depending on the situation on national as well as local level are there great opportunities to energy efficiency in snowmaking. These are some of the objectives behind this review.

1.2 Purpose

The primary purpose of the review has been to compile knowledge approximating energy consumption at snowmaking. It also aims to raise the awareness of possible strategies of energy efficiency.

This gives the opportunity for ski associations to compare their own costs of energy per m^3 of snow with the average costs of ski facilities in Sweden. The purpose of the review has also been to create a blueprint to calculate energy costs.

Based on the information in this report the energy consumption and the cost of energy from an existing snow gun can be compared to the consumptions and cost of a new snow gun. The reader is able to convert possible savings into financial figures.

1.3 Objective and expected result

The objective of the report has been to conduct a comprehensive review of the energy usage in the process of snowmaking. The overall aim has been to include a wide theoretical survey that presents the actual situation regarding snowmaking at cross-country ski facilities. Another component was to carry out objective tests and measurements to determine how modern snow guns perform.

The sub targets of the report have been to:

- Compile statistics to describe the current situation at Swedish cross-country ski facilities regarding energy usage.
  <u>How much energy does an existing snow gun consume when it produces snow?</u>

- Compile results from earlier conducted surveys/tests/reviews concerning snowmaking; this to be able to compare external data to the test results from this report.
  How have earlier tests been conducted? How can those tests be improved? What results has come out of those tests?

- Conduct tests regarding energy usage with different brands of snowmaking with the purpose to create comparable key figures.
  <u>How much energy does average modern snowmaking consume during the production of snow?</u>

- Create a list of proposals of energy efficiency strategies that can be applied by a cross-country ski area with snowmaking.
  <u>What arrangements can be made by a cross-country ski area to save energy?</u>

- Specify the possible energy savings potential perceived from a local to a national perspective.
  How much energy can be saved?

1.4 Disposition

The report consists of two parts - the first part present the pre-study and the second part lays out the design and the results of the tests. Then follows a discussion of the tests and the results. The conclusions that have been made out of the pre-study and the test results are presented at last.

The content of the pre-study consist of earlier conducted tests and reviews, and a comprehensive statistic summary of the answers to the questionnaires. The earlier test results that have been taken into account are primarily from the trials that are conducted in Lech, Austria, every third year. The statistics are compiled from the answers of the questionnaires that were sent to cross-country ski facilities in Sweden.

The second part of the report presents the extensive practical part of the project, including design and test results. For the reader that is satisfied with a summation rather than details from every test - a summary is presented in the end of this part.

2 Pre-study

The purpose of the pre-study has been to create an understanding of the energy usage regarding snowmaking in Sweden. Also to learn from earlier, if any, surveys that has been conducted on the subject.

The first part of the pre-study presents an outline of the snowmaking facilities that exists for cross-country skiing in Sweden. The review has been conducted by the Swedish Cross-Country Ski Association and the information has been processed through this project.

The project has sought information from other reviews of snowmaking. The objective was to find both methods and results that were relevant for this project. Later in the report it will be evident that two test references with documentation have been found.

2.1 The cross-country ski tracks of Sweden with snowmaking – environment and standard

In the document *"Sveriges snökanonspår – miljö och standard"* (Sweden's snowmaking tracks – environment and standard) several facts presented by Swedish snowmaking facilities are presented. The project behind this report has chosen to lift out and use relevant facts of energy usage in the process of snow production. In the document are other activities related to snowmaking that these facilities set out, i.e. loading and movement of snow, but these activities have not been taken into account.

The inventory was conducted through questionnaires that were sent to all known facilities in the country. The outcome showed that there are approximately 100 Swedish cross-country ski facilities that have snowmaking equipment. Approximately 70 percent of these 100 facilities have, to different extent, answered the questionnaires.

Figure 2-1: Example of mobile snowmaking (source: www.lenkosnow.com).

2.2 Snow production at snowmaking facilities in Sweden

The questionnaire that was given to Swedish cross-country ski areas included questions such as:

- *Does the ski area use snowmaking to produce snow?*
- *In that case – how many, and what type of snowmaking equipment is used?*
- *How much snow does this snowmaking equipment produce?*
- *How much energy and water does the snowmaking consume?*
- *At what temperature does the production of snow begin?*

The outcome of the questionnaires shows that both lances and fan guns are commonly used among Swedish ski facilities; 43 facilities answered that they have lances, 35 facilities answered that they have fan guns and 6 facilities answered that they have both lances and fan guns.

Figure 2-2 illustrates the results from the inventory, where the volume of produced snow per season is declared for each ski area. In average are approximately 7500m^3 snow/season produced, based on the answers from 53 facilities. However, the mean value is dramatically enhanced by one ski area. Corresponding median value are significantly lower at approximately 5000m^3 snow/season.

The answers from the questionnaires indicate that there are different judgments concerning temperature; at what temperature the snowmaking should start. The average opinion states that approximately – 5.5° C is a reasonable temperature to start at.

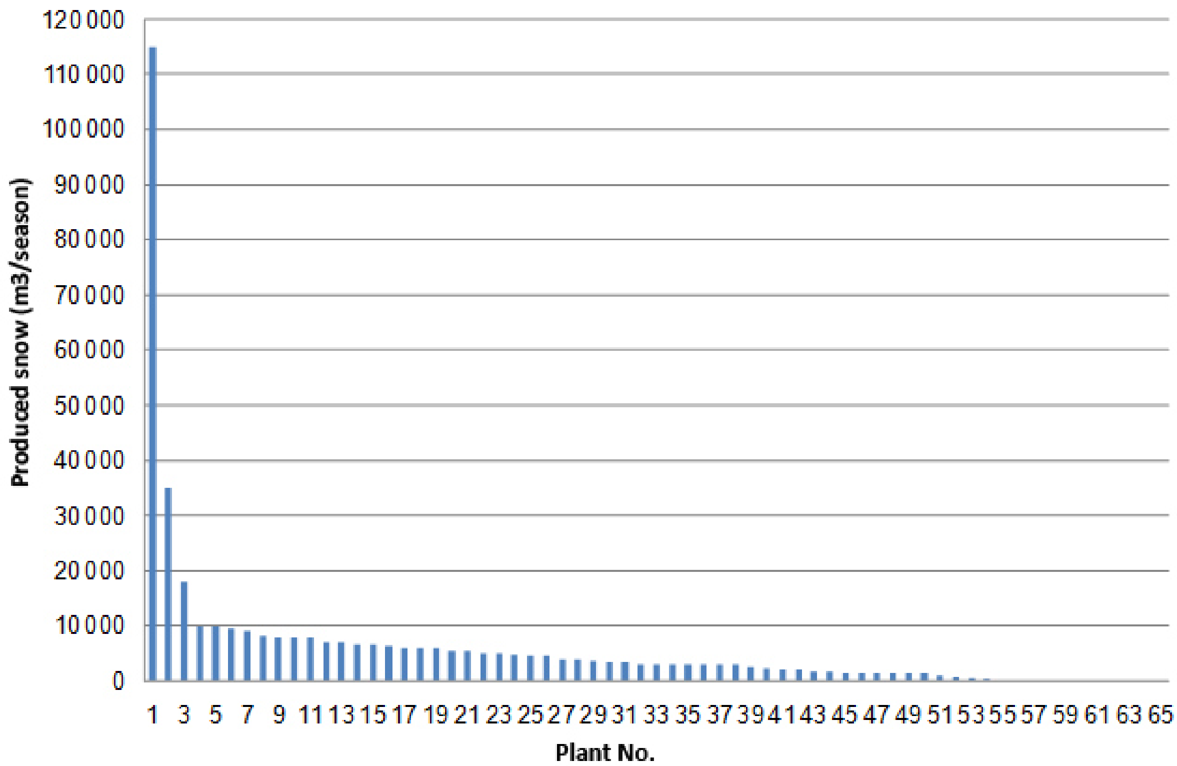


Figure 2-2: Snow production at Swedish cross-country ski areas.

To sum up could it be concluded that around 500 000 – 750 000 m^3 of snow are produced yearly at Swedish cross-country ski areas. The figures are based on the mean and median values of the ski areas that answered this particular question. The values are regarded as representative for all the 100 ski areas that use snowmaking. On top of this are there ski areas and events such as "Vasaloppet", when normally approximately 60 000 m^3 of snow are produced.

The alpine ski areas are not included in this survey, but represent in absolute numbers a substantially greater snow production. In this project is exclusively mobile snowmaking for cross-country ski areas studied.

2.3 Energy usage at the ski areas

In the questionnaires the amount of consumed energy is asked for, but this is usually not exactly measured or followed up. 33 ski areas provided an estimation of the energy use in kWh or in SEK (Swedish currency). To simplify the estimations 1 kWh = 1 SEK was used in the calculations, these results are in Figure 2-3. The figure show the yearly energy use per ski area. The spread of results are naturally considerable, since the energy usage is depending on factors such as variations in production of snow, type of equipment and climate conditions.

To be able to put this energy usage in relation the calculation is based on key figures of used energy per unit of volume-produced snow ($kWh_{electricity}/m^3_{snow}$). In 31 cases there is data for both production-volume and energy usage. In one case an unreasonable number occurred (33 $kWh_{electricity}/m^3_{snow}$), which has been deleted from the statistics. The results are declared in Figure 2-4.

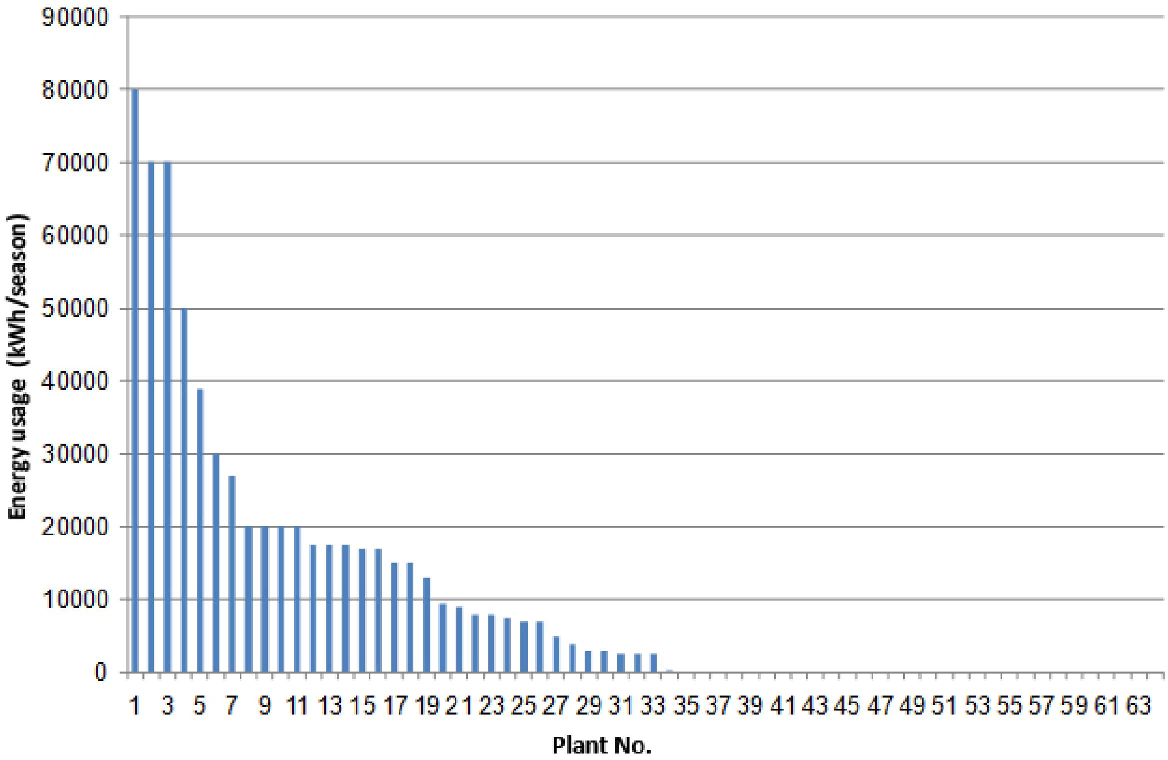


Figure 2-3: Energy usage (electricity) in kWh/season at the approached ski areas.

What appears in the figure above is that the differences are considerable and that the value varies between 1 to 14 $kWh_{electricity}/m^3_{snow}$. The variations depend most likely at the uncertainty in the estimations and the different conditions at the ski areas.

The mean value from the 30 ski areas has been calculated to 4.3 $kWh_{electricity}/m^3_{snow}$ and the corresponding median to 3.5 $kWh_{electricity}/m^3_{snow}$.

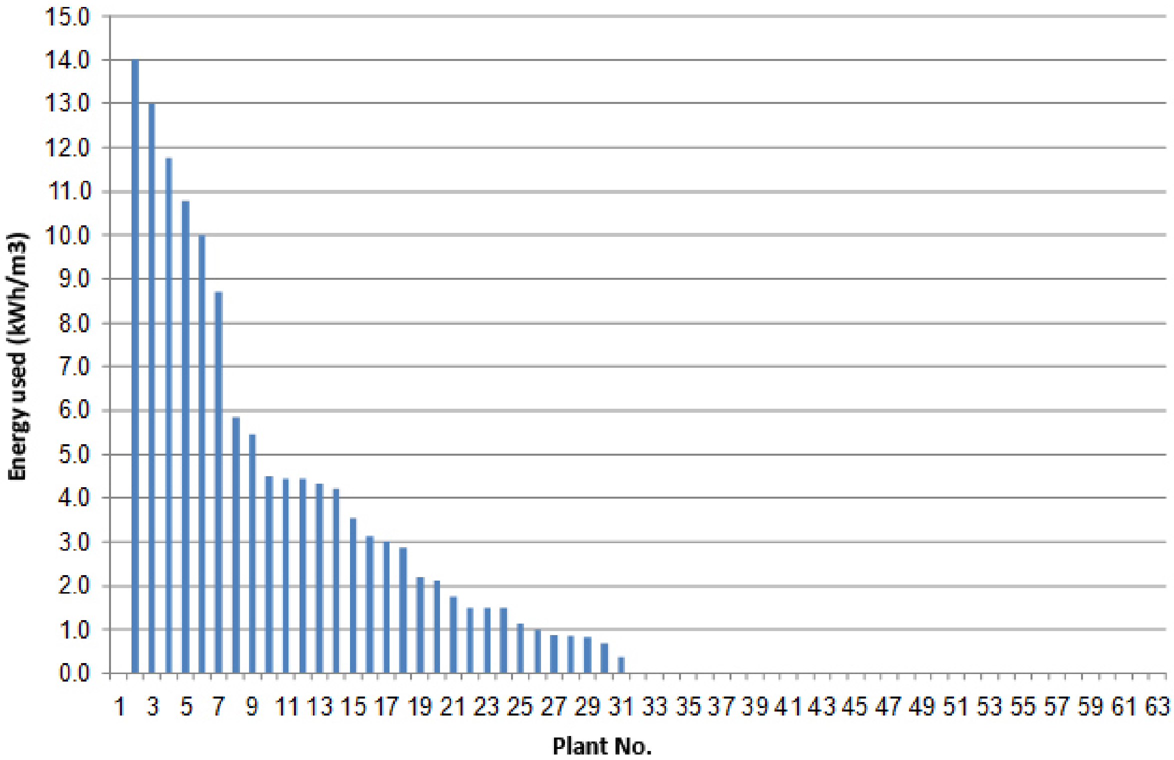


Figure 2-4: Energy usage per produced volume of snow (kWh/m³).

2.4 Summary of results

The questionnaires resulted in the following outcome:

- Number of cross-country ski areas with snowmaking: **100**
- The total snow-volume per year:
  - Mean value: approximately **7 500 m^3** per ski area
  - Median value: approximately **5 000 m^3** per ski area
- Energy usage – 30 ski areas:
  - Large variation: 1 - 14 $kWh_{el}/m^3_{snö}$
  - 3.5 – 4.3 $kWh_{electricity}/m^3_{snow}$ (median – mean value)

2.5 Snowmaking and methods of testing

This section presents a summary of available data for snowmaking euipment. The following part do also deal with earlier tests and results from those.

2.5.1 The Lech tests – method

Performance tests of snowmaking equipment is conducted in Lech, an Austrian ski resort. The last test was completed in 2009. The aim that these tests should be conducted every 3 years is stated in the test report.

Some criticism has been directed towards the test execution. In 2009 did not Techno Alpine and DEMAC participate, despite attempt of "persuasion". Otherwise, participates most of the major players in the industry. 20 snowmaking equipment were present in 2009. All equipment was tested on two occasions to cover different ambient temperatures and conditions.

Figure 2-5: Pictures of the Lech tests.

Each test is performed in a total of 30 minutes. The first 15 minutes are used for startup and adjustment. Then the snowmaking goes on further for 15 minutes in manual mode for the measurement itself. Furthermore, is the aim in the tests to achieve a snow density of 400-500 kg/m^3. The density is measured at three points in front of the snowmaking. These measurments is subsequently evaluated with respect to density and snow depth. Since the density is the important measurement parameter for the outcome, is the density weighted in terms of snow depth at each measuring point.

After analyzing the test results from these tests it was found that there is rarely a large difference in density between the measurement points during a specific test. The measurment equipment is designed with a "swamp" in which any free water from the snow could be detected. However, no water was found during the tests conducted in 2009.

The volume of water and electricity are measured in purpose for the evaluation. In the case of electrical energy, is the energy measured with energy meters to each snowmaking unit. Energy useage from the central services such as air compressors and water pump are determined by calculation. The total energy is the sum of the measured and calculated values. These are reported separately in the minutes along with foreclosed climate data. Also the noise level for each unit is measured and recorded. The produced snow is calculated from water flow and snow density measurment where the weighted average value is used.

2.5.2 The Lech tests – results

In the following section is the results from tests in Lech compiled to obtain a comparative basis for their test results. As mentioned earlier, did 20 equipments participate and all were tested two times, generating about 40 measuring points. Figure 2-6 shows the results from the density measurements was developed in the tests in 2009. The figure illustrates how the medium density in the tests varied with the ambient dew point. It is noted that the desired density was achieved quite well with a mean of 432 kg/m^3.

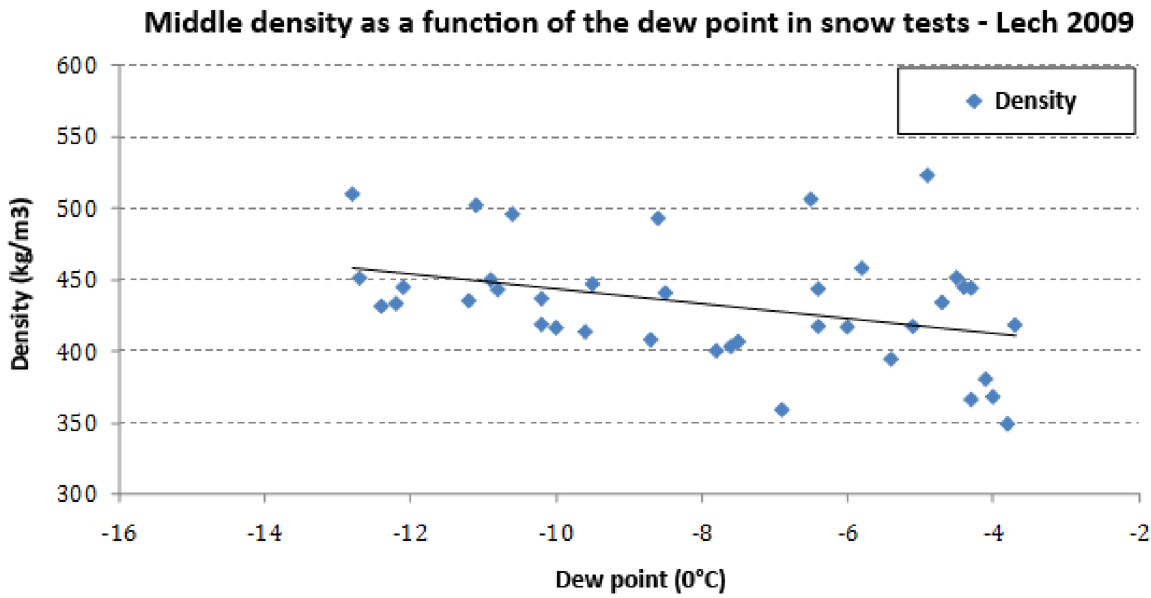


Figure 2-6: The snow density vs. dew point for all Lech tests.

Figure 2-7 presents the snow capacity (the volume produced snow per hour) for each snow gun as a function of the dew point. At first glance, the figure is considered to be a bit unclear when all test results are presented. The figure is primarily meant to illustrate the trend, ie. snow increases with decreasing dew point.

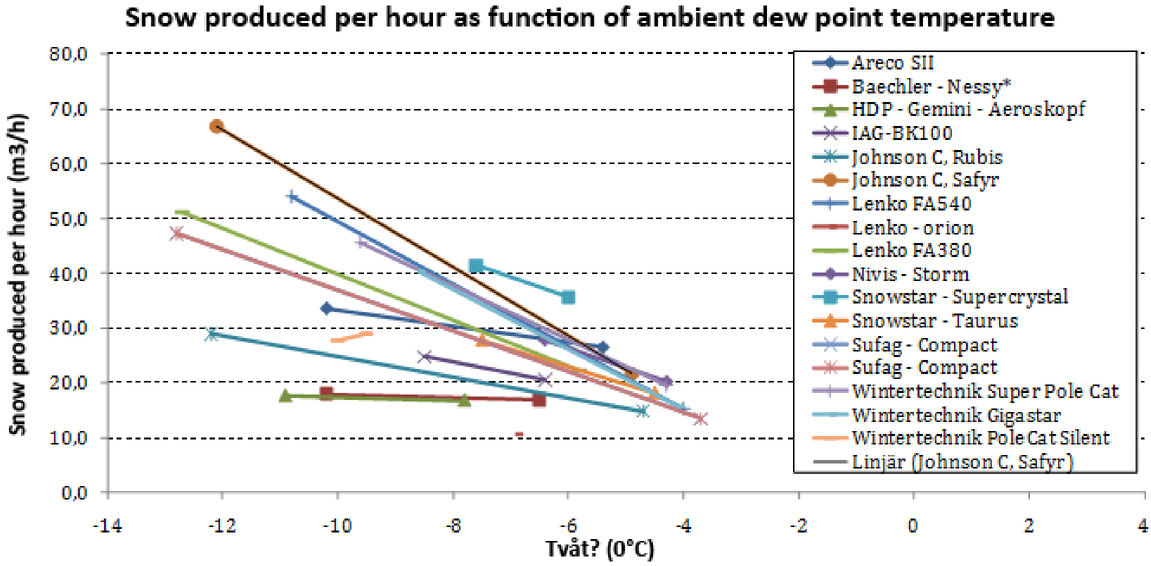


Figure 2-7: The snow production vs. dew point at the Lech tests.

Figure 2-8 shows the results from Figure 2-7 independent of the test and snowmaking. Figure 2-7 illustrates a series of points where the snow is compared to the dew point. Figure 2-8 gives a clearer picture of the snow increases with decreasing temperature. The conclusion is that the mean value for the snow production of the whole test group is 28 m^3/h and increases by about 10 percent for every degree the dew point decreases.

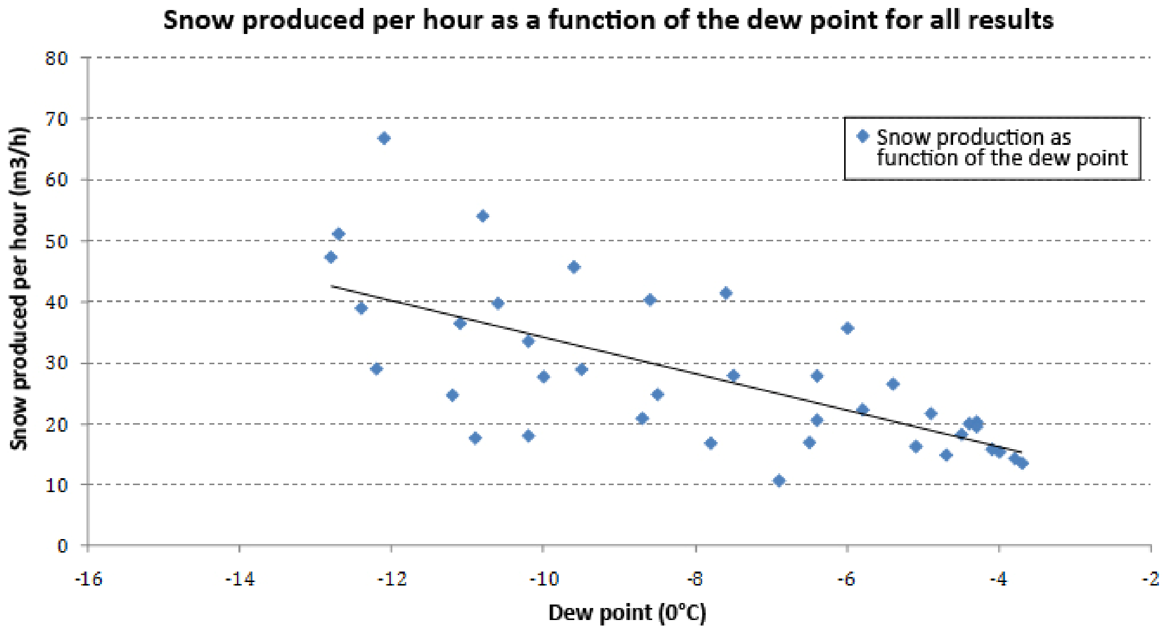


Figure 2-8: The snow production vs. dew point at the Lech tests.

A very interesting key figure is of course the energy use per volume amount of snow. Figure 2-9 shows this ratio as a function of the dew point for all snowmaking that took part in the tests in Lech 2009. A somewhat clearer picture is given in Figure 2-10 where all the measurement points are independent of the snowmaking equipment.

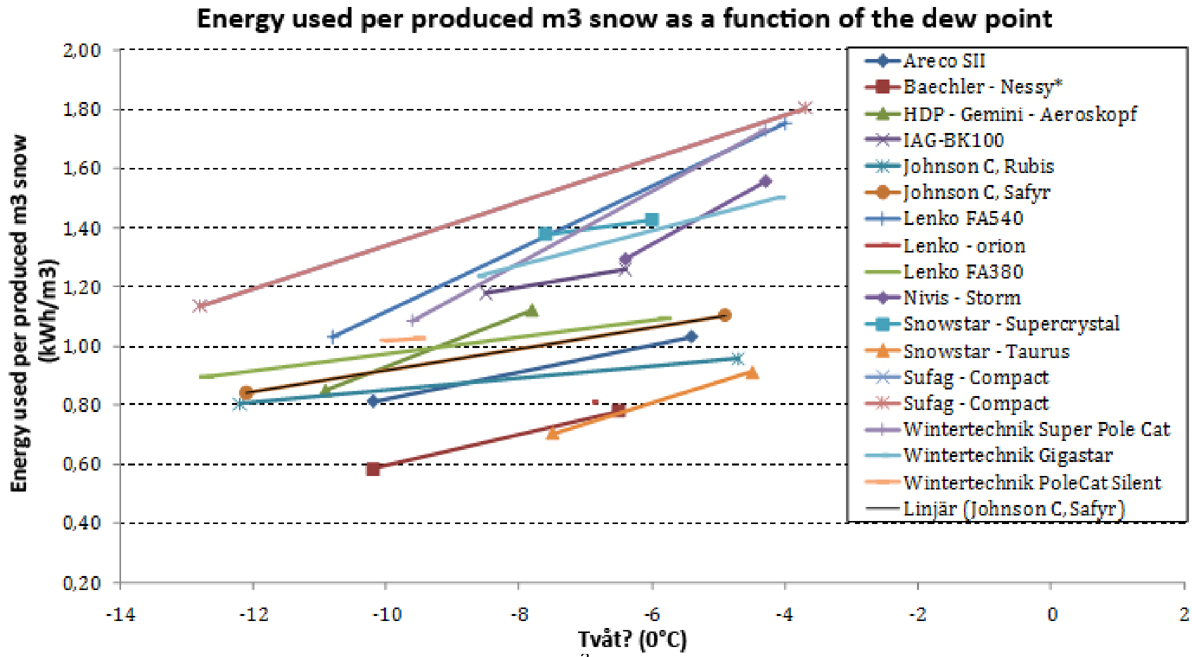


Figure 2-9: Energy use (kWh/m³) vs. dew point for the Lech tests.

Figure 2-10 shows clearly how the energy use per snow volume relate to the ambient dew point temperature. From the figure it is clear that the spread in energy is large from 0.6 kWh/m to 1.8 kWh/m³. Mean value of all results was calculated at 1.3 kWh/m³. From the figure it is also apparent how a falling dew point temperature also contributes to reduced energy use. In general reduces the consumed energy per snow volume by 7 percent per °C (dew point).

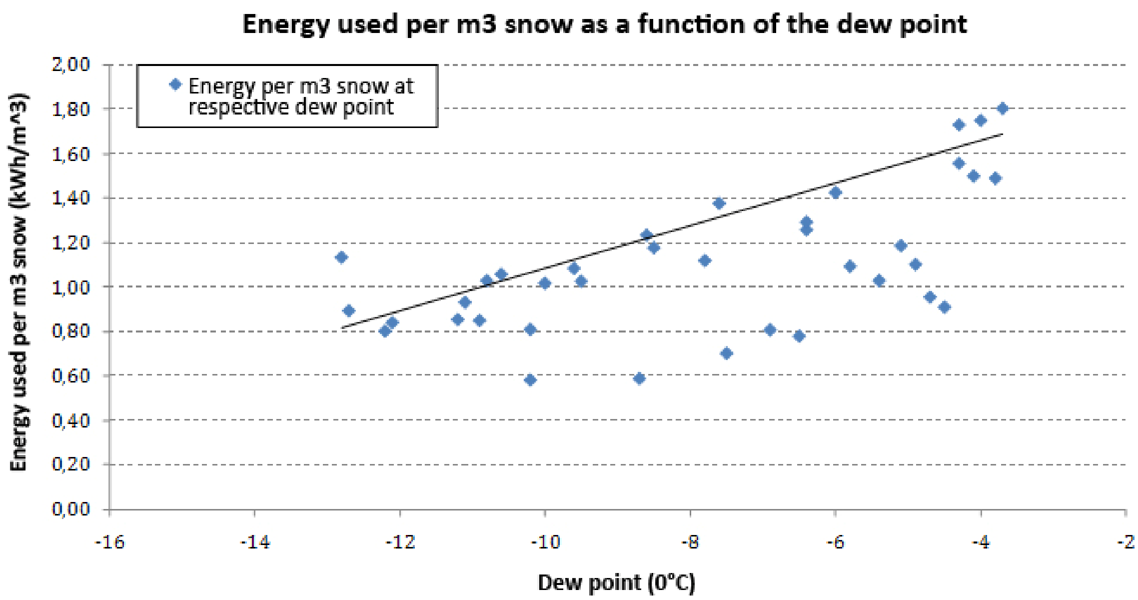


Figure 2-10: Energy use (kWh/m³) vs. dew point at the Lech tests.

2.5.3 Holiday Valley test - method

Also in the U.S., Holiday Valley (NY), has performance tests been conducted whith snowmaking in order to identify the capacity and energy use. These tests are referenced continuously in the text to Holiday Valley test (HVT), not to be confused with Leach test and the tests in Lugnet, Falun.

The testing method of HVT has been developed by Eastman Kodak at Snowmax and all tests have been performed by the staff at Holiday Valley Ski Resort. The design is similar to the method used in the tests in Lech with the exception of the calculation of the volume produced snow. At determination of snow volume does HVT apply a method with a grid consisting of measuring sticks. Each stick is placed with a distance of 10 feet in a square pattern. When calculating the volume the snow depth has been read by manually on each stick (after completed test) and multiplied by the base area 10x10 feet.

Figure 2-11 illustrates how the measuring sticks are deployed in a grid at the testing area in the region of Holiday Valley, USA. Calculations of the volume is made in Excel, as shown in Figure 2-12, where the manually read values from each measuring stick is entered into the document.

Figure 2-11: View over the testing area at Holiday Valley, USA (NY).

HKD Standard
Volume Calculations

	a Row	b Row	c Row	d Row	e Row	f Row	g Row	h Row	i Row	j Row	k Row
Stake 11	10	0	0	0	10	0	0	0	0	0	0
Stake 10	20	10	0	20	20	10	10	0	10	10	0
Stake 9	20	10	20	30	30	20	20	0	0	20	20
Stake 8	10	20	30	40	30	30	30	30	30	30	30
Stake 7	20	20	30	60	60	30	20	30	20	40	40
Stake 6	30	30	40	140	160	50	30	40	70	90	40
Stake 5	30	40	100	160	380	110	50	110	310	170	50
Stake 4	20	50	140	270	300	210	120	370	360	190	80
Stake 3	20	40	130	270	240	190	210	240	280	230	90
Stake 2	20	30	70	140	170	120	120	210	210	110	50
Stake 1	20	30	40	50	60	70	80	100	80	40	20

Cubic Ft per Acre Ft	43,560.000
GPM	82.000
GPH	4,920.000
Duration of test (hrs)	6.000
Gallons Used	29,520.000
Cubic Feet of Snow	9,120
Acre Feet of Snow	0.209
Gallons/Acre Foot	140,996.842
CFM	55
Air Cost per Acre foot	$ 31.52
Engergy Cost per Acre ft.	$ 79.14

Figure 2-12: The test results from one of the tests at Holiday Valley.

2.5.4 Holiday Valley – results

The results indicate that the produced snow volume only has been established on the basis of snow depth (measuring sticks). This opposed to Lech-tests, where the water volume and snow density also was parameters in the tests. Subsequently, have the measured energy and the accumulated amount of water been put in relation to snow volume (acre-foot). Table 1 and Table 2 present a summary of the data produced in the tests. The results and performance of the tests in Holiday Valley should primarily be used to support the planning of our own test performance; this because the information about the methodology and results are rather uncertain. Therefore is there no further analysis made of the results obtained from these tests.

Table 1: Results as energy use per produced snow volume ($/acre-ft) at dew point -5.8°C.

Energy Efficiency Rank	Gun Type	CFM	GPM	kW	Air Cost per Hr.	Pumping Cost per Hr.	Total Energy Cost per hr.	Hrs. per acre ft.	Blend kW rate	Air Cost per Acre ft.	Pumping Cost per Acre ft.	Total Energy Cost Per Acre ft.
1	Bachler "Nessy"	4	28	0.8	$ 0.08	$ 0.10	$ 0.18	134	0.1	$ 11	$ 13	$ 24
2	Rubis	25	44	5	$ 0.50	$ 0.93	$ 1.43	85	0.1	$ 43	$ 80	$ 122
3	T-A T-9	22	24	4.4	$ 0.44	$ 0.52	$ 0.96	156	0.1	$ 69	$ 81	$ 150
4	HKD Standard	75	44	15	$ 1.50	$ 0.83	$ 2.33	85	0.1	$ 128	$ 71	$ 199
5	Techno Alpin Fan	0	48	18	$ 1.80	$ 1.04	$ 2.84	78	0.1	$ 141	$ 81	$ 222
6	HKD Spectrum	100	44	20	$ 2.00	$ 0.83	$ 2.83	85	0.1	$ 170	$ 71	$ 241
7	SMI Super Pole Cat	0	60	31	$ 3.10	$ 1.25	$ 4.35	63	0.1	$ 194	$ 78	$ 272
8	Double Borax	235	80	47	$ 4.70	$ 1.66	$ 6.36	47	0.1	$ 220	$ 78	$ 298
9	Borax	118	40	23.6	$ 2.36	$ 0.83	$ 3.19	94	0.1	$ 221	$ 78	$ 299
10	SV10201	120	37	24	$ 2.40	$ 0.73	$ 3.13	101	0.1	$ 243	$ 74	$ 317
11	Rat G II	590	57	118	$ 11.80	$ 1.14	$ 12.94	65	0.1	$ 772	$ 75	$ 847
12	K-3000	470	40	94	$ 9.40	$ 0.83	$ 10.23	94	0.1	$ 881	$ 78	$ 959
13	SV 10 @120 / 30 cfm	120	34	24	$ 2.40			110				

Table 2: Results of energy use per produced snow volume ($/acre-ft) at dew point -10°C.

Energy Efficiency Rank	Gun Type	CFM	GPM	kW	Air Cost per Hr.	Pumping Cost per Hr.	Total Energy Cost per hr.	Hrs. per acre ft.	Blend kW rate	Air Cost per Acre ft.	Pumping Cost per Acre ft.	Total Energy Cost Per Acre ft.
1	Bachler "Nessy"	3.5	40	0.7	$ 0.07	$ 0.83	$ 0.90	60	0.1	$ 4	$ 50	$ 54
2	Rubis	25	84	5	$ 0.50	$ 1.66	$ 2.16	33	0.1	$ 16	$ 54	$ 70
3	SV 10 @120 / 30 cfm	30	60	6	$ 0.60	$ 1.25	$ 1.85	42	0.1	$ 25	$ 52	$ 77
4	HKD Standard	55	82	11	$ 1.10	$ 1.66	$ 2.76	29	0.1	$ 32	$ 48	$ 79
5	T-A T-9	22	38	4.4	$ 0.44	$ 0.73	$ 1.17	68	0.1	$ 30	$ 50	$ 80
6	Ratnik Proto Stick	101	65	20.2	$ 2.02	$ 1.35	$ 3.37	42	0.1	$ 85	$ 57	$ 141
7	Techno Alpin Fan	0	98	18	$ 1.80	$ 2.08	$ 3.88	38	0.1	$ 69	$ 79	$ 148
8	SV10201	120	58	24	$ 2.40	$ 1.25	$ 3.65	43	0.1	$ 104	$ 54	$ 158
9	SMI Super Pole Cat		120	31	$ 3.10	$ 2.49	$ 5.59	31	0.1	$ 97	$ 78	$ 175
10	HKD Spectrum	100	65	20	$ 2.00	$ 1.35	$ 3.35	58	0.1	$ 115	$ 78	$ 193
11	Borax	94	49	18.8	$ 1.88	$ 1.04	$ 2.92	77	0.1	$ 144	$ 80	$ 224
12	Double Borax	188	98	37.6	$ 3.76	$ 2.08	$ 5.84	38	0.1	$ 144	$ 80	$ 224
13	Rat G II	524	92	104.8	$ 10.48	$ 1.87	$ 12.35	41	0.1	$ 425	$ 76	$ 501
14	K-3000	345	60	69	$ 6.90	$ 1.25	$ 8.15	63	0.1	$ 431	$ 78	$ 509

3 TEST PROCEDURE – TESTS OF SNOWMAKING EQUIPMENT AT LUGNET SKI STADIUM IN FALUN, SWEDEN.

This chapter describes the performance of the snowmaking tests, which is the procedure that took place during our own tests at Lugnet ski stadium in Falun. The starting point was to meet the objective of the test, in other words to compare the energy use of different snowmaking equipments. In order to do this was there a need to map out the snowmaking system, from that the water is taken from a pond until the snow is produced. The chapter is divided into one part describing the method, and one part that describes the measurement equipment used in the assessment.

3.1 Method of execution

To fulfill the aim and purpose of the tests did it take that a number of parameters were set to allow comparability of results. In order to simplify the snowmaking system, and thereby ensure that all vital measuring points were taken into account, was a schematic sketch drawn (see Figure 3-1). In the figure is the snowmaking a "black box" with a surrounding system.

In the sketch the reader find an arrow 1) that symbolizes the state before the snowmaking. This arrow aims at the supply of water to the snowmaking. Subsequently is energy and air added in the arrow 2) to finally receive snow as symbolized in arrow 3).

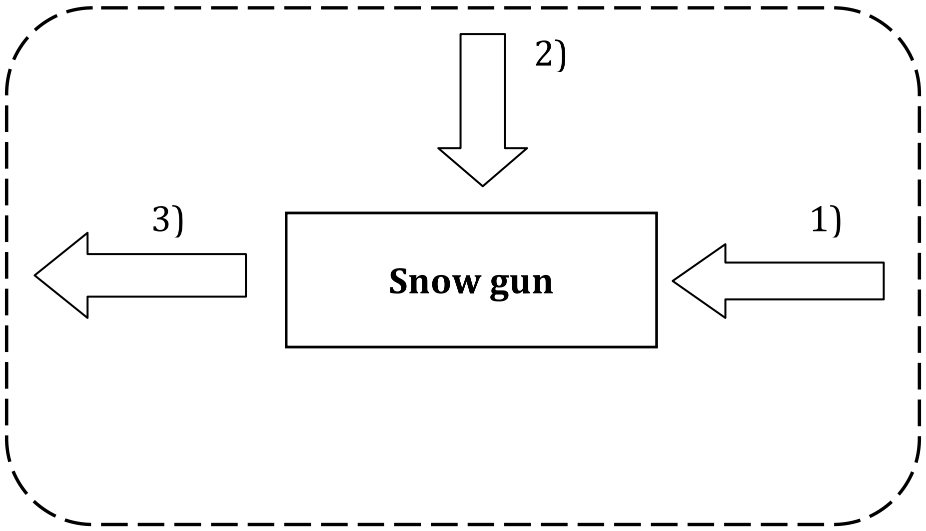


Figure 3-1: Schematic illustration of a snowmaking system. Arrow 1) in the figure illustrates the state before the snowmaking, arrow 2) provision of electricity and air to reach the state 3) in the term of snow.

3.1.1 Water supply

Water is needed in order for the snowmaking to be able to produce snow. The water flow to the snowmaking is caused by a pressure difference. In state 1) has the water flow to be measured as well as water pressure and water temperature. This was performed by a measuring tube was constructed, in which the associated temperature, pressure and flow sensors were mounted on the pipe, as shown in Figure 3-2. Since it takes energy to deliver water to each snowmaking unit is it essential that the performance of the central pump is included in the calculations. A central pump located at the water park raises the water pressure from the ambient pressure to approximately 23 bar (which was the level that the ski stadium Lugnet in Falun was design for). The pressure difference to their surroundings then gives rise to the flow that allows production of snow in each snowmaking unit. The pump work is in itself a function of the difference in pressure and flow as shown below.

$$\dot{E}_{pump} = \frac{\dot{V} \cdot \Delta P}{\eta_t}$$ Ekvation 1.

$\dot{E}_{pump}$ – Pump power [W]
$\dot{V}$ – Volume flow [m³/s]
ΔP – Pressure increase [Pa]
η_t – Overall efficiency [~0,65]


Figure 3-2: Measuring tube with belonging pressure, flow and temperature sensors.

3.1.2 Energy

Electricity is needed for the applied amount of water to become snow. The electricity is used to run fans, compressors, heating nozzles, etc. The input power and thus the energy can easily be measured with an electric meter. The measuring equipment is described in detail in later chapters.

3.1.3 The produced amout of snow

The produced amount of snow must be mapped in order to properly compared different snowmaking equipments. Parameters such as snow quality and snow volume is essential for comparisons. These parameters are however not as easy to measure. To determine how much a snowmaking unit produces (and place that amount in relation to energy use) would it be appropriate to weigh the snow and thus determine the weight and volume. However, it turned out early that it was not practically possible.

A method was used where the volume of produced snow is determined by snow depth measurements within a predefined range. The snow volume was also calculated by using the added volume of water quantity and the snow mean density. The results from the two methods were then compared to get an idea of the measurement accuracy of the results. The two methods, gross and net method, are described separately below.

Snow volume measurment – The gross method

The gross method is based on the total volume of water for each snowmaking unit, and the mean density of the produced snow. As previously described is the water volume measured by the flow sensors mounted outside the measurement pipe (more on this in the chapter conserning measuring equipment). The relationship of the gross volume of snow is given by Equation 2.

$$m_{water} = (\rho \cdot V)_{water} \quad \rightarrow \qquad \text{Ekvation 2.}$$

$$V_{snow} = \sum m_{water} / \rho_{snow} \sim m_{water} / \bar{\rho}_{snow}$$

m_{water} – Mass of water $[\mathrm{Kg}]$
ρ_{water} – Water density, $\sim 1000\ [\mathrm{Kg/m^3}]$
V_{water} – Total volume of water $[\mathrm{m^3}]$
$\bar{\rho}_{snow}$ – Average density of the snow $[\mathrm{Kg/m^3}]$
V_{snow} – Gross volume of snow $[\mathrm{m^3}]$

Equation 2 above assumes that all supplied water turn into snow. As shown in the relationship is the mean density of the snow a parameter that must be fixed. To be absolutely correct should the snow density continuously be multiplied by the current water volume. This was however not practical, so the means the density of the entire testing period was used as an approximation.

The snow density was determined by using a number of tolldishes, which were placed in a defined area on an orthogonal line in front of each snowmaking unit. The distance between the tolldishes was about five meters (approximately 3 tolldishes per unit). Each tolldish had a definite volume and weight. A tolldish got weighed when it was filled with snow. With the weight and volume known – the density could be calculated. During each test was continuous measurements of the density carried out to get a representative mean value. The left picture in Figure 3-1 shows a tolldish, where the snow's weight was measured to calculate its density. The right image shows the visual observations of the snow structure.

Figure 3-3: Tolldishes with snow for density measurements (left) and snow samples for visual observation (right).

Measurement of snow volume – The net method

The basis for the net method was the actual amount of snow produced. To determine the snow volume was first off all an orthogonal range (35 meters in length and 20 meters in width) delimited in front of each fan gun and lance (see Figure 3-4). The figure illustrates the area seen from above. The target area were divided into a grid of scale 5 feet between each node. Each node represented a measuring point. "Building sticks" were used, which were placed in each node as shown in Figure 3-5. These were then used as a measuring stick to determine the depth of snow after each test session and then interpolating the volume. The method with the measuring stick is described in the text accompanying Figure 3-6.

A demarcated area in front of each snow gun and lance were divided into a grid. Each "box" has an element of 5 * 5 meters where the total length of the span is 35 meters and 20 meters in width. Each node in the grid was then a measurement point.

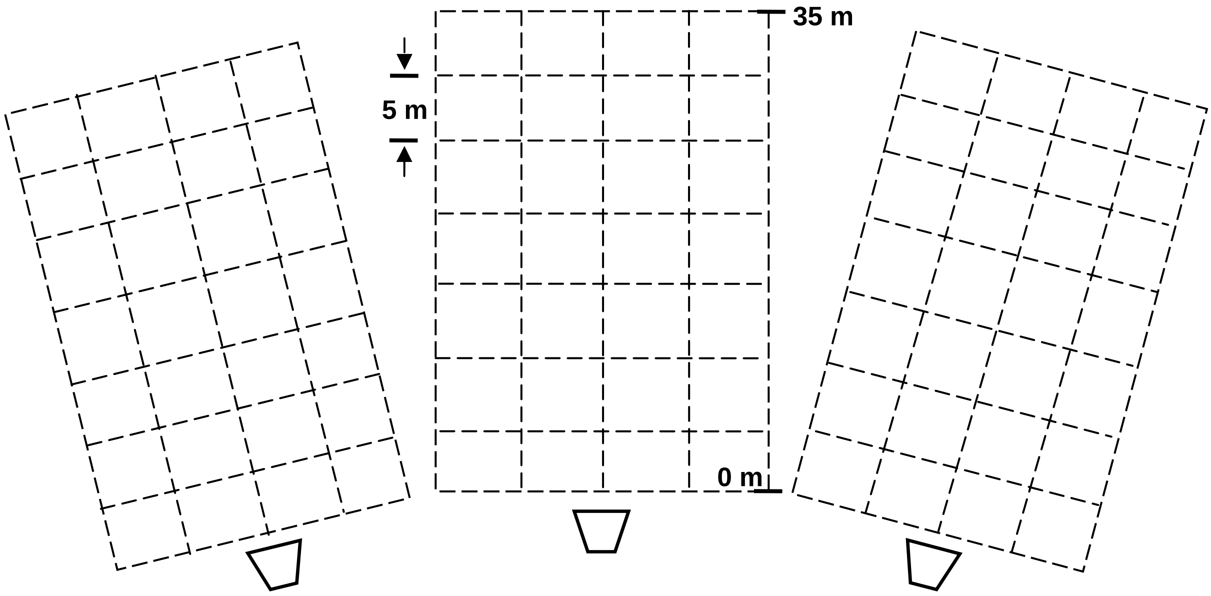


*Figure 3-4: A demarcated area in front of each fan gun/lance was divided into a grid. Each "box" measures 5 * 5 meter where the total length of the span is 35 * 20 meters.*

Figure 3-5: Measurements of the area and placing "building sticks" in the nodes construct the grid.

The measuring sticks (the "building sticks") were placed in the grid before each test session. There were two marks on every stick. One marker (red) formed a zero level and the second marker (blue) showed a distance of 1 meter from the zero level, as shown in Figure 3-6. To determine the snow depth was the distance L2 (as shown below) measured after each completed test for each node. The snow depth was then calculated as $L_3 = L_1 – L_2$, where L_1 is always 1 meter.

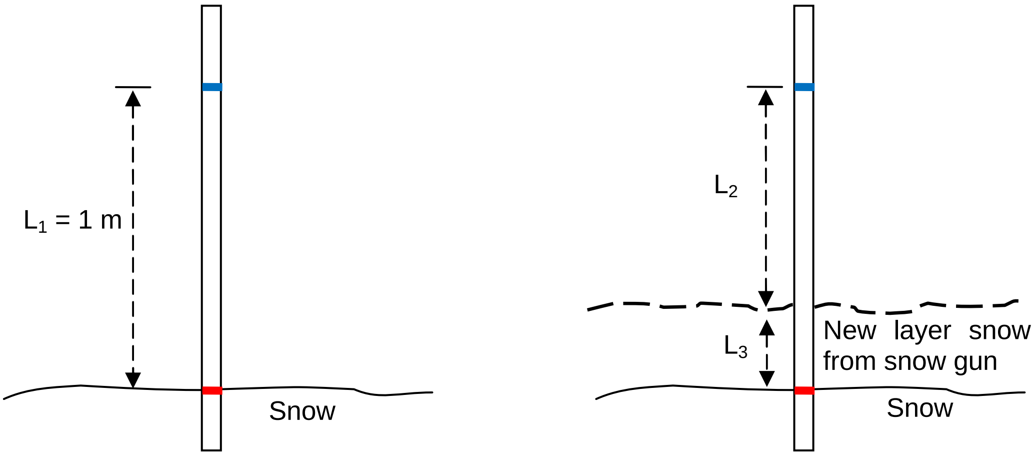


Figure 3-6: The measuring sticks are used to determine the snow depth in the measuring area. The results are then used to calculate the net volume of snow.

When the snow depth at each node were calculated and entered in an Excel sheet, the volume of new snow in the test area were determined. It was done by calculating the volume of discrete compartments, and then summarizing these. The volume of each finite element was determined by multiplying the base sale (B x D as in Figure 3-7) with the height. The height is an average value of the surrounding nodes according to elevation:

$$\bar{L}_3 = \sum_{N=1}^{N=4} \frac{L_{3,N}}{4}$$ Ekvation 3.

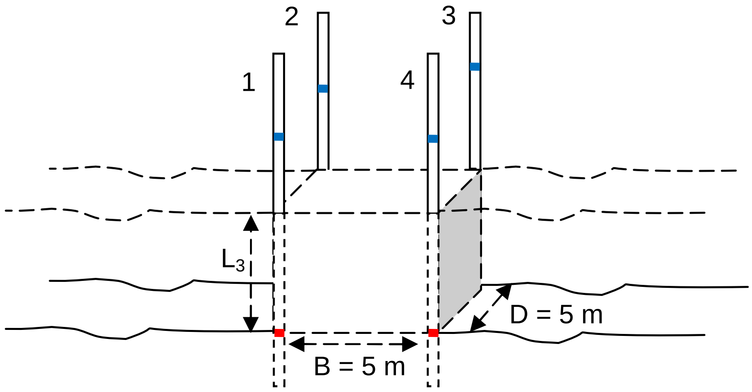


Figure 3-7: The volume produced snow is determined by calculating the volume of discrete compartments and summarizing these.

3.1.4 Test procedure

The tests were conducted with three parallel fan guns/lances at each round. The testing area were constructed, with associated mesuring sticks, before the start of each test. Each measuring stick were placed in a pre-drilled hole so that the red mark came at the height of the existing snow level.

After this procedure was the measuring equipment checked and all settings were verified and determined that they were properly aligned for the purpose. At the same time were the energy meters manually put at zero. The test started after this and the actual start time was recorded. The actual test time was destined to 3 hours. Density measurements were conducted continuously during the test. Time and results for each density sample was recorded and entered in an Excel spreadsheet. In connection with the density samples were also the very structure of the snow considered, which gave a subjective understanding of the snow quality.

The fan guns/lances were tured off and the test was considered completed after three hours. The actual time the test was completed got noted. When the test was completed the use of electrical energy was established to each fan gun and lance through manual reading of each energy meter. The energy use was recorded and then began the process of reading the height L_2 at each node. The height of each node was recorded and entered in an Excel sheet where the volume was calculated as previously described.

Finally were the testing area gromed in order to smooth the ground and prepare for new tests.

Figure 3-8: The picture to the left illustrates three parallel fan guns. The picture to the right display the building sticks/measuring sticks and a grooming machine that is preparing the testing area

Many thanks to the staff of Lugnet ski stadium in Falun for their great effort during the tests.

3.2 Measurement equipments

The measuring equipment consisted of flow meters, pressure and temperature sensors, weighing equipment and energy meters. To ensure good accuracy of the measurements were three identical measuring tube of length 1500 mm each (50 mm in diameter) constructed. The function of the measurement tube was to ensure a stable flow in the measuring unit. The flow, pressure and temperature sensors where then mounted on the measuring tube.

In addition to the above equipment was also a weather station used to measure and record the ambient weather conditions. A data logger was used in order to communicate and gather data from the various sensors.

3.2.1 Flow meter

An ultrasonic flow meter was used to measure the water flow to each snowmaking unit. The reason this type of flow meter was chosen is the relatively high pressures used in the snowmaking. The snowmaking system at Lugnet ski stadium in Falun is designed for a water pressure equivalent to ~ 22 bar. Even higher pressures are common in snowmaking, which however limits the choice of flow meters. The corresponding water pressure directly affects a meter placed internally “in” the flow. The majority of the flow meters available on the market can withstand pressures up to 16 bar, and then more exclusive models are needed. An ultra-light flow meter measures the flow regardless of pressure. This is because the sensors are mounted externally, outside of the tube. The water speed is measured with the ultrasound and the volume flow is then calculated based on the size of the measurement tube. This provides a measurement accurate maximum of +/- 2 percent in the flow range 0 - 400 litres/minute (Flexima, 2011).

Figure 3-9 below illustrates the two sensors that measure the water speed. The sensors are installed at a fixed distance from each other, where the gap is calculated on the basis of the central unit and the pipe wall thickness, material and diameter. The signal cables from the sensors are connected to the central unit that displays the current flows directly into the display. Furthermore, the main unit is equipped with analogue outputs where the current information continuously can be stored with the data logger.

Figure 3-9: The two sensors placed externally on the measuring tube are shown to the left. These are connected to the central unit to the right. The brand of the flow sensor is FLEXIM.

3.2.2 Pressure sensor

To measure the pressure in each measuring tube a pressure sensor of the model KELLER 22S was used (http://www.keller-druck.com). These sensors are available for different pressure levels up to 250 bar. Sensors that were adapted for the range of 0-35 bar were used in the snowmaking tests. The precision of this type of sensor is within 1 percent at a water temperature of between 0° C to 50° C. The sensor then sends out an analog voltage signal where the voltage varies proportionally to the pressure. The signal (0 - 5V) is then saved continuously in the data logger and translated to the corresponding pressure.

Figure 3-10: Pressure sensor from KELLER. A pressure sensor that was adapted for 0 - 35 bar was used during the tests.

3.2.3 Temperature sensor

The water temperature was measured by using thermocouples. A thermocouple is a temperature sensor consisting of two wires of different materials. The two wires are separated from each other with an insulating material, except from the ends of the threads. At one end (the measuring unit) are the wires assembled together. In the opposite end are they separated. A temperature difference between the two ends then gives rise to a potential difference between the wires in the end where they are not assembled. To convert the voltage difference to a temperature in the measuring point is it required that the temperature of the part that is joined are known. This temperature is measured with high accuracy in the data logger which also measures the voltage. Thermocouples of type T was used with an accuracy within 0.2° C. Type T is mostly used at low temperatures in the range -200° C to 350° C.

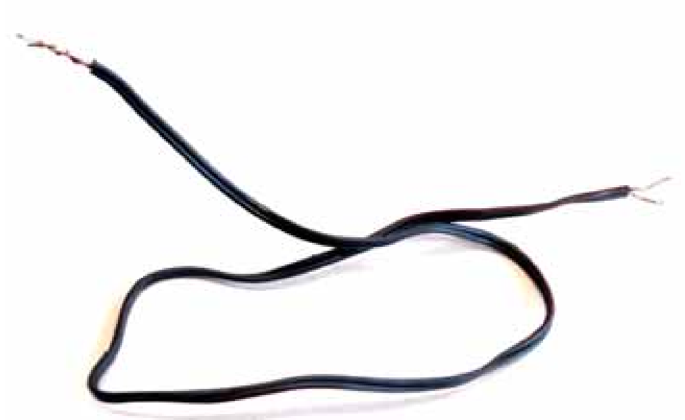
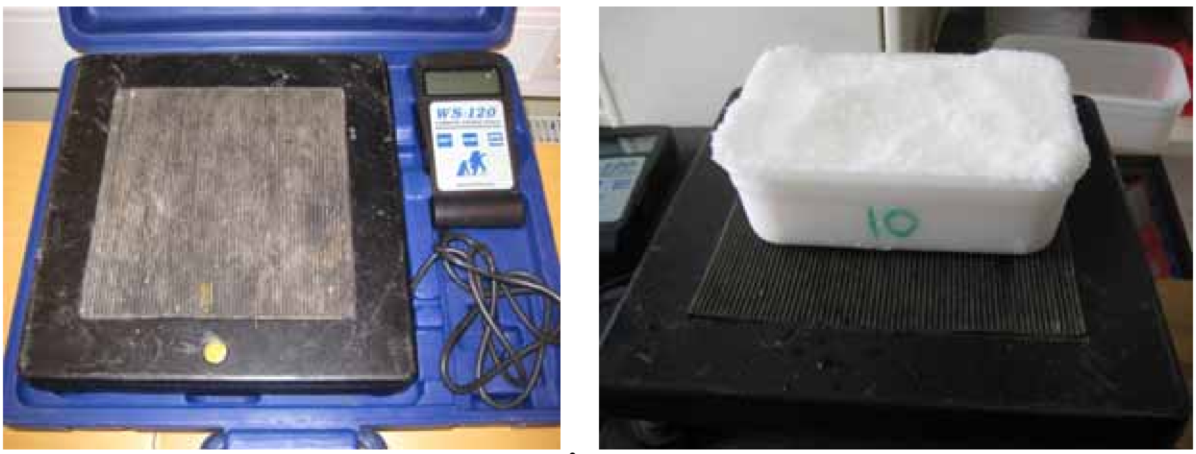


Figure 3-11: Thermocouples of type T.

3.2.4 Weighing

To determine the density of the snow was a container with a specified weight and volume used. The containers were filled with snow and placed on a weighing machine (see Figure 3-12). The weight was registered with high accuracy. The range of the scale was 0 - 120 kg with a resolution of 10 grams, and an error margin of ~ 1 percent.



Figur 3-12: Mätvåg med tillhörande kärl.

3.2.5 Energy meters

Energy meters were used to determine the quantity of electrical energy to each snowmaking unit (excluding the central pump). Energy meters were designed for three phase (up to 80 A) and was equipped with a display for manual reading of electric power as well as energy. Each energy meter was placed in an enclosure to protect the equipment from surrounding elements. Each energy meter was supplied with fast connections (63 A female/male) to easily switch between different snowmaking after completed test.

Figure 3-13: Energy meter with enclosure.

3.2.6 Weather station

Climate and weather data were measured with a weather station of model HOBO U30. The measuring station was equipped with sensors to measure wind speed, ambient temperature, humidity, ambient air pressure and solar radiation sensors. Unfortunately was there no wind sensors available. The mast, with associated sensors, was rigged on the wall off the measuring wagon (Figure 3-14). Data from the weather station was saved separately in the accompanying data logger.

Figure 3-14: Weather station rigged at the measuring wagon.

3.2.7 Datalogger

A logger, model Agilent 34980A, was used for the collection of data. The logger is equipped with both analog and digital inputs with high-resolution at measurements. The logger has also been equipped with pulse counters, and relays capable of breaking currents of up to 2 A at 300 V. In addition to the inputs are there analog outputs which makes it possible to control other applications with voltage (0 - 10 V) or current (4 - 20 mA).

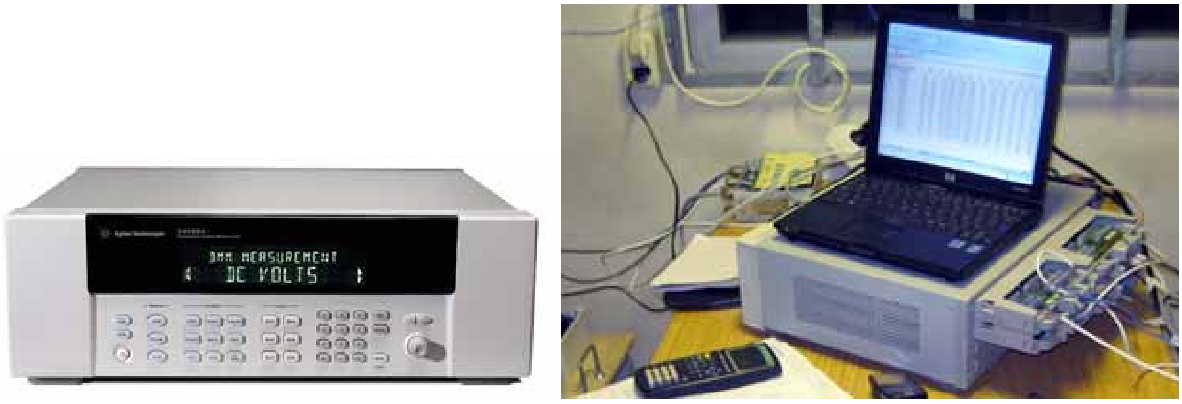


Figure 3-15: Weather station rigged at the outside wall of the measuring wagon.

4 TEST RESULTS – TRIALS OF SNOWMAKING EQUIPMENT AT LUGNETS SKI STADIO, FALUN

The tests were conducted at two different occasions in week 5 and 7 of 2011. At the first attempt, during week 5, was it impossible to perform any longer test period due to unfortunate weather. However, these test results are valuable since the snowmaking took place at a ambient temperature of – 2°C, which makes it possible to compare the performance of the snowmaking equipment at different weather conditions.

The weather conditions were more favourable at the second occasion. The ambient temperature during week 7 varied between -6°C and -20°C. Seven trials of testing were in total conducted during this second week of trials.

The tested equipment is declared for in Figure 4-1 to Figure 4-5. The pictures are placed without any specific order in relation to the test results. A summering is given at the end of the chapter.

*Figure 4-1: To the left **Areco** (Standard) and to the right **Snowtech** (T60).*

*Figure 4-2: To the left **Toppteknik** (NESSy 10 meter.) and to the right **Johnson Controls** (MRA6, 6 meter).*

*Figure 4-3: To the left **Toppteknik** (Släde, 3 meter) and to the right **Areco** (Supersnow).*

*Figure 4-4: To the left **Snowtech** (lans A30, 9 meter) and to the right **Snowtech (**T40).*

*Figure 4-5: Sow gun from **Areco.** Model: Sufag Super Silent*

4.1 Test 1 – Week 5

As described in chapter 3, only one test was conducted during week 5. The test was performed on the 2nd of February and started at 06:30 in the morning. The test period ended right before 09:00 am. The reason that the test did not last for the prescribed 3 hours was that no measurable snow was produced during the first 2 hours. The test was called off in consultation with the participants.

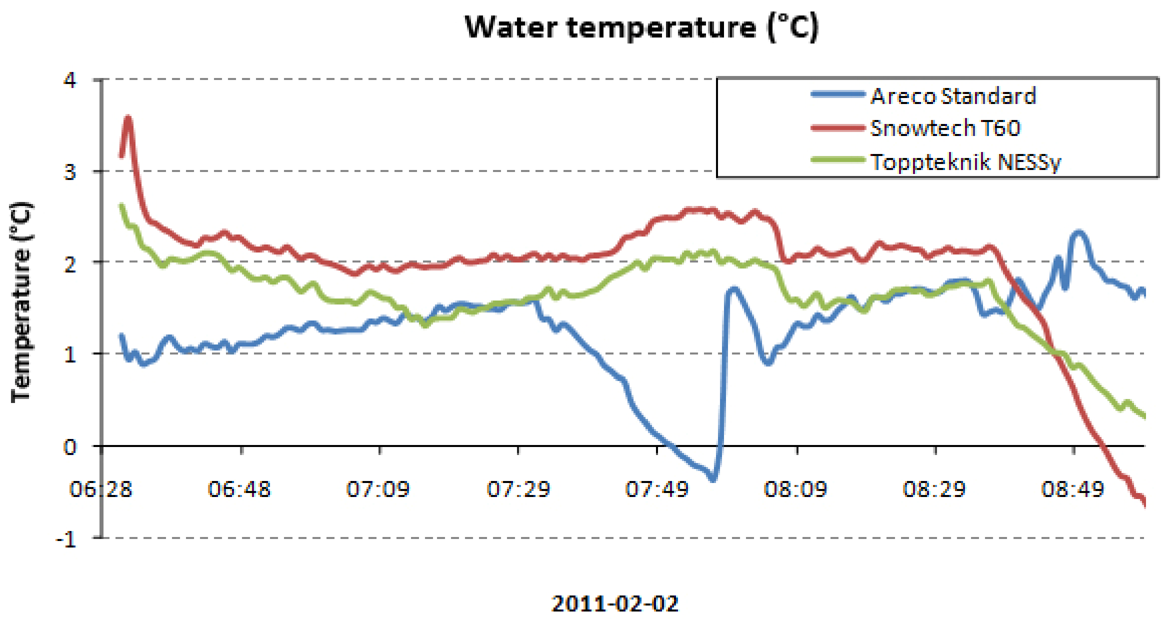
4.1.1 Test 1.1 – 2nd February

The results from the test are presented below. The performance of the participating fan guns and lances are presented first. After that follows a map of weather- and climate data during the measuring period. The test was conducted with the following snowmaking equipment: Areco Standard, Snowtech T60, and the lance Toppteknik NESSy.

Performance

In Figur 4-6 are the results from the measurements of water temperatures to Snowtech T60 and Toppteknik NESSy (red and green graph in the figure) 2°C +/- 0,5 during the measuring period.

The blue graph in the figure (Areco Standard) shows that the water temperature declined to below 0°C at about 08:00 am. This was due to rising ambient temperature, which resulted in that the fan gun automatically turned off. Because of this, water was stuck in the measuring tube, which in turn lead to ice formation. The flow was not recorded due to the ice preventing the ultra sound sensors recording the speed of the water. This is revealed in Figure 4-7 and Figure 4-8, the pressure sensor shows pressure while the flow sensor is not indicating any flow during this period. Figure 4-9 shows how Areco Standard is turned off right after 07:30 in the morning.



Figur 4-6: Vattentemperaturen till respektive lans/snökanon.

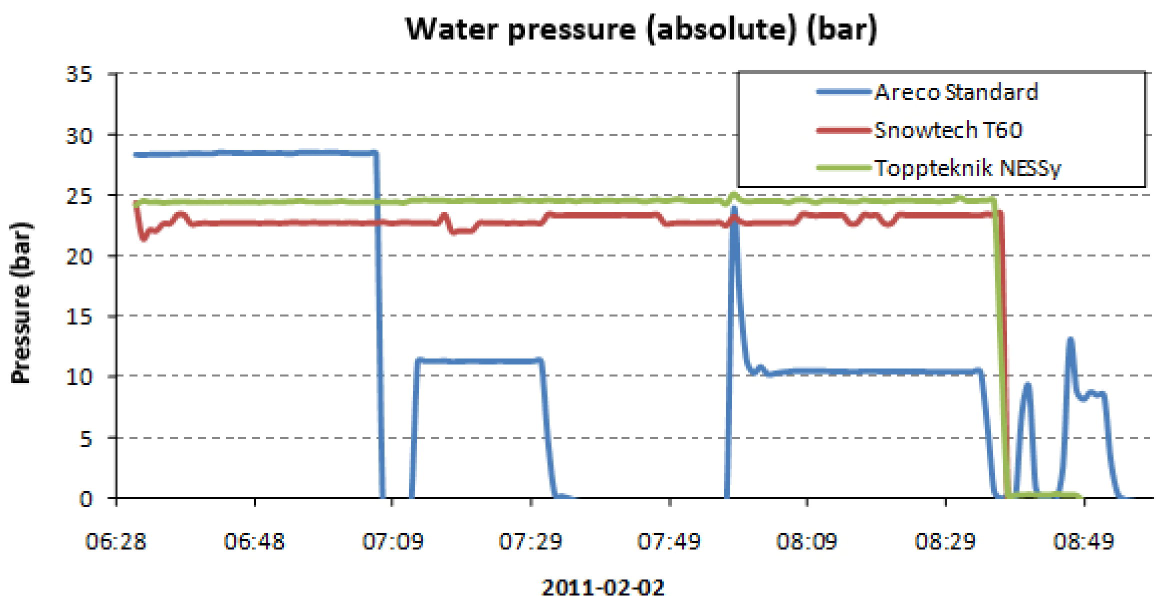


Figure 4-7: Water pressure in each measuring tube during the measuring period.

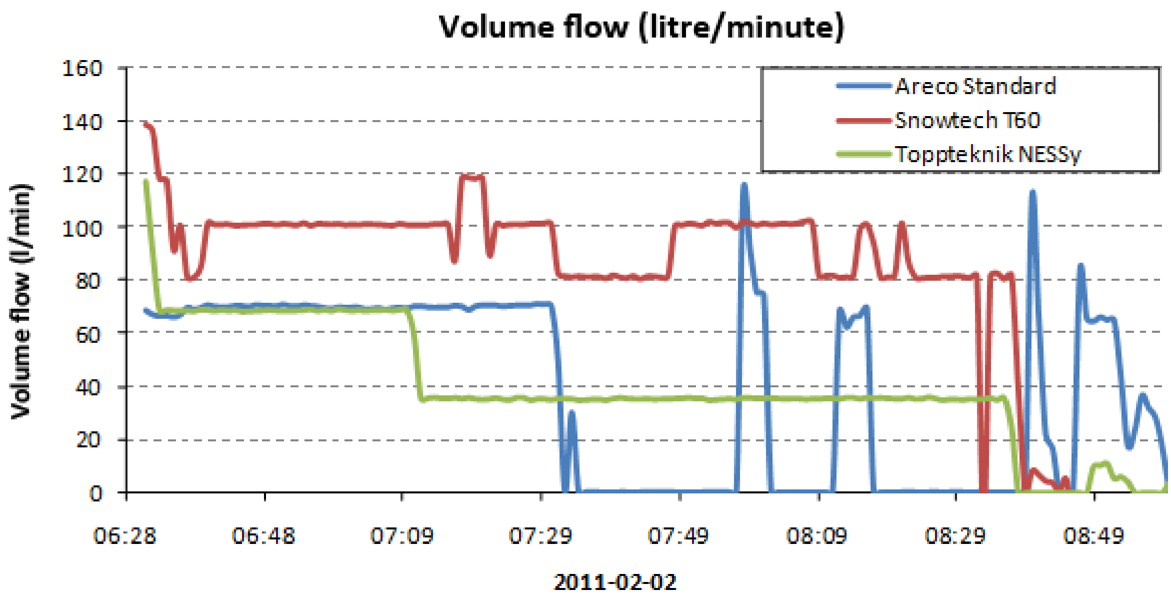


Figure 4-8: The flow to each fan gun/lance during the test period.

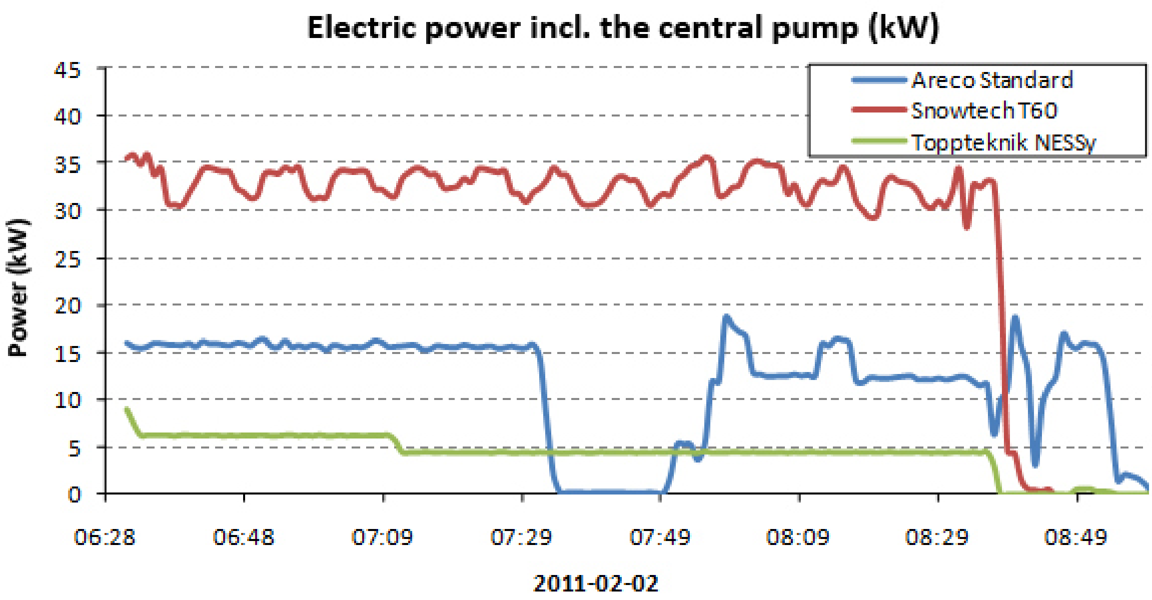


Figure 4-9: The added electric energy; the central pump included.

Weather- and climate data

Figure 4-10 to Figure 4-13 presents the ambient conditions during the test period. Figure 4-10 indicates the ambient temperature and corresponding dew point. The blue graph show that the temperature varied from -3°C, at the beginning of the test, to -0,6 °C, when the test was called off. Corresponding dew temperature was -4°C and -3,1°C. As earlier pointed out; was there no snow production due to rising temperatures. The “snow” that was produced in the beginning of the test consisted mostly of water, in which the density was high.

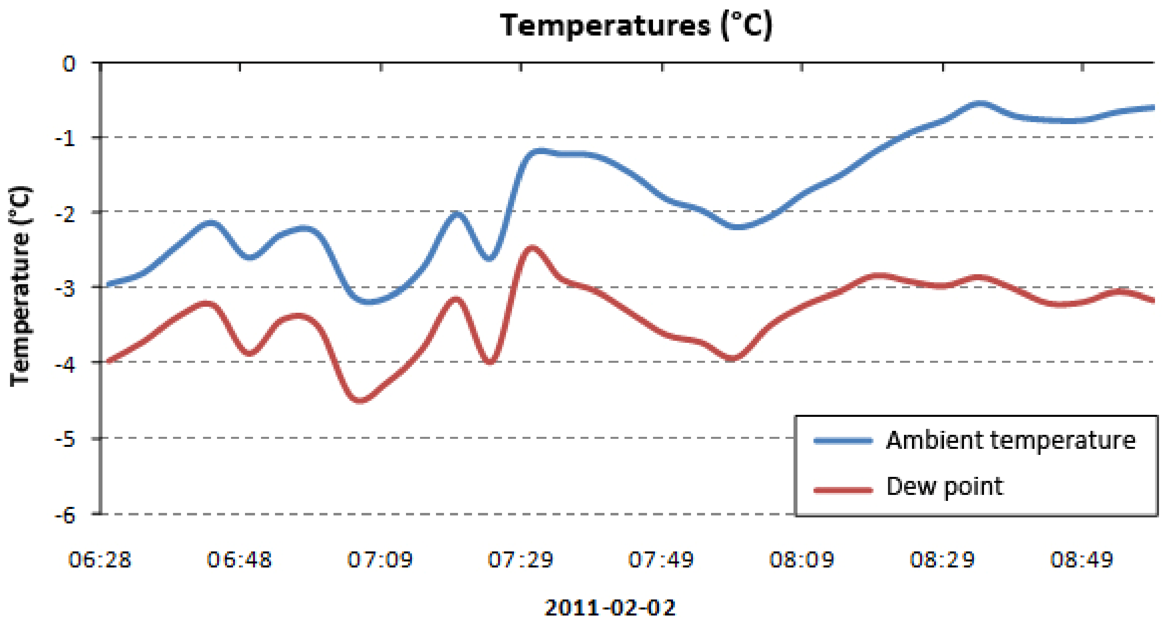


Figure 4-10: Ambient temperature and dew point as a function of time.

The relative air humidity and the ambient air pressure are illustrated in Figure 4-12. According to the graphs the air humidity vaied during the test and decreased gradually from the start. The ambient pressure was fairly constant, at around 983 mbar.

The impact of the solar insulation was insignificant, since the major part of the test was conducted before sunrise (see Figure 4-13). The blue graph in Figure 4-11 indicate the average wind speed to have been calm during the entire test.

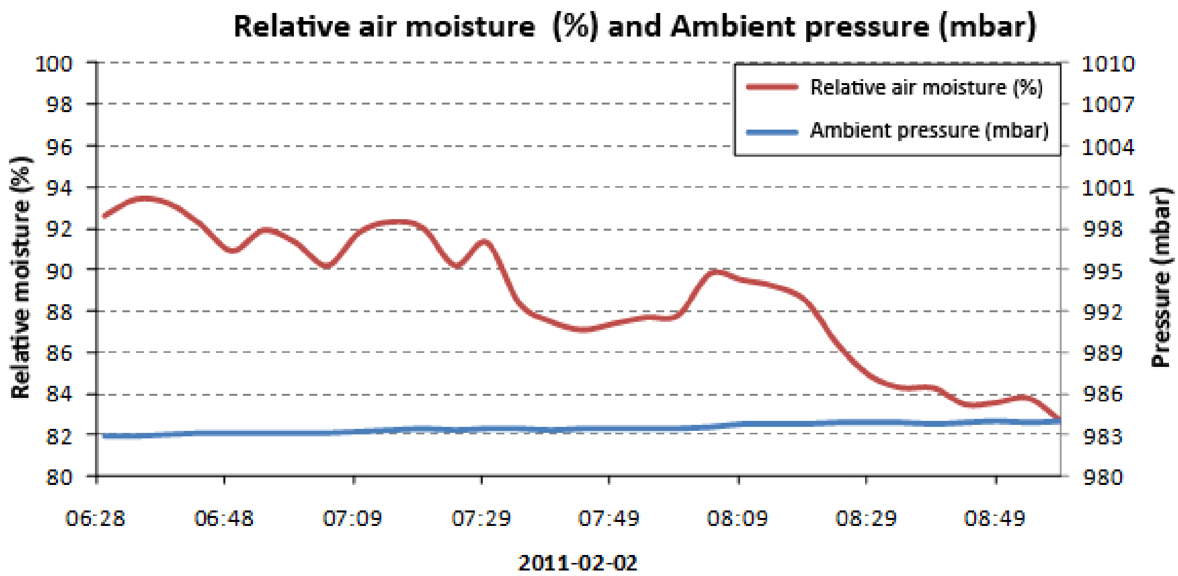


Figure 4-12: Relative air humidity and ambient pressure during the measuring period.

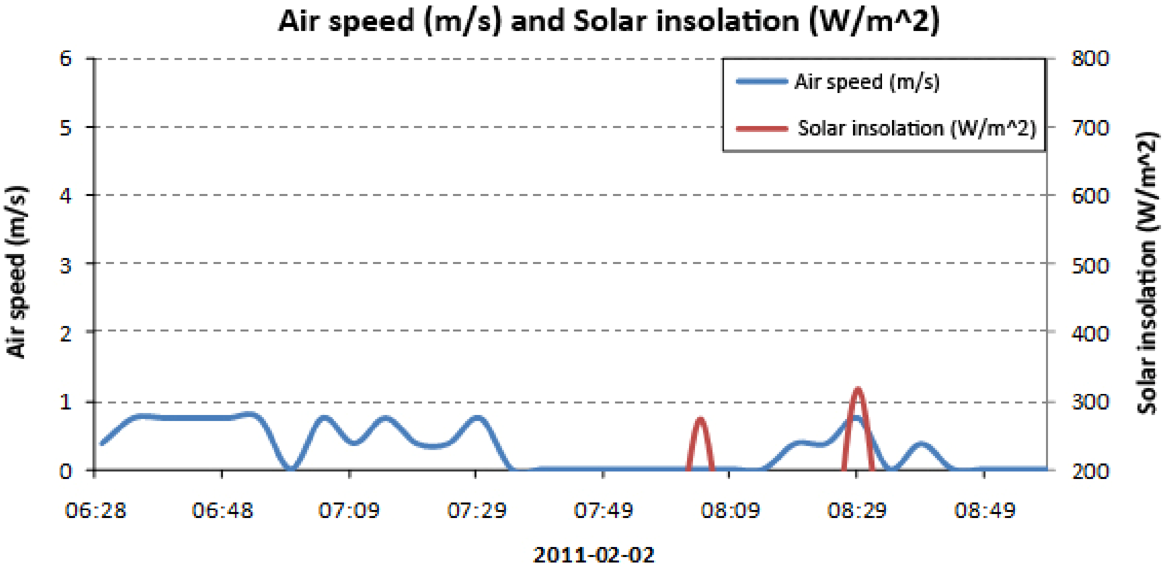


Figure 4-13: The figure illustrates the variation in wind speed and solar insulation during the measuring period.

4.2 Test 2 – Week 7

The first test during week 7 started in the afternoon of the 14th of February. After that two tests per day conducted with the last test ending in the afternoon, Thursday 17th of February. The weather was considerably colder during this second week of trials compared to the first week.

4.2.1 Test 2.1 – Day 1 (14th Feb)

During the first test in week 7 were the fan guns of Snowtech T60 and Areco Supersnow and the lance Toppteknik NESSy. The measurements started at 05:00 pm and ended at 08:00 am. The results from this test will be presented below. First are the results from the performance of the snowmaking equipment, then the ambient conditions and climate data during the given test period. A summary of interesting key figures and results from the measurements are presented last.

Performance of snowmaking equipment

Figure 4-14 illustrates the continuous samples of density that were conducted during the measuring period. The density varied between 400 – 500 kg/m^3, with the exception of the snow sample that showed a density of more then 570 kg/m^3 (blue graph in Figure 4-14).

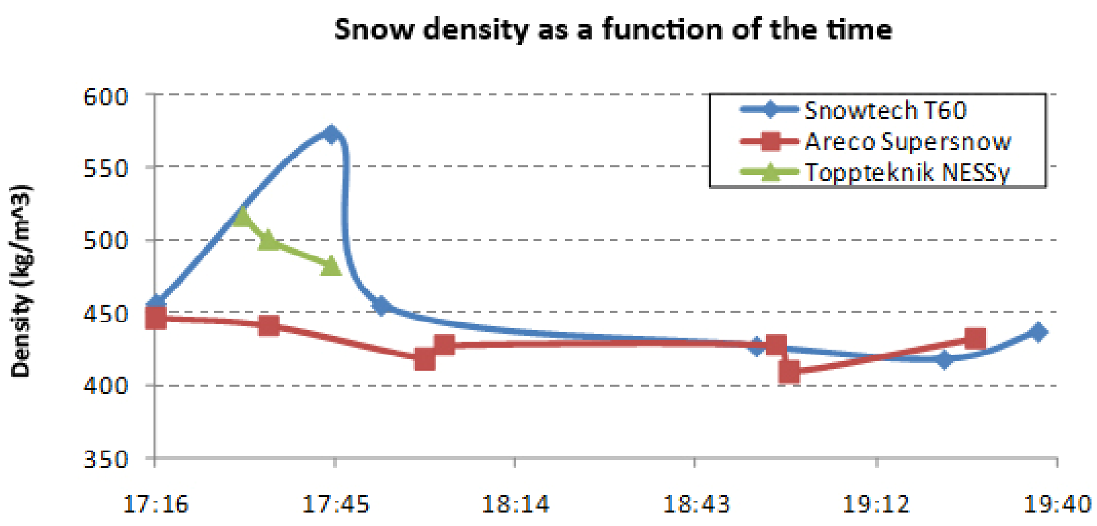


Figure 4-14: The figure illustrates how the snow density varies during the test.

Figure 4-15 indicates how the water temperature in each measuring tube varies over time. Since some snowmaking equipment includes heating is the water temperature probably not the same at measuring tube as at the nozzle.

The figure shows that the water temperature is different for each measuring tube; one probable case to the difference is the speed of the water and the water flow. Since the water flow to the lance NESSy is less then to the other snowmaking equipment, is this lance more affected by the ambient temperature. Also the distance from the source of water is having an impact. The water is more affected if it is transported for a long distance with a low speed, compared to a shorter distance of transportation with a high speed.

The green graph in Figure 4-15 illustrates that the water temperature to NESSy is decreasing considerable after 07:00 pm. This is due to that NESSy had to quite the test earlier then planed and the measuring tube was dismantled for the night. It is the ambient temperature that makes the "water temperature" to drop.

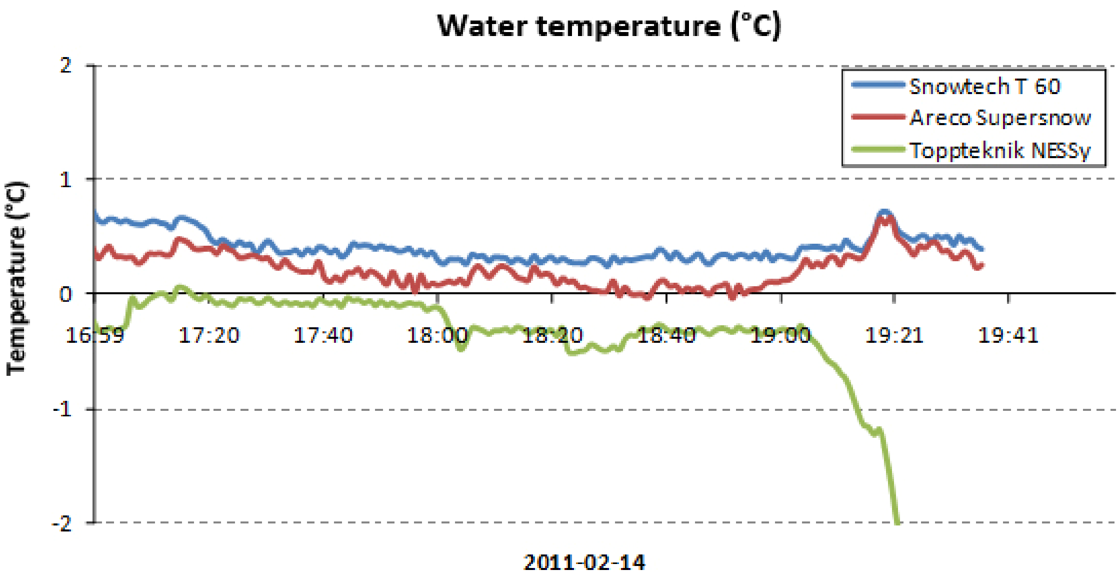


Figure 4-15: The graphs show how the water temperature in the measuring tubes varies over time. As the figure illustrates is it a marginal difference in water temperature.

In Figure 4-16 and Figure 4-17 is the water pressure for each measuring tube presented. The pressure sensors that were used are adapted to cold temperatures but at the same time sensitive to ice formation. This is displayed in Figure 4-16, where the peaks in the beginning of the series of measurements indicates that the sensors have a build up of ice. The ice-plugs were then removed with infusion of heat. This resulted in "peaks of pressure" once the sensors started to work again.

In Figure 4-18 is the electric power for every one of the snowmaking equipment during the test period presented. The central pump is also included in the figure. The pump power is, as earlier described, developed through calculations - in these calculations are the volume flow and the pressure increase of the central pump vital parameters.

Figure 4-18 show that the lance NESSy had to be turned off at approximately 06:10 pm. This resulted in that the water flow and the pressure in the measuring tube was reduced, which is illustrated in Figure 4-16 and Figure 4-17. Around 06:20 pm was NESSy once again turned on and the electric power was increasing. However, the lance had to be shut down after a little more than 15 minutes. Figure 4-16 seems that the pressure has remained after the lance NESSy had been turned off. This is probably due to ice formation ("ice plug") in the pressure sensor. The failure was detected at the time of the test, but nothing to solve it was done at this point since the lance was turned off and the measuring tube was dismantled for the night.

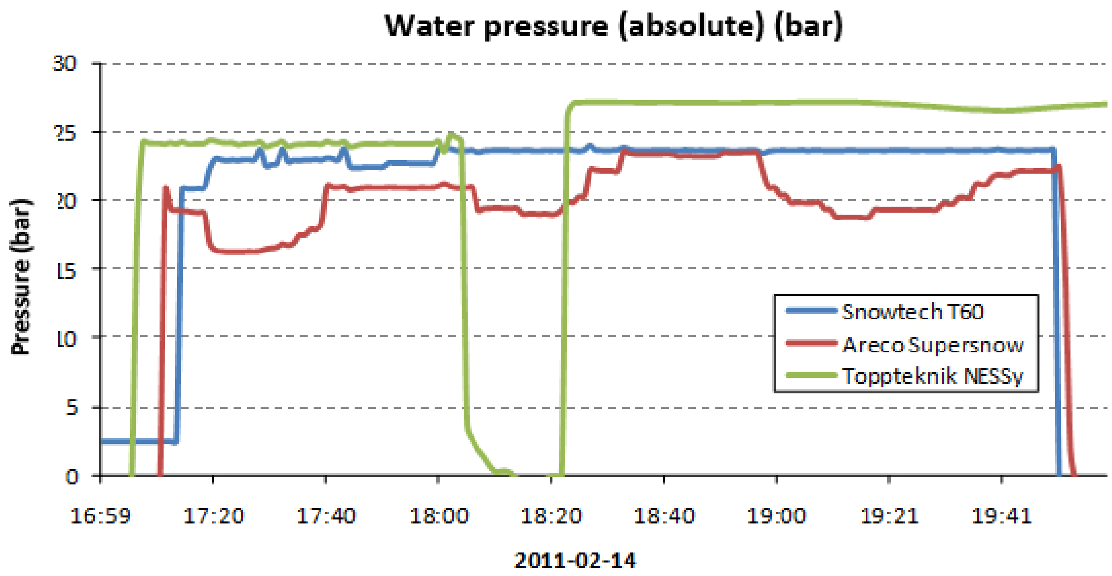


Figure 4-16: The graphs illustrate the water pressure in each measuring tube. The pressure sensors are sensitive for ice formation, which appears by the fact that i.e. the pressure exceeds 25 bar even though there is no flow.

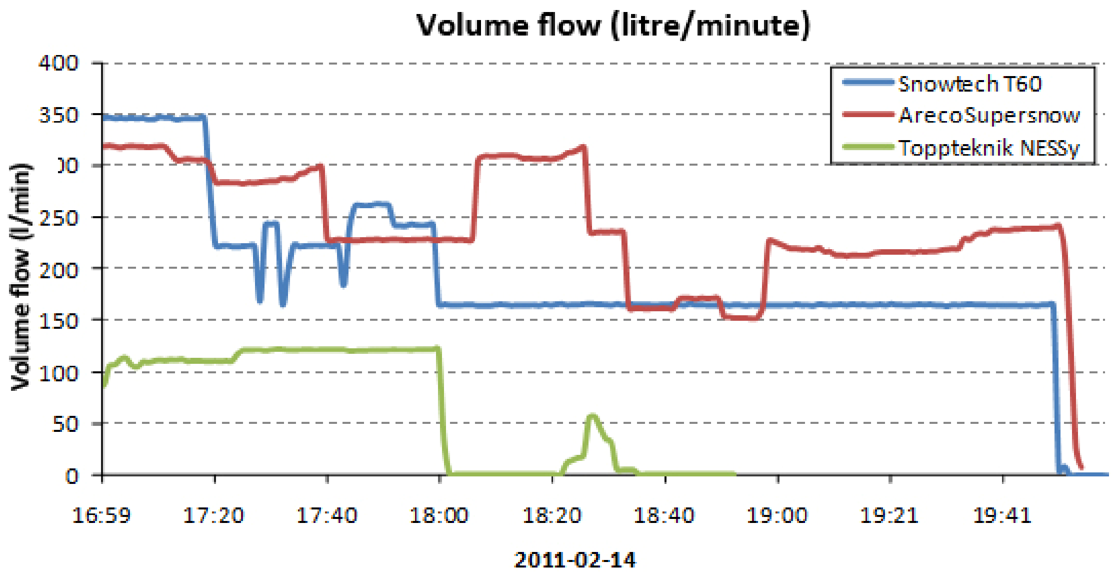


Figure 4-17: The figure illustrates the variations of water flow to each fan gun/lance during the test period.

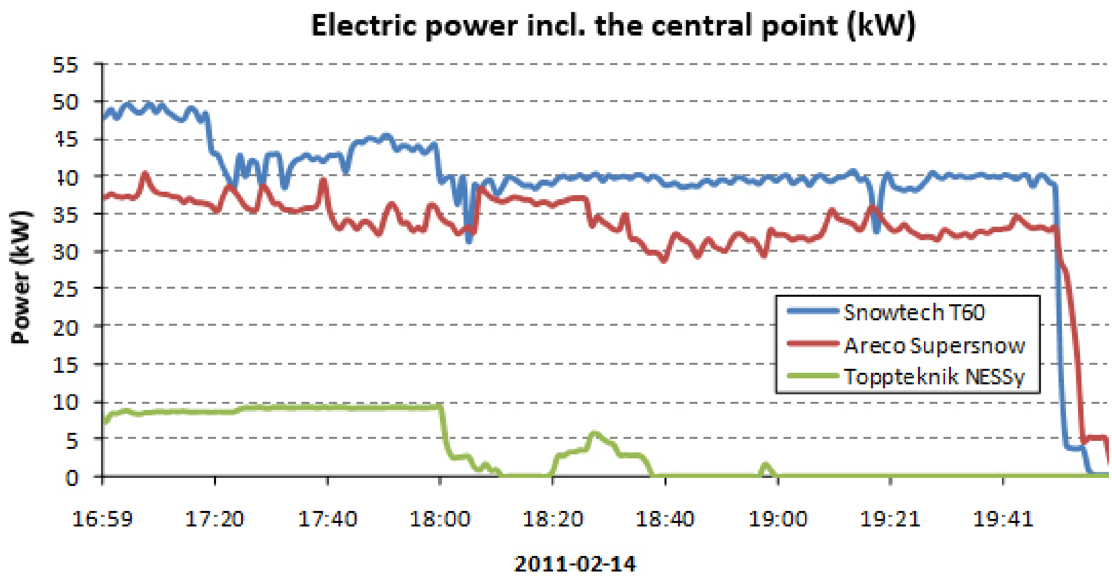


Figure 4-18: The figure illustrates the variations over time of the electric power. The central pump is included in the declared power

Climate and weather data

In Figure 4-19 to Figure 4-21 is the climate and weather data during this testing period presented. Figure 4-19 illustrates how the ambient temperature and dew point varied during the period. It was relatively cold during the evening with an average temperatures of -16 °C. The relative humidity (see red graph in Figure 4-20) fluctuated around 86 percent while the ambient pressure indicated a low pressure (blue graph in Figure 4-20).

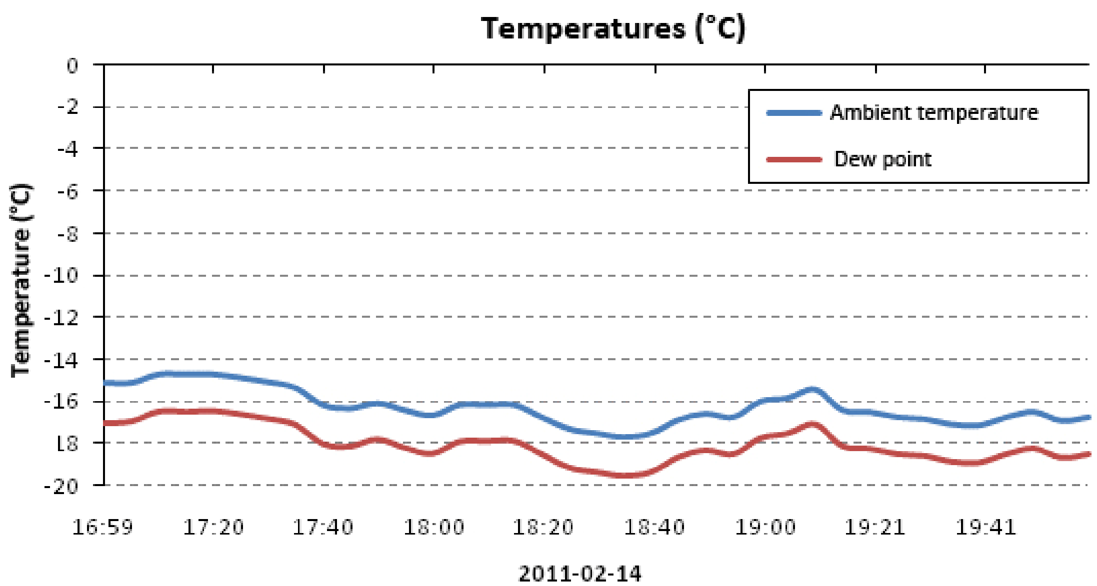


Figure 4-19: The ambient temperature varied between -14°C to -18°C during that night. The mean temperature was measured at -16°C.

It was almost windless during the evening of February 14. The average wind speed was less than 0.5 m/s, indicating a slight breeze. According to Figure 4-21 did the wind speed exceed 1 m/s at only two occasions during the measuring period. Further, the test was conducted in the evening, which meant that the sun's rays, according to Figure 4-21, were constantly 5.6 W/m2.

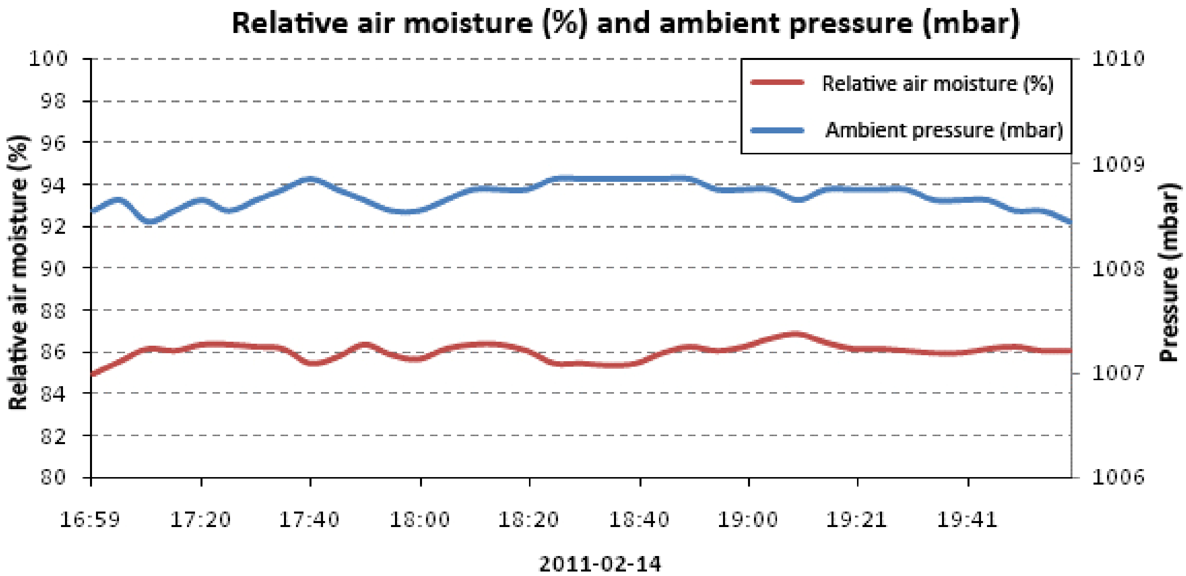


Figure 4-20: The relative air humidity and the ambient air pressure were relatively stable during the measuring period.

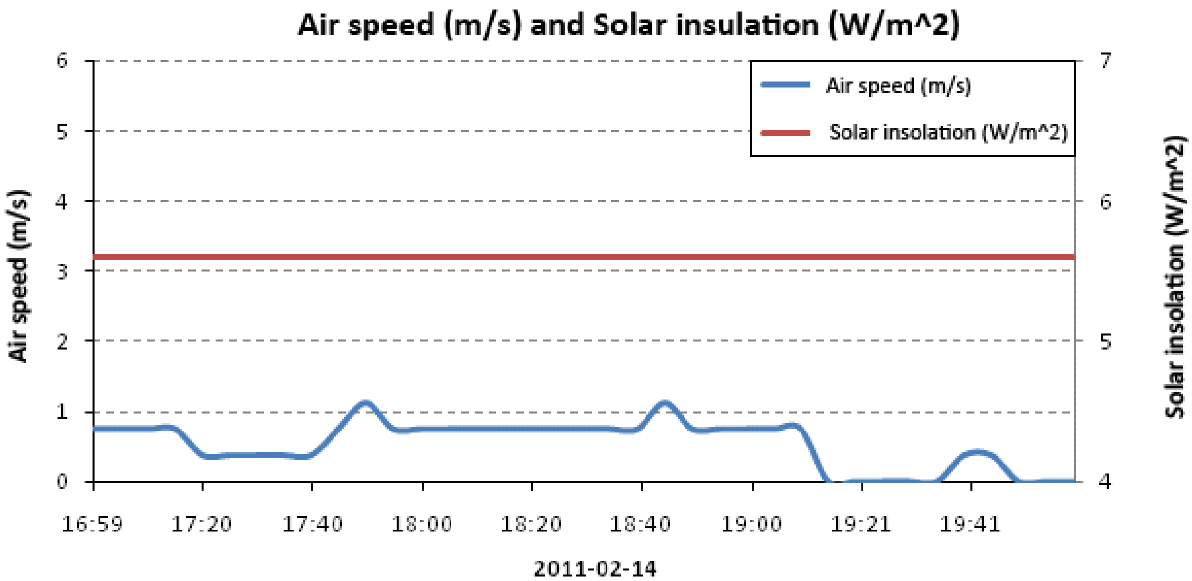


Figure 4-21: The figure shows the wind speed and the solar insulation as a function of time. The solar radiation was unchanged during the night since the sun had had gone down.

Compilation of results and key figures

Table 3 summarizes the data produced in the tests. The table provides two types of snow volumes, namely gross and net volume. Gross volume bases the estimated snow volume on the assumption that all the added amount of water turns into snow. This snow volume is calculated from the previous description of medium density as input parameter. The net volume is the measured volume in which measurements are carried out after each test.

The ratio between the measured amount of snow and the estimated output provides an indication of the reliability of results. The ratio should, in theory, be less than one (ratio <1). If the ratio between net and gross volume is just under one (0.7 <ratio <1) – then this indicates that the estimated mass of snow and the result obtained is in good agreement. The measurement values have therefore high reliability.

Table 3: Summary of results from the test February 14.

TEST 2.1: 2011-02-14 Kl. 17:00 to 20:00	Snowtech T60	Areco Supersnow	Toppteknik NESSy
Used power (excl. central pump) [kWh]	88,4	62,5	3,8
Used power to the central pump [kWh]	31,8	38,8	6,9
TOTAL POWER USED [kWh]	**120,2**	**101,3**	**10,8**
Total used water volume [m^3]	35,4	43,3	7,7
Average density snow [kg/m^3]]	470	429	499
SNOW VOLUME GROSS [m^3]	75,4	101,0	15,5
SNOW VOLUME NET [m^3]	64,6	86,2	22,2
SNOW VOLUME AVERAGE [m^3]	**70**	**94**	**19**
TOTAL POWER PER GROSS VOLUME SNOW [kWh/m^3]	**1,59**	**1,00**	**0,70**
TOTAL POWER PER NET VOLUME SNOW [kWh/m^3]	**1,86**	**1,18**	**0,48**
TOTAL POWER PER AVERAGE VOLUME SNOW [kWh/m^3]	**1,72**	**1,08**	**0,57**
Other ratio			
Power to the central pump	26%	38%	64%
Power to gun/lance	74%	62%	36%
Power per volume amount water [kWh/m^3_water]	3,39	2,34	1,39
Proportion between net and gross volume of snow	0,86	0,85	1,43
	SUMMARY CLIMATE AND WEATHER DATA		
	At the start	Mean value	At the end
Ambient temperature [°C]	-15,1	-16,3	-16,7
Dew point [°C]	-17,1	-18,1	-18,5
Air moisture [%]	85%	86%	86%
Air speed [m/s]	0,8	0,5	0,0
Solar insolation [W/m^2]	5,6	5,6	5,6

Figure 4-22 illustrates the results from the snow volume measurments performed after each completed test. The figure depicts snowfall position seen from above. The level 0 m presents the starting point for the fanguns and the lance. From the figure it is possible to deduce where the produced amount of snow has accumulated, i.e. the actual "hit" of the fan guns and the lance. The figure also shows snow depth at different positions; based on estimated snow depth since snowfall (net volume).

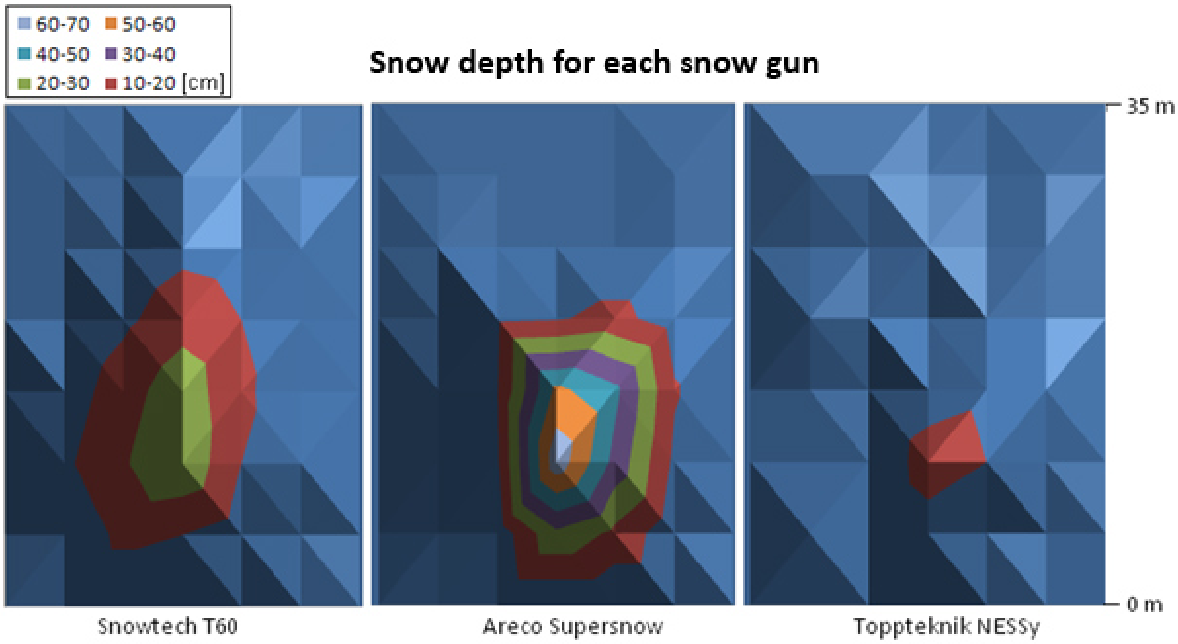


Figure 4-22: The figure illustrates the “hit point” for each fan gun/lance. From the figure is it possible to read the snow depth at different positions.

4.2.2 Test 2.2 – Day 2, AM (15 February)

On February 15 started the first test at 10:00 am and ended at 01:00 pm. The participating suppliers were SnowtechT60, Areco Standard, and Toppteknikmodel Nessy.

Figure 4-23 to Figure 4-27 presents the performance of the fan gun and the lance from the completed performance period. This is followed by the ambient conditions prevailing during the measurement period. Finally collated results and key figures in a table. The compilation also presents the snow depth in an illustrative figure with an image of the produced snow for each participant.

Performance of the snowmaking equipment

Figure 4-23 shows that the snow density from the participating units was in the same region during the second half of the performance period. During the first part of the test Nessy (green graph in Figure 4-23) showed a high density of 660 kg/m3 with a flow rate of 200 liters per minute (Figure 4-26). To reduce the density the lance was adjusted (change of nozzle) resulting in a shorter outage. The interruption is clear that the reduced flow / power output during the same time (Figure 4-26/Figure 4-27).

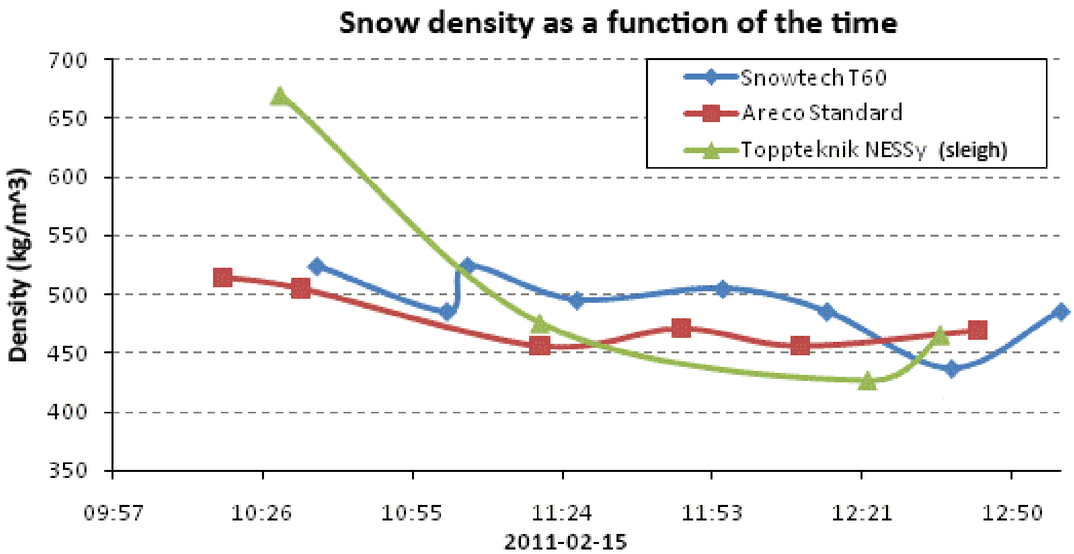


Figure 4-23: The figure illustrates how the snow density varies during the test for each fan gun/lance. During the second half of the test was the snow density relatively equal between the units.

Figure 4-24 and Figure 4-25 presents the results from the measurements of water temperature and water pressure for each measuring tube. The water temperature was almost the same for all participants during the period except during the time when adjustments were made of the lance. No problems with icing of pressure sensors were revealed during the test, as shown in Figure 4-25. Studying Figure 4-25 closer, it appears that SnowtechT60 and ToppteknikNessy (sled) has a relatively constant pressure. Comparing this with Areco Standard (red graph in Figure 4-25) it shows that this fan gun has automatic regulation resulting in pressure differences over time.

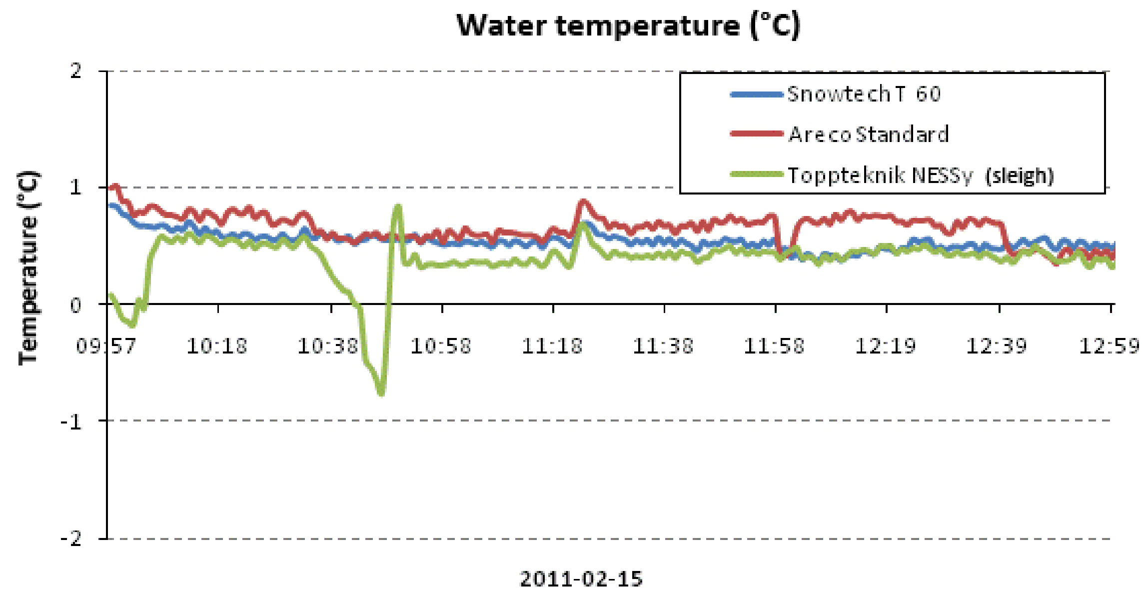


Figure 4-24: The graphs above show how the water temperature in the measuring tubes varies over time.

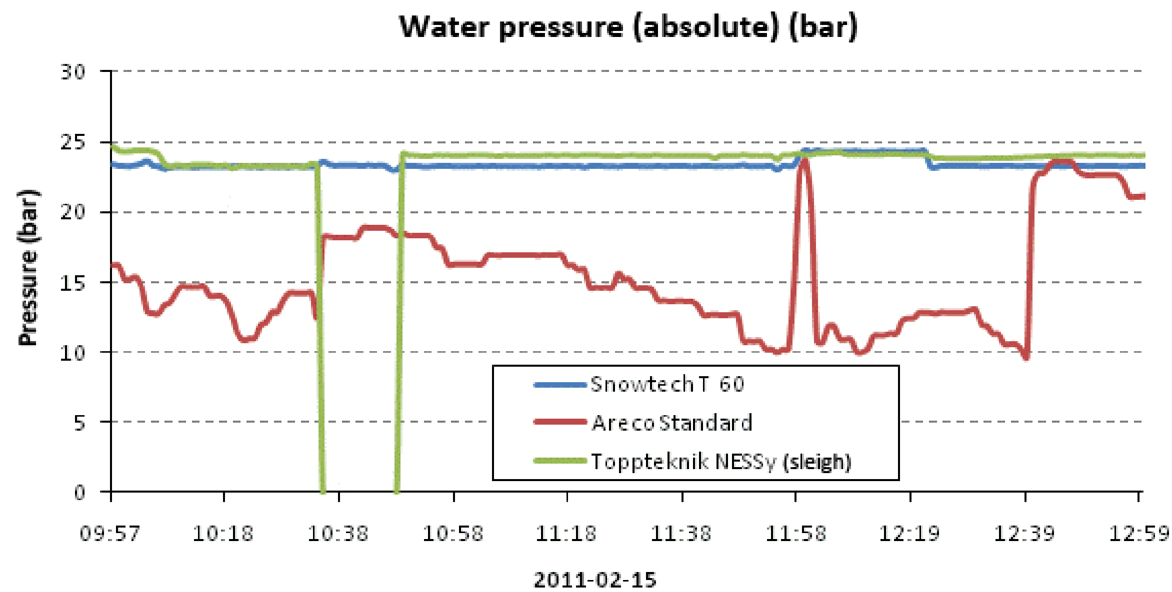


Figure 4-25: The graphs show the water pressure in each measuring tube during the test period. From the figure it can be read that no complications with icing of the pressure sensors occurred during the test.

Figure 4-26 illustrates how the flow of water to each fan gun/lance varied over the test period. From the figure it is possible to deduce how the adjustments of the lance affect its flow. According to the green graph (NESSy sled), was the flow 200 liters per minute before the change of nozzles. Then the flow was reduced to about 120 liters per minute. From the graphs, it also appears that SnowtechT60 and ToppteknikNESSy has a relatively constant flow during normal operation while Areco Standard (red graph) continuously regulate flow.

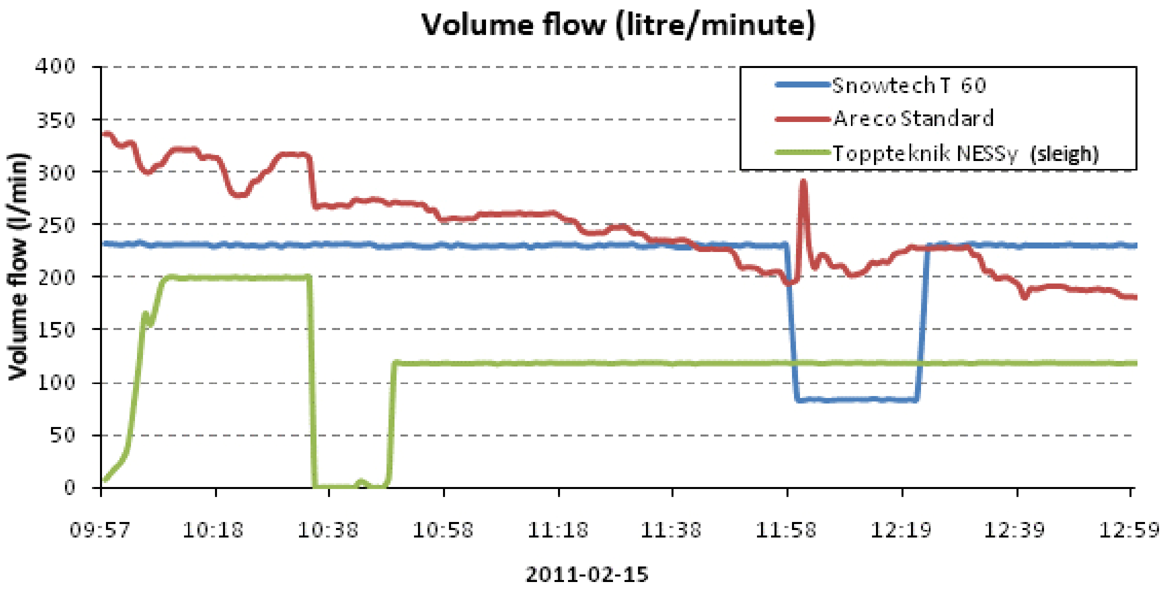


Figure 4-26: The figure illustrates how the water flow to each fan gun/lance varies during the test period.

The electrical power input to each gun and lance is shown in Figure 4-27. The blue graph in the figure (SnowtechT60), however, is misleading and not accurate. This is due to the relatively high electrical output which affects the energy meter's signal frequency. The energy meter sends out digital signals in the form of voltage pulses which are then interpreted by the data logger. The frequency of pulses (number of pulses per second) is proportional to the effect. A high-power creates a high frequency of pulses. If the power gets too high then the data logger is not capable of registering the pulses, which creates "dips" in power (as seen in Figure 4-27). It must be emphasized that this does not affect the outcome in terms of energy use. The energy is read manually from the energy meter before and after each completed test and is thus independent of the data logger registration.

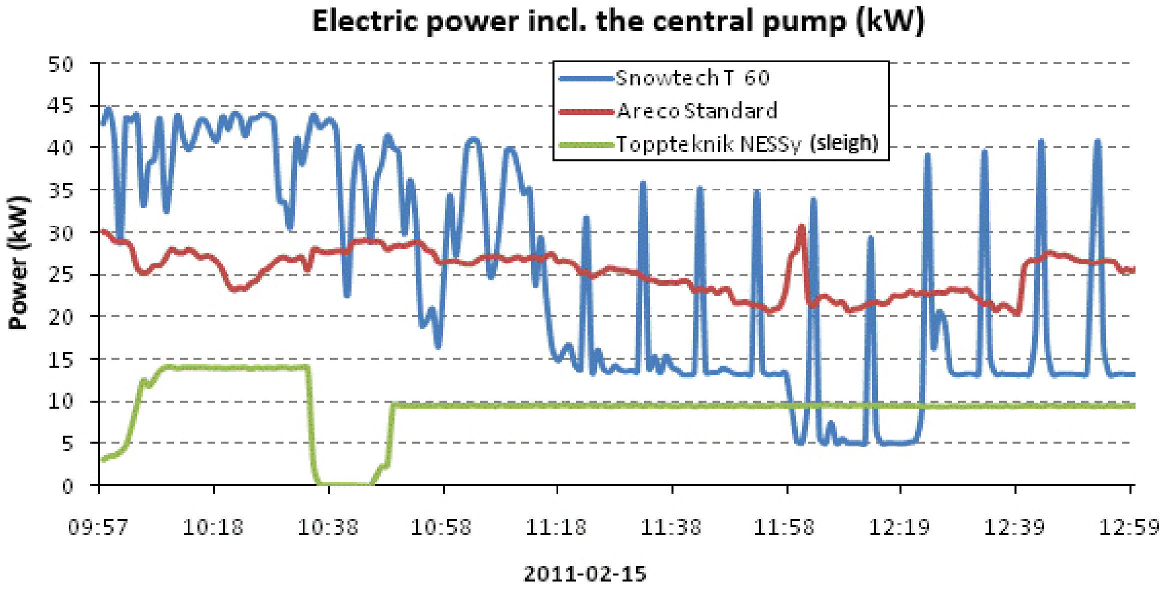


Figure 4-27: The figure illustrates how the electric power varies over time during the test.

Climate and weather data

The ambient temperature and the corresponding dew point are reported in Figure 4-27. The relative humidity (Figure 4-28) ranged around 88-89 percent during the test period. In Figure 4-29 is the data presented on how the wind speed and solar radiation varied. The wind speed was relatively low with a mean of 0.5 m/s, which corresponds to a slight breeze. The radiation from the sun, however, varied between 400 W/m^2 to 900 W/m^2 for the test. The high solar radiation above 900 W/m^2 at a single time is remarkable. This type of high solar radiation is otherwise common in the summer.

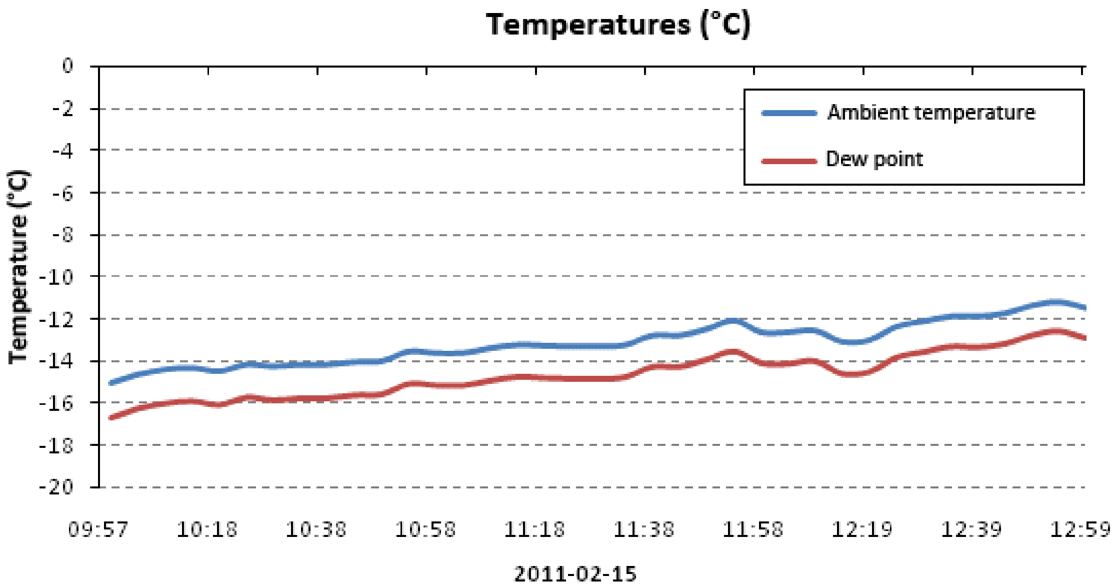


Figure 4-28: The ambient temperature varies between -15°C till -12°C during the early day. The mean temperature was measured to -13°C.

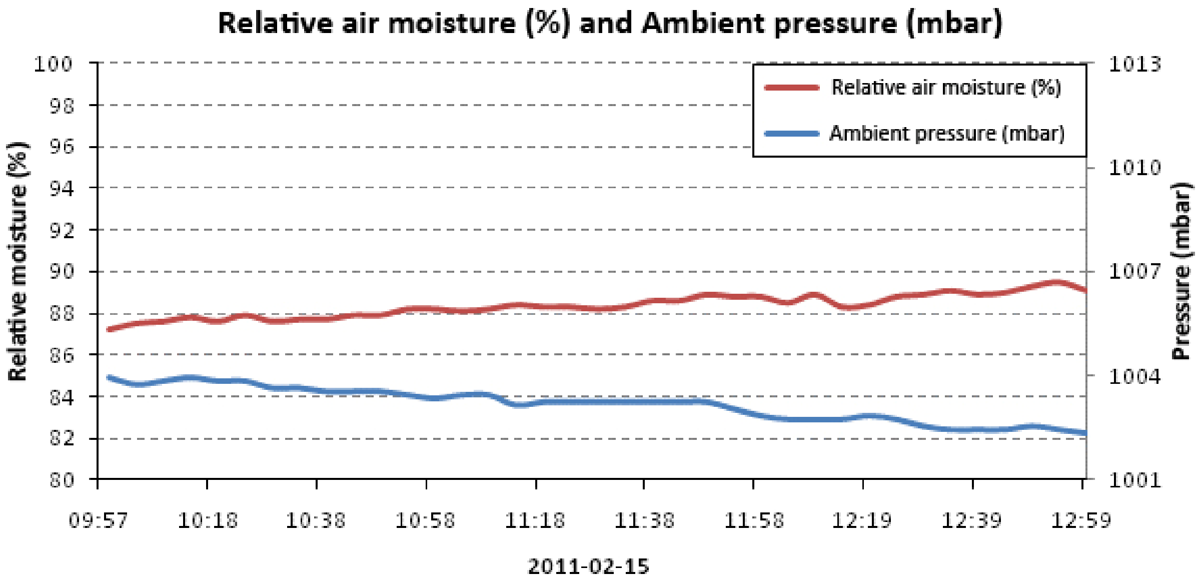


Figure 4-29: The relative air humidity and the ambient pressure were fairly stable during the test period.

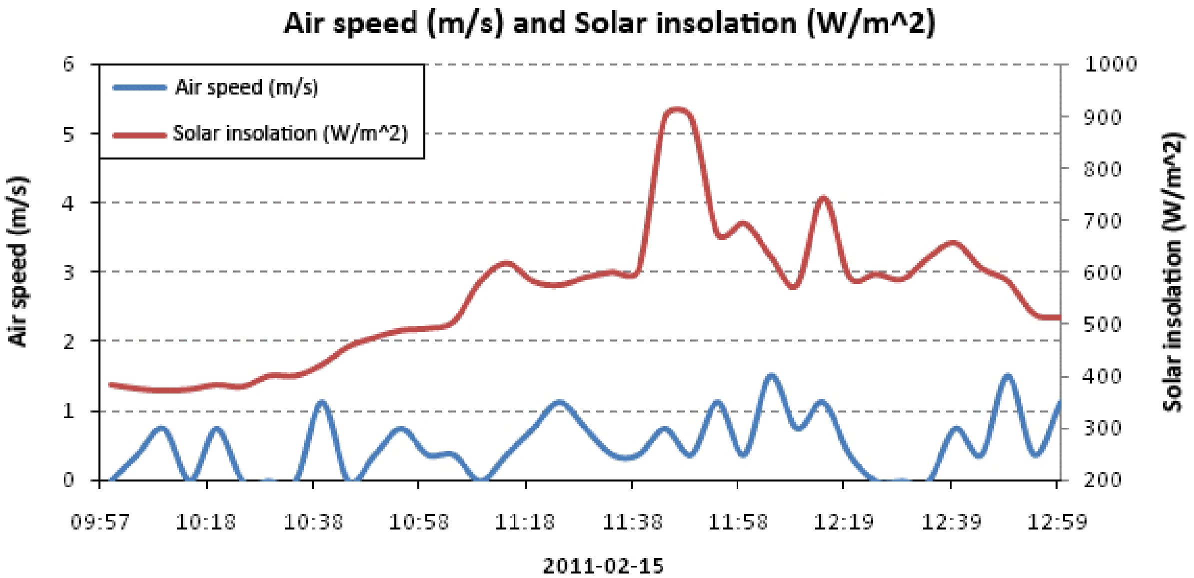


Figure 4-30: The figure shows the wind speed and the solar insulation as a function of time.

Compilation of results and key ratios

Table 4 summarizes the results and key figures obtained from the test. The amount of used electrical energy are, as noted above, manual readings from the energy meters. Like previously is the gross volume of snow on the estimated snow volume based on snowpack mean density. The net volume, on the other hand, is the actual measured volume. Figure 4-30 describes "the hit" of the produced amount of snow and also how the depth of snow is distributed in the target area.

Table 4: Compilation of results from the test February 15.

TEST 2.2: 2011-02-15 Kl. 10:00 to 13:00	Snowtech T60	Areco Standard	Toppteknik NESSy (släde)
Used power (excl. central pump) [kWh]	102,0	52,0	8,0
Used power to the central pump [kWh]	36,1	41,3	20,5
TOTAL POWER USED [kWh]	**138,1**	**93,3**	**28,5**
Total used water volume [m^3]	40,2	46,0	22,8
Average density snow [kg/m^3]]	492,7	478,7	509,7
SNOW VOLUME GROSS [m^3]	81,6	96,0	44,7
SNOW VOLUME NET [m^3]	53,9	94,9	26,7
SNOW VOLUME AVERAGE [m^3]	**68**	**95**	**36**
TOTAL POWER PER GROSS VOLUME SNOW [kWh/m^3]	**1,69**	**0,97**	**0,64**
TOTAL POWER PER NET VOLUME SNOW [kWh/m^3]	**2,56**	**0,98**	**1,07**
TOTAL POWER PER AVERAGE VOLUME SNOW [kWh/m^3]	**2,04**	**0,98**	**0,80**
Other ratio			
Power to the central pump	26%	44%	72%
Power to gun/lance	74%	56%	28%
Power per volume amount water [kWh/m^3_water]	3,44	2,03	1,25
Proportion between net and gross volume of snow	0,66	0,99	0,60
	SUMMARY CLIMATE AND WEATHER DATA		
	At the start	Mean value	At the end
Ambient temperature [°C]	-15,0	-13,15	-11,5
Dew point [°C]	-16,3	-14,7	-13,0
Air moisture [%]	87,2%	88,4%	89,1%
Air speed [m/s]	0	0,52	1,14
Solar insolation [W/m^2]	383	553	513

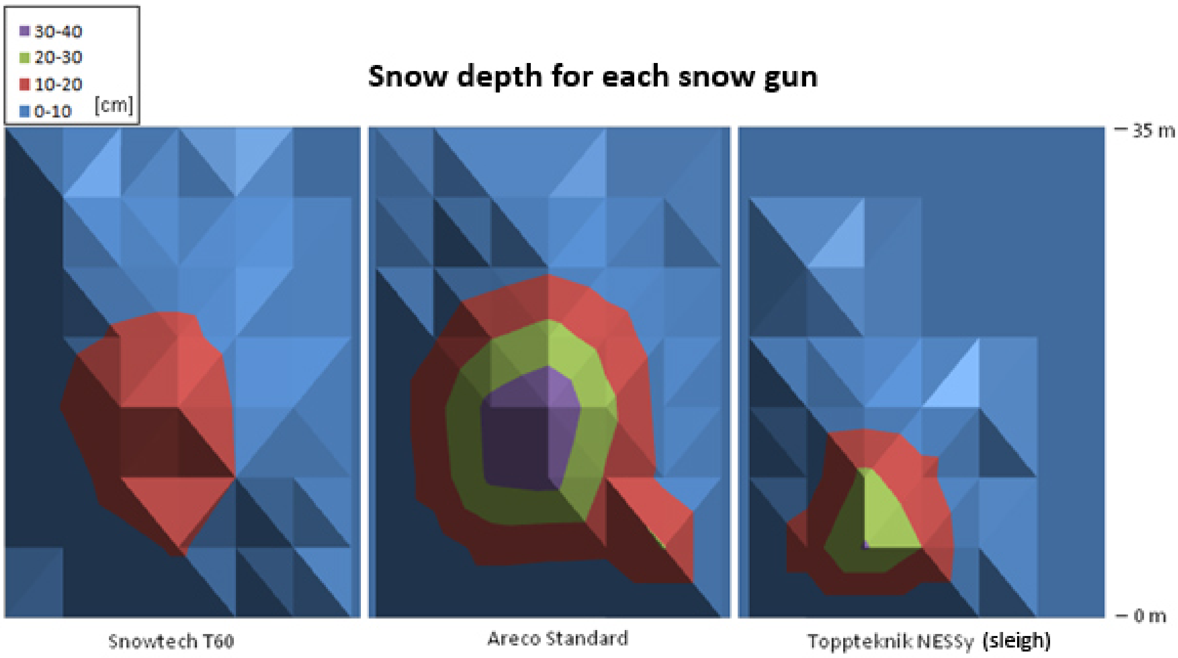


Figure 4-31: The figure illustrates the "the hit area" for each fan gun/lance. It is possible to read the snow depth at different positions from the figure.

4.2.3 Test 2.2 – Day 2, afternoon (February 15)

During the afternoon of February 15 was the second test for the day carried out. On this occasion attended only two suppliers of snow making; namely Snowtechwith a lance, and Johnson Controls with a lance. The measurement period started just after three o'clock in the afternoon and ended just after six in the evening.

Like previously, we first present the performance results, followed by climate and weather data. Finally, a summary of interesting key indicators and results from the measurements are presented in in table form.

Performance of snowmaking equipment

Figure 4-31 shows how the density fluctuated during the measurement period. As shown by the two graphs were the density relatively similar between the two test objects. The average density was measured at 453 kg/m^3 (Snow Tech) and 464 kg/m^3 (Johnson Controls).

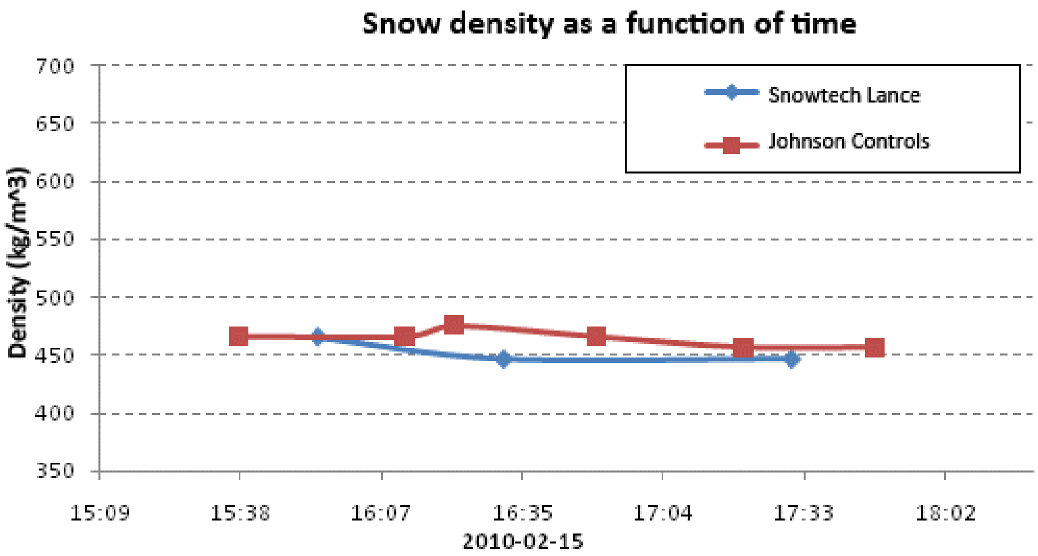


Figure 4-32: The figure illustrates how the snow density varies during the test for each lance. The snow density was similar for the two suppliers.

Figure 4-32 illustrates how the water temperature was changed during the test period. For most of the test the temperature ranged between 0.4° C to 1.0° C. The corresponding water pressure was virtually constant throughout the test for the two lances (see Figure 4-33). The blue graph in Figure 4-33 indicate two "pressure-spikes" at 04:30 pm and 05:10 pm. What this may have been due to is unclear - apart from these two exceptions were the two pressures almost identical.

As shown in the Figure 4-34 did the flows differ between the two suppliers. The lance from Johnson Controls (red graph) had a higher water flow during most of the performance period compared with the lance from Snow Tech. The difference is also reflected in Figure 4-35, in which the use of electrical power are presented. A stronger water flow results in increased pumping work, which also leads to a higher total electrical output.

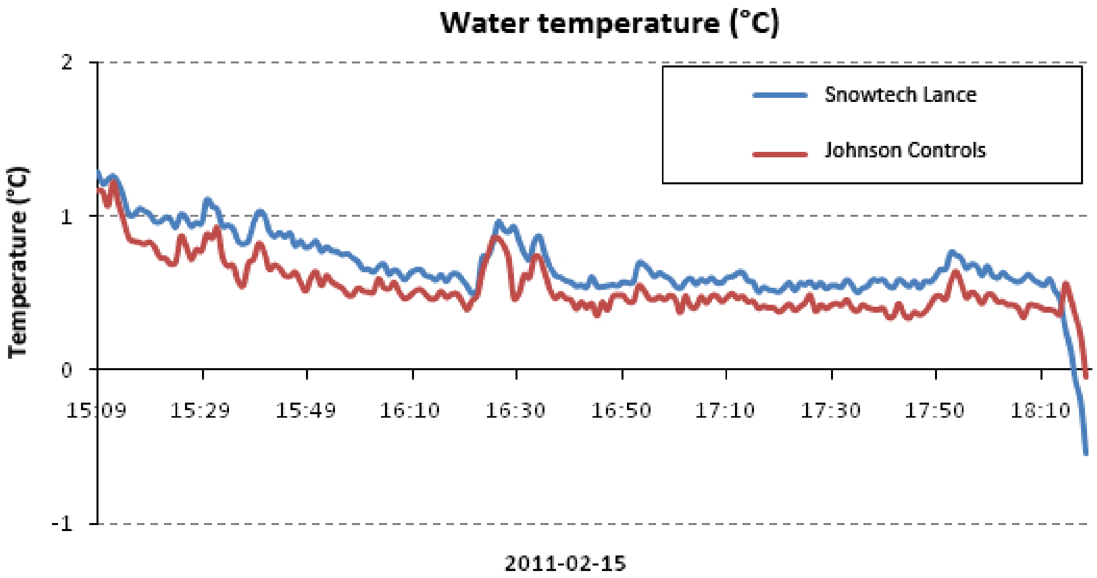


Figure 4-33: The graphs above show how the water temperature in the measuring tubes varies over time.

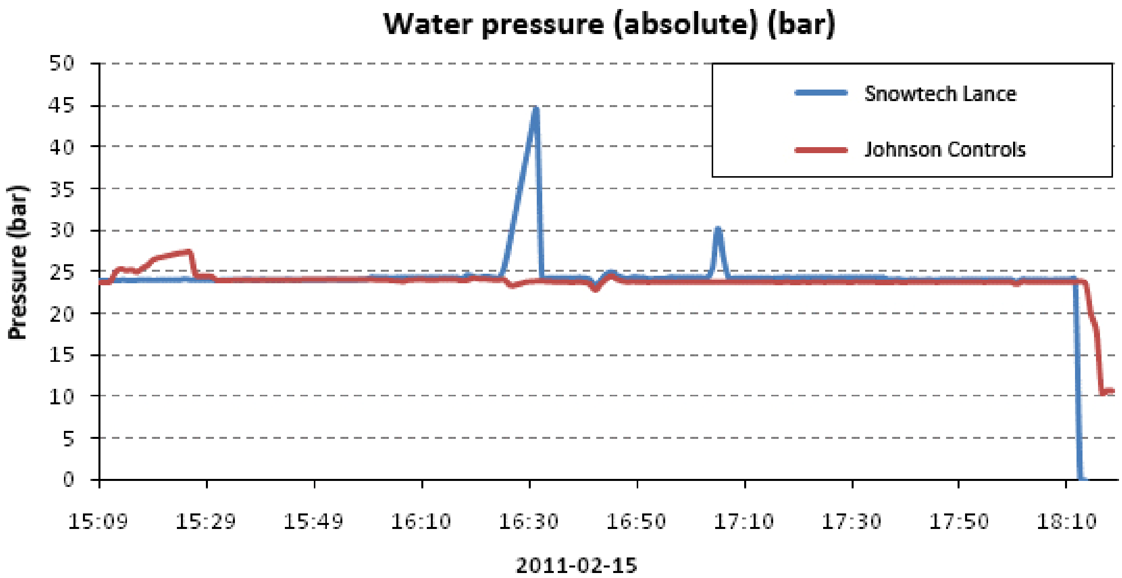


Figure 4-34: The graphs show the water pressure in each measuring tube during the test period.

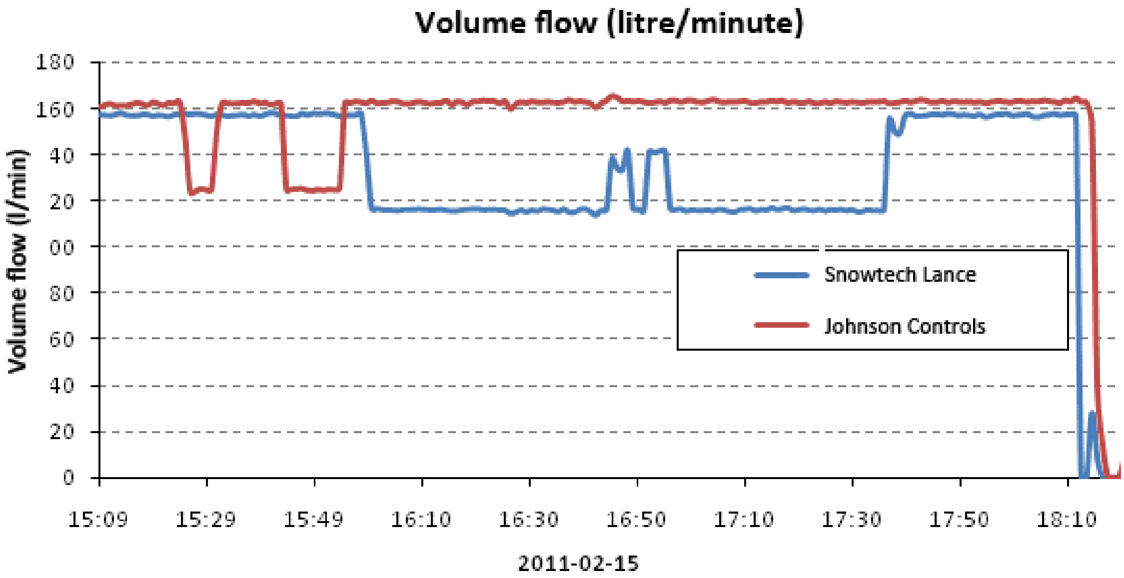


Figure 4-35: The figure illustrates how the water flow to each fan gun/lance varies during the test period.

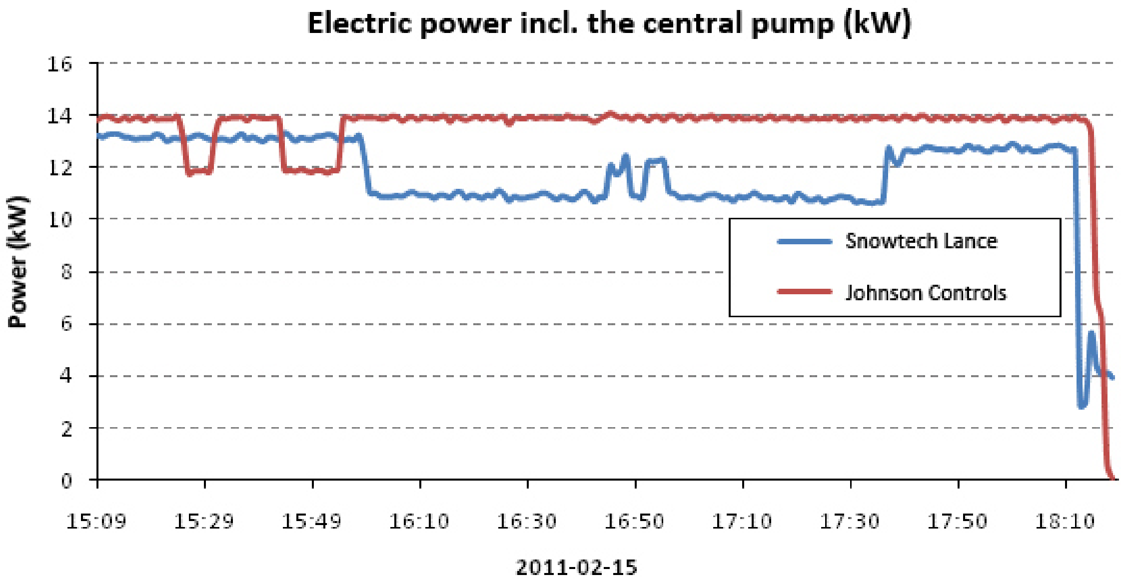


Figure 4-36: The figure illustrates how the electric power varies over time during the test.

Climate and weather data

During the test period was the ambient temperature almost constant (see Figure 4-36). The average temperature was measured at -11° C during the night. The relative humidity (Figure 4-37) increased gradually during the test from around 88 Percent to 90 Percent. The ambient air pressure indicated on a low pressure when the mean value during the measurement period amounted to 1000 mbar.

The wind speed ranged throughout most of the test between 0 m/s and 1 m/s with an average wind speed of 0.6 mph (light winds). According to Figure 4:38 were the solar radiation most noticeable during the beginning of the test. In the second half of the performance period, the sun had gone down with the result that the radiation from the sun basically ceased.

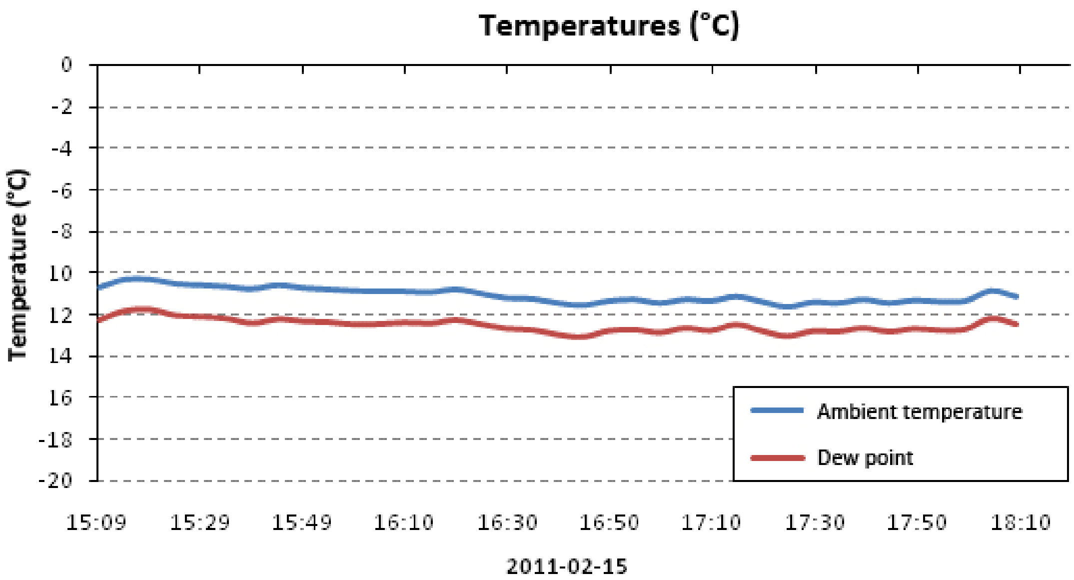


Figure 4-37: The ambient temperature varied between -10°C till -12°C during the night. The mean temperature was measured to -11°C.

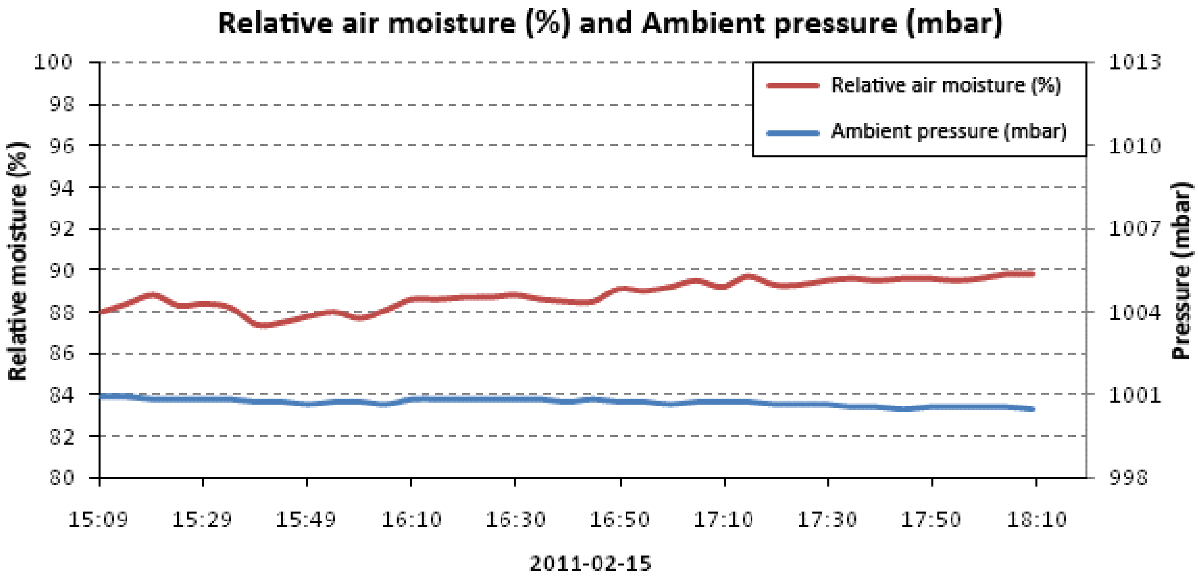


Figure 4-38: The relative air humidity and ambient pressure was fairly stable during the performance period.

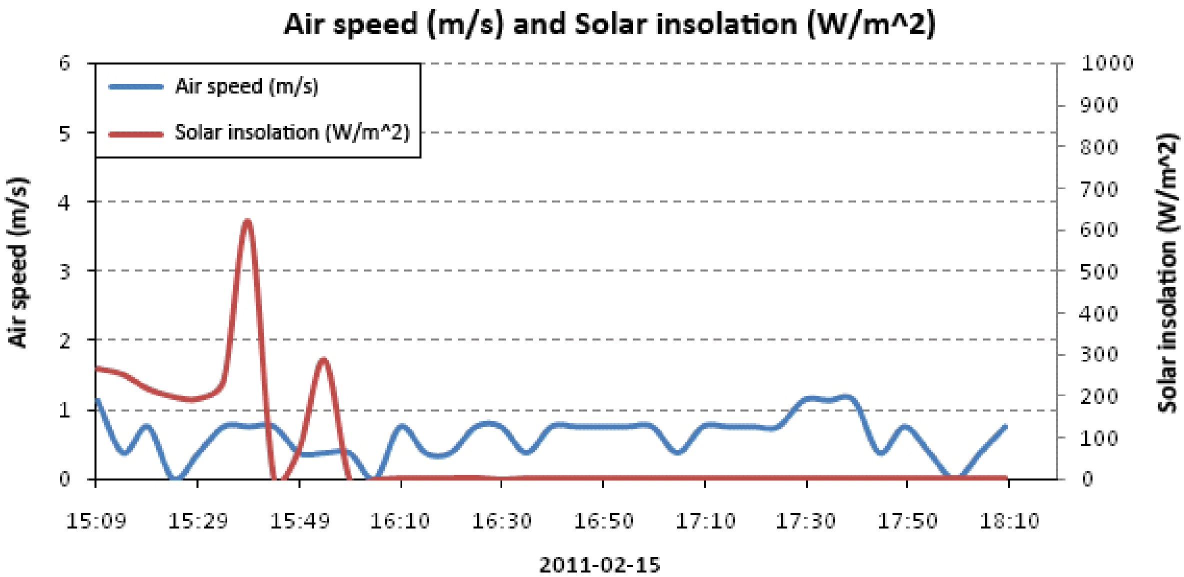


Figure 4-39: The figure shows the wind speed and the solar insulation as a function of time. The solar radiation was most notable during the first hour of the test.

Compilation of results and key figures

Table 5 summarizes the results and key figures obtained from the second test February 15. Figure 4-39 shows how the production quantity of snow from each lance has been allocated in the target area. The snow depth at different positions can be read from the figure.

Table 5: Compilation of the results from the second test February 15.

TEST 2.2: 2011-02-15 Kl. 15:10 to 18:10	Snowtech Lans	Johnson Controls Lans	
Used power (excl. central pump) [kWh]	15,6	17,0	
Used power to the central pump [kWh]	22,6	26,8	
TOTAL POWER USED [kWh]	**38,2**	**43,8**	
Total used water volume [m^3]	25,2	29,9	
Average density snow [kg/m^3]]	453,1	464,4	
SNOW VOLUME GROSS [m^3]	55,5	64,3	
SNOW VOLUME NET [m^3]	50,0	53,7	
SNOW VOLUME AVERAGE [m^3]	**53**	**59**	
TOTAL POWER PER GROSS VOLUME SNOW [kWh/m^3]	**0,69**	**0,68**	
TOTAL POWER PER NET VOLUME SNOW [kWh/m^3]	**0,76**	**0,82**	
TOTAL POWER PER AVERAGE VOLUME SNOW [kWh/m^3]	**0,72**	**0,74**	
Other ratio			
Power to the central pump	59%	61%	
Power to gun/lance	41%	39%	
Power per volume amount water [kWh/m^3_water]	1,52	1,47	
Proportion between net and gross volume of snow	0,90	0,83	
	SUMMARY CLIMATE AND WEATHER DATA		
	At the start	Mean value	At the end
Ambient temperature [°C]	-10,7	-11,0	-10,5
Dew point [°C]	-12,3	-12,5	-12,5
Air moisture [%]	88,0%	88,8%	89,8%
Air speed [m/s]	1,14	0,62	0,76
Solar insolation [W/m^2]	267	66	4

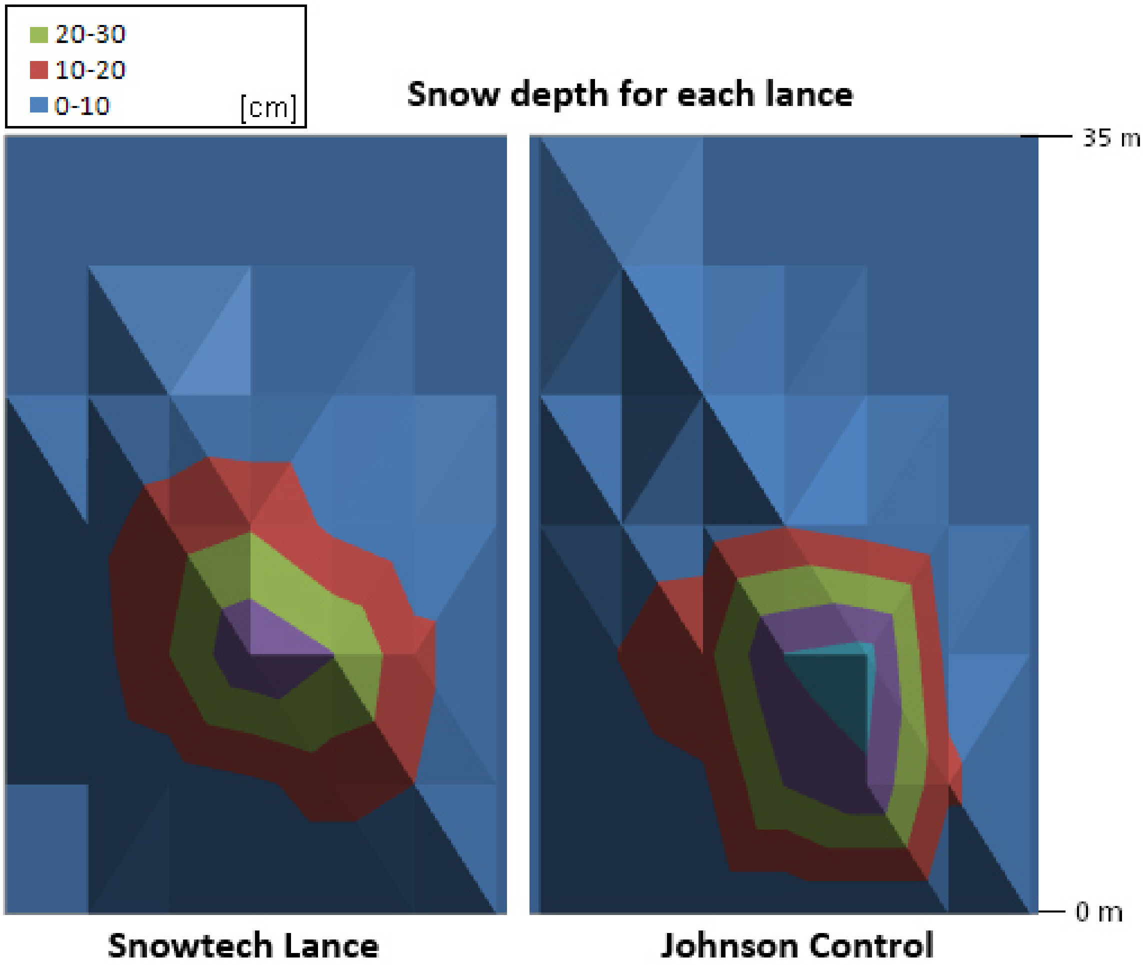


Figure 4-40: The figure illustrates "the hit rate" for each lance. The snow depth at different positions can be read from the figure.

4.2.4 Test 2.3 – Day 3, AM (February 16)

The morning test February 16 began at 09:35 in the morning. The participating suppliers in the test time was Areco with its standard model, Johnson Controls with its lance, and Toppkenik with NESSy. Due to an electrical fault, which sparked the current safety equipment after a litte more than two and a half hour, resulted in that data collection was suspended for half an hour earlier than planned.

<u>**Performance of snowmaking equipment**</u>
Figure 4-40 describes how the density varied during the test period. The results show that the density remained relatively stable in the range 400-450 kg/m^3 for all suppliers during the measurement period.

In Figure 4-41 the graphs illustrates how the water temperature was changed during the test. The figure declare, among other things, that the water temperature never went under 0.5° C. This indicates that there probably was no ice formation during the period. From the figure it also appears that Areco Standard (blue graph) had a slightly higher water temperature than the other participants.

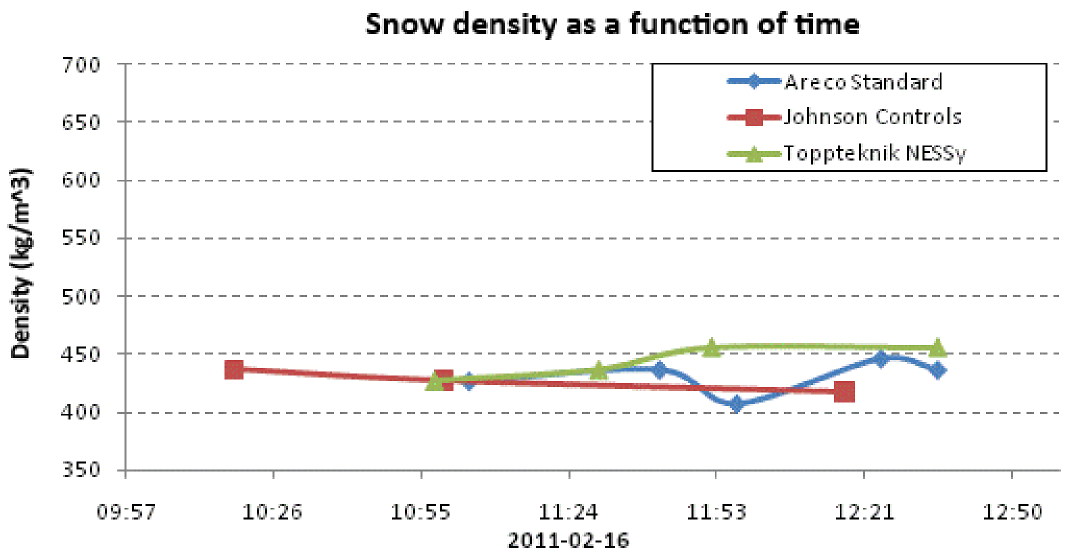


Figure 4-41: The graphs in the figure illustrate how the density varies during the test. The results show that the density was similar between the suppliers.

The water pressure and the water flow in the each measuring tube is displayed in Figure 4-42 and Figure 4-43. Studying how the water pressure varied during the measurement period, it appears that NESSy (green graph in Figure 4-42) started a little later than the others since no pressure was measured at the beginning of the test. If compared with Figure 4-42, a flow is however, shown in this period. This can be explained by that the flow tube was washed out continuously (while NESSy was adjusted) in fear of "ice plugs" in the measuring tubes. For this reason was there a flow but no pressure during the period when the water was drained out to the surrounding environment. Stable pressure and flow was registered shortly before 10:00 am - indicating normal operation.

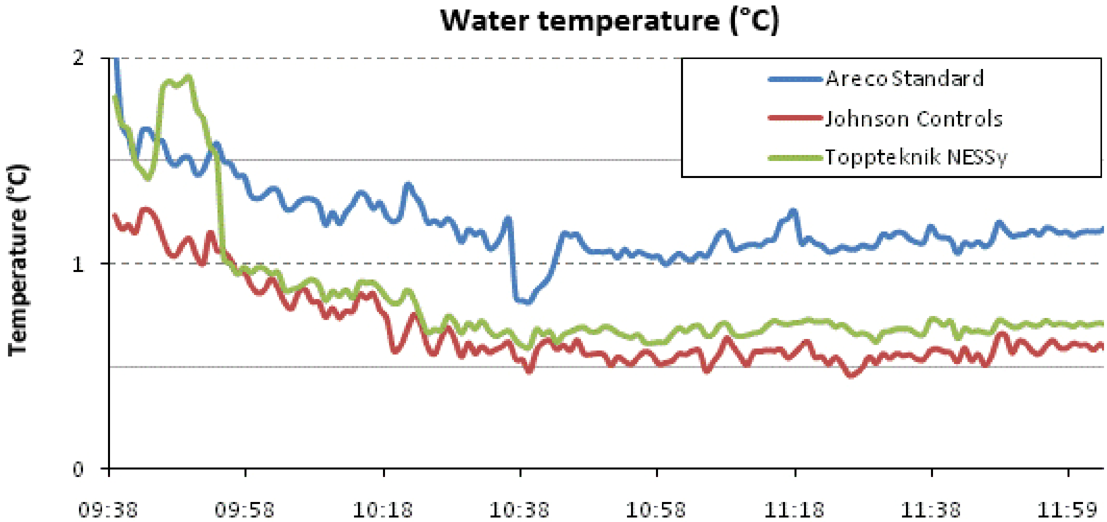


Figure 4-42: The graphs illustrate how the water temperatures in the measuring tubes alter during the measuring period. The blue graph (Areco) indicates that the water temperature in general has been slightly higher compared to the red graph (Johnson Controls) and green graph (Toppteknik).

From Figure 4-42 it also appears that the fan gun Areco Standard regulates the pressure continually, while the lances (red and green graph) is working with a constant pressure. Equal of the pressure produced by the central pump (the "maximum pressure").

The total use of electricity output is reported in Figure 4-44. From the figure it is clear that the fan gun, Areco Standard, has a higher power input compared with the respective lance (Johnson Controls and ToppteknikNESSy). This of course depends on the design, since fan guns have a fan to produce and distribute the snow.

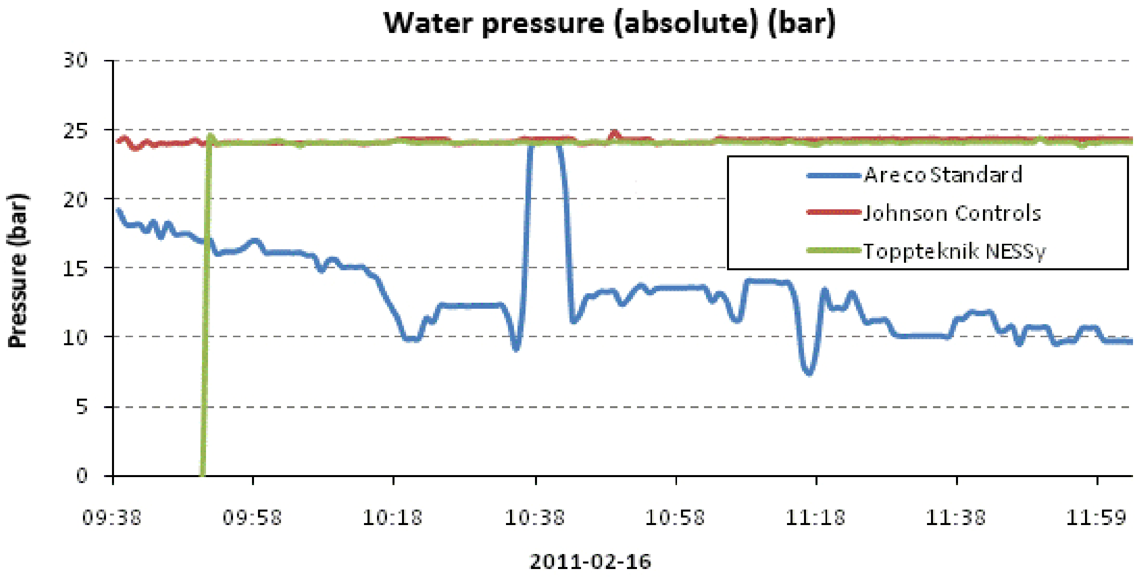


Figure 4-43: The graphs illustrate how the water pressure in each measuring tube varies over time.

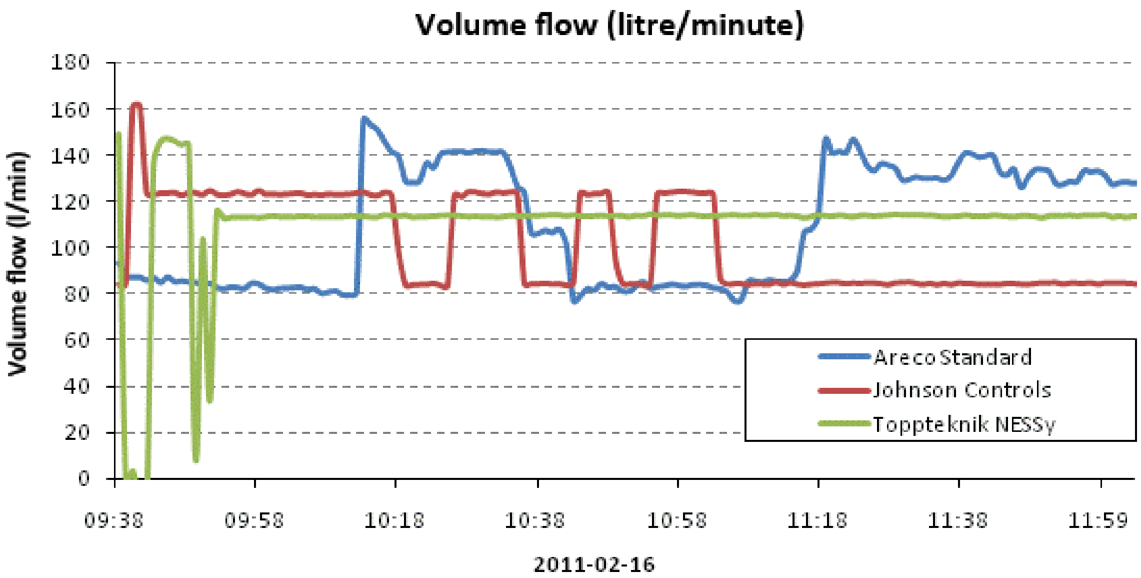


Figure 4-44: The graphs illustrate how the flow volume altered during the measuring period. The green graph show that the flow to NESSy varied in the beginning of the test – to keep a constant flow later on.

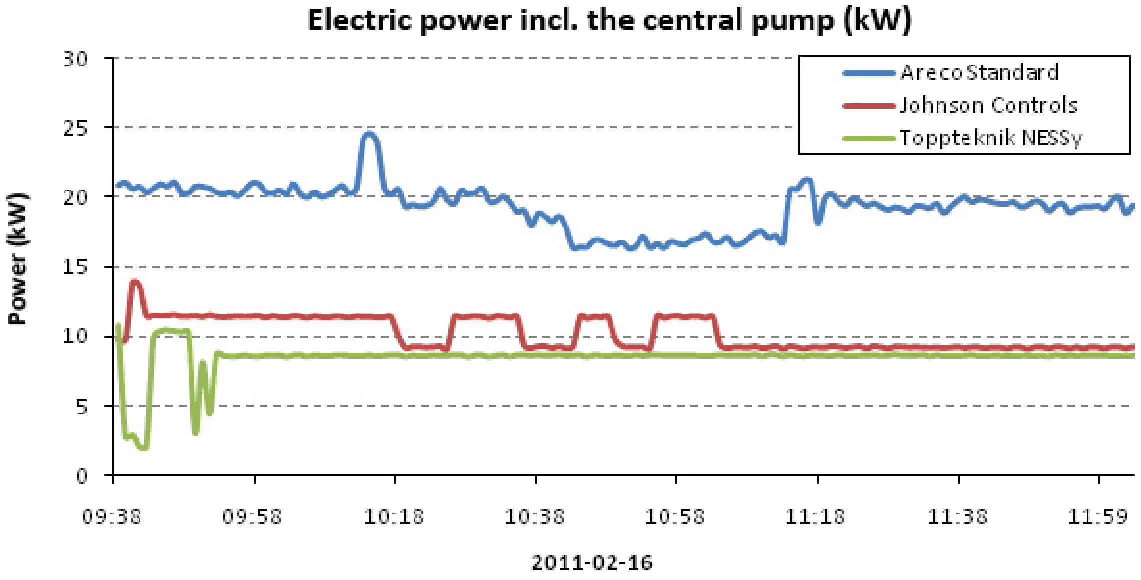


Figure 4-45: The figure shows the total power to each fan gun/lance.

Climate and weather data

Figure 4-45 to Figure 4-47 describes the climate and weather conditions that were present during the test period. The temperature profile (see Figure 4-45) shows a slight rise in temperature as the test proceeded. The average temperature was measured at 8° C while the dew point was on average -9° C in the same period.

The wind was relatively mild during the test with an average wind speed of 0.7 m/s (light winds). The solar insulation varied more (see Figure 4-46), where the mean value during the test was set at 388 W/m^2. The relative humidity and the ambient air pressure is presented in Figure 4-47.

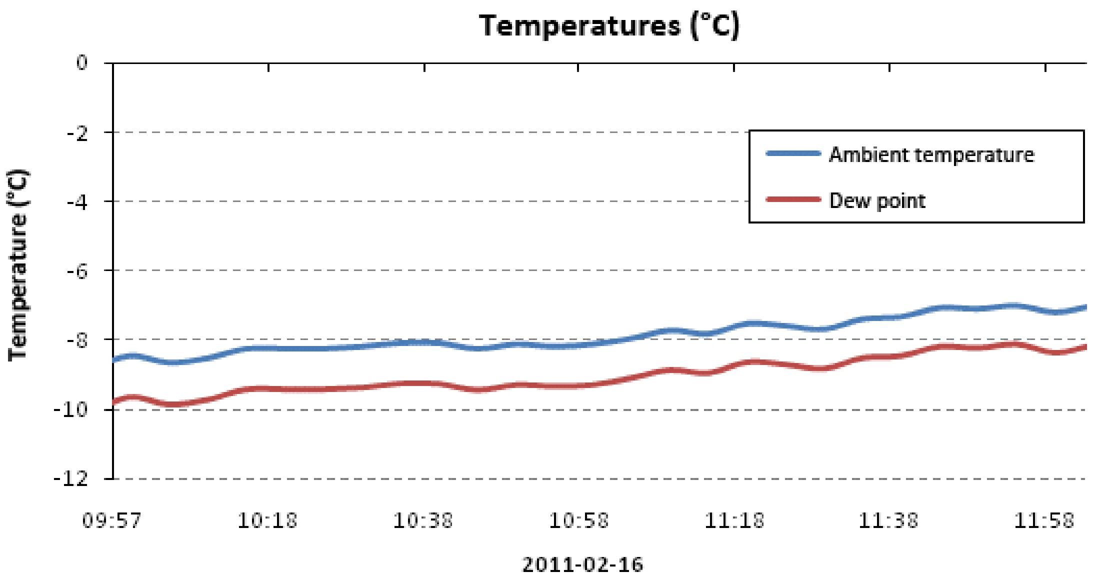


Figure 4-46: The ambient temperature and corresponding dew point during the test period.

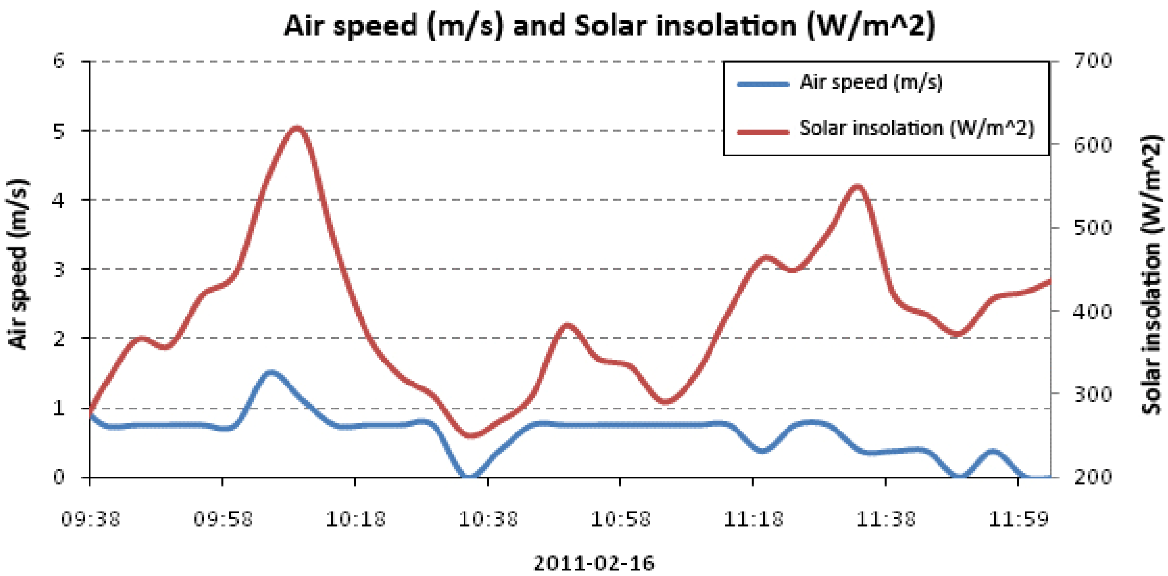


Figure 4-47:The wind speed and solar insulation as a function of time.

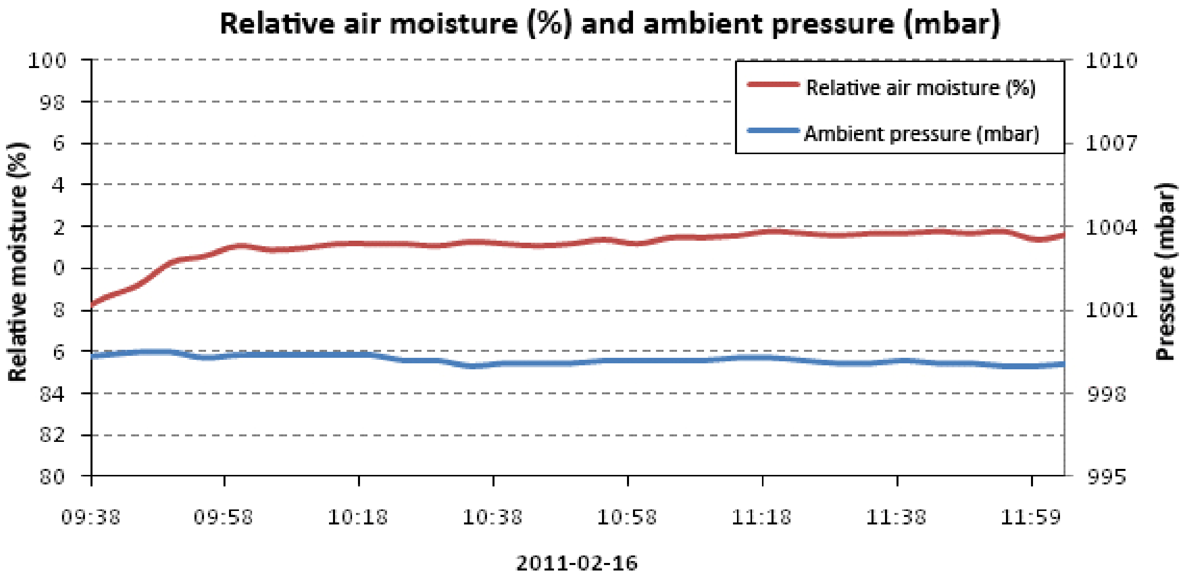


Figure 4-48: The relative humidity and the ambient pressure during the measuring period. The relative humidity increased during the test with 4 percent.

Compilation of results and key figures

Table 6 below summarizes the results and key figures that was developed after the conducted test. As described in the introduction to this subchapter was there an electrical fault at the end of the test period. The consequence of error was that the earth fault breaker "tripped" and that the data logging was interrupted. The error did not receive attention until the test should actually have been completed. This resulted in that the measurement data from the last half hour could not be saved. By contrast, did the snow production proceed until about 12:35 pm. In this way is the snow volume (net) is overestimated in comparison to other values. These data is therefore indicated in red in the table. Chapter 4.3 - "Summary of test results" do not include the red values in the analysis. This chapter is not affected by the electric fault. Other values (results and key figures) are correct in relation to the measuring period.

In Figure 4-48 is the results of the level measurements for snow depth reported. The measurements were taken after each test .

Table 6: Compilation of results from the first test February 16.

TEST 2.3: 2011-02-16 Kl. 09:35 to 12:05 (2 ½ h)	Areco Standard	Johnson Controls	Toppteknik NESSy
Used power (excl. central pump) [kWh]	32,8	11,7	6,2
Used power to the central pump [kWh]	14,5	13,4	14,6
TOTAL POWER USED [kWh]	**47,3**	**25,1**	**20,8**
Total used water volume [m^3]	16,1	14,9	16,3
Average density snow [kg/m^3]]	431,1	427,2	456,3
SNOW VOLUME GROSS [m^3]	37,4	34,9	35,6
SNOW VOLUME NET [m^3]	34,8	36,2	41,6
SNOW VOLUME AVERAGE [m^3]	**36**	**36**	**39**
TOTAL POWER PER GROSS VOLUME SNOW [kWh/m^3]	**1,26**	**0,72**	**0,58**
TOTAL POWER PER NET VOLUME SNOW [kWh/m^3]	**1,36**	**0,69**	**0,50**
TOTAL POWER PER AVERAGE VOLUME SNOW [kWh/m^3]	**1,31**	**0,71**	**0,54**
Other ratio			
Power to the central pump	31%	53%	70%
Power to gun/lance	69%	47%	30%
Power per volume amount water [kWh/m^3_water]	2,93	1,68	1,28
Proportion between net and gross volume of snow	0,93	1,04	1,17
	SUMMARY CLIMATE AND WEATHER DATA		
	At the start	Mean value	At the end
Ambient temperature [°C]	-9,3	-8,0	-7,0
Dew point [°C]	-11,0	-9,3	-8,1
Air moisture [%]	87,6%	91,0%	91,7%
Air speed [m/s]	1,14	0,65	0,0
Solar insolation [W/m^2]	292	388	441

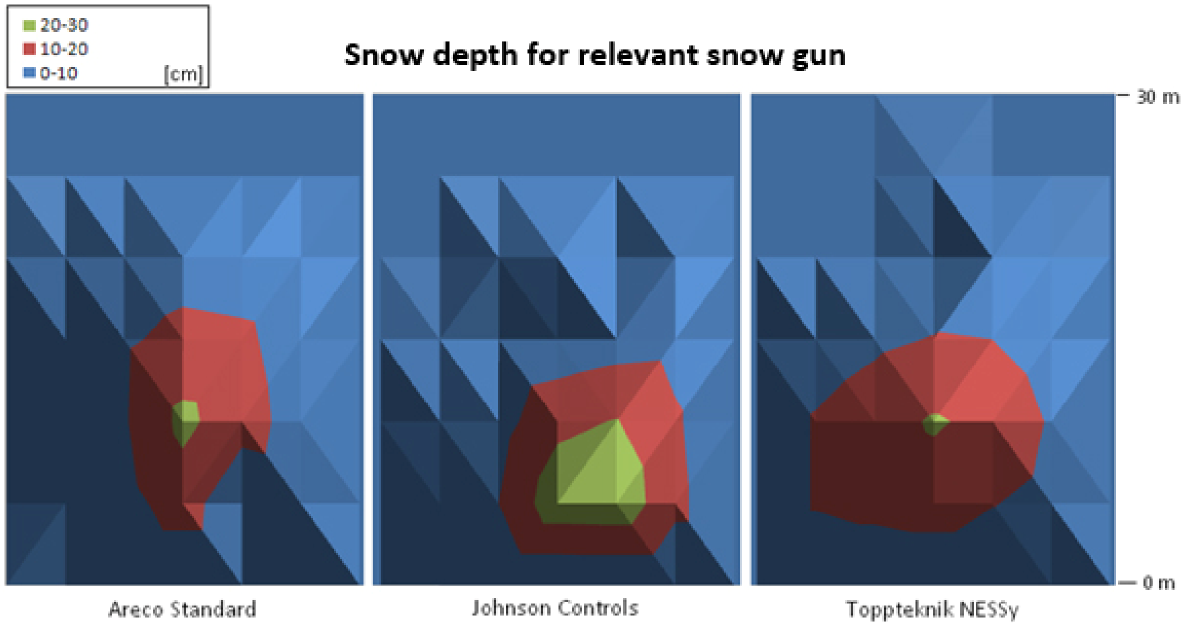


Figure 4-49: The figure illustrates the "hit rate" for each lance and fan gun after the test.

4.2.5 Test 2.3 – Day 3, afternoon (February 16)

The second test was conducted during the afternoon and evening of February 16; starting at 02:37 pm and ending at 05:37 pm. According to plan should three fan guns/lances have been tested at each occasion, but due to technical complications was one of those excluded. The test in the afternoon did only include two suppliers: namely Areco, Super Snow, and Snowtechwith its T40 model.

Performance of snowmaking equipment

Figure 4-49 below shows the results from the snow density tests that continuously was collected. According to the previous description and agreement were the aim to have the snow density at around 380 kg/m^3. It appeared, however, as the tests proceeded, that this objective was difficult to achieve. The objective was, however, obtained during this test session. As shown in the figure for snow density did the two fan guns produce snow with a density of about 380 kg/m^3, for a period of the test series.

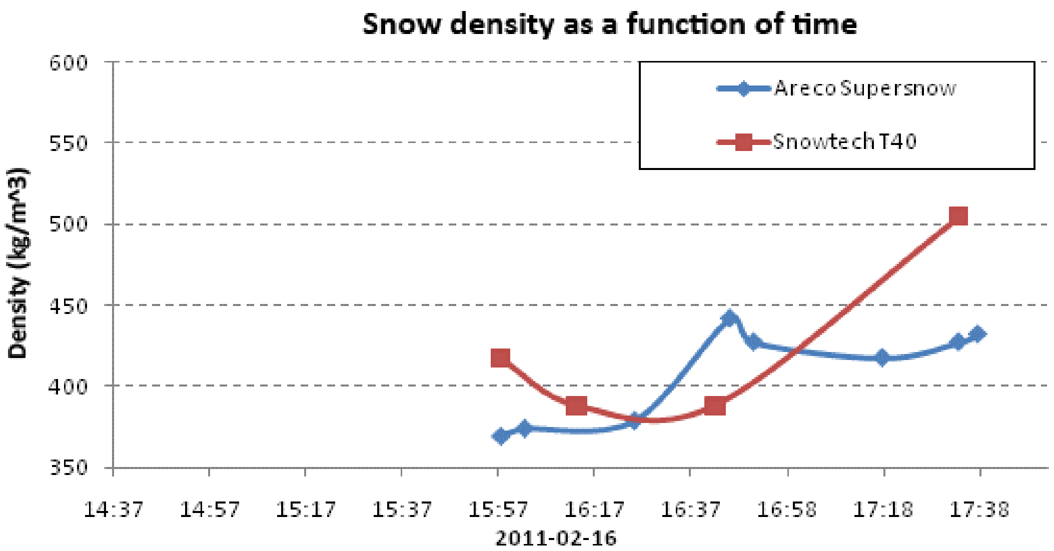


Figure 4-50: The graphs show the density and how it varies over time. The results indicate that the objective to have a density of 380 kg/m^3 was reached during the measuring period.

Figure 4-50 describes the water temperature in each measuring tube during the test. According to the graphs where the temperatures never below 0.5° C in any of the measuring tubes. This indicates that there probably was no ice formation. The temperature profile was relatively similar between the two fan guns. The water temperature was slightly higher for the Super Snow, as indicated by the blue graph in Figure 4-50.

The water pressure in the measuring tubes as a function of time is presented in Figure 4-51. The red graph in the figure shows how the pressure to SnowtechT40 remained relatively constant during the test. The pressure corresponding to the pressure the central pump unit supplies. The blue graph in the same figure shows how the pressure to Areco Supersnow fluctuated during the same period. In this case, the pressure is adjust to the fan gun which gives rise to the continuous pressure change.

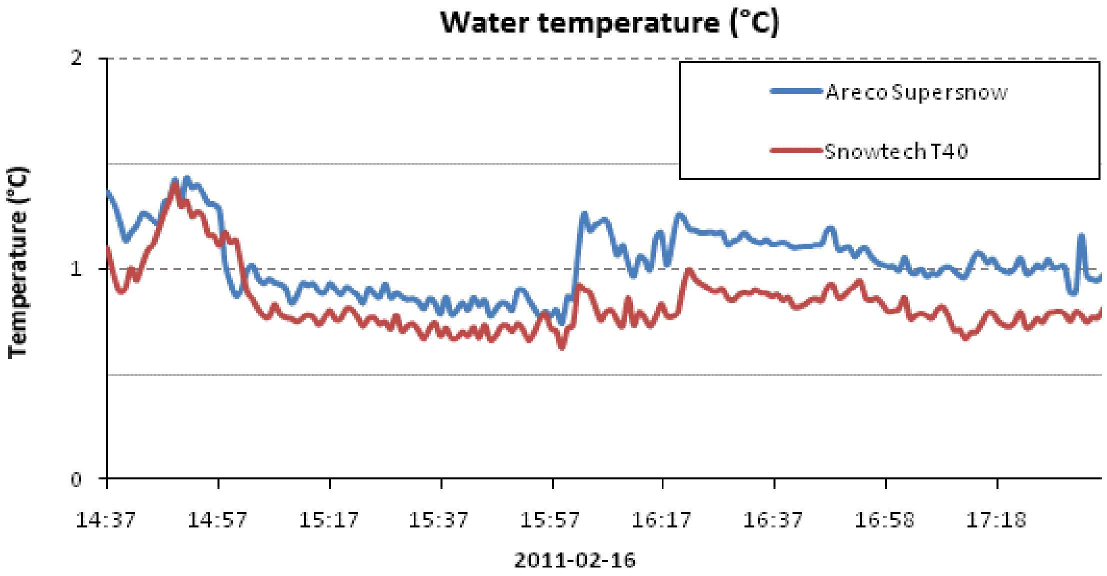


Figure 4-51: The temperature of the water during the test period.

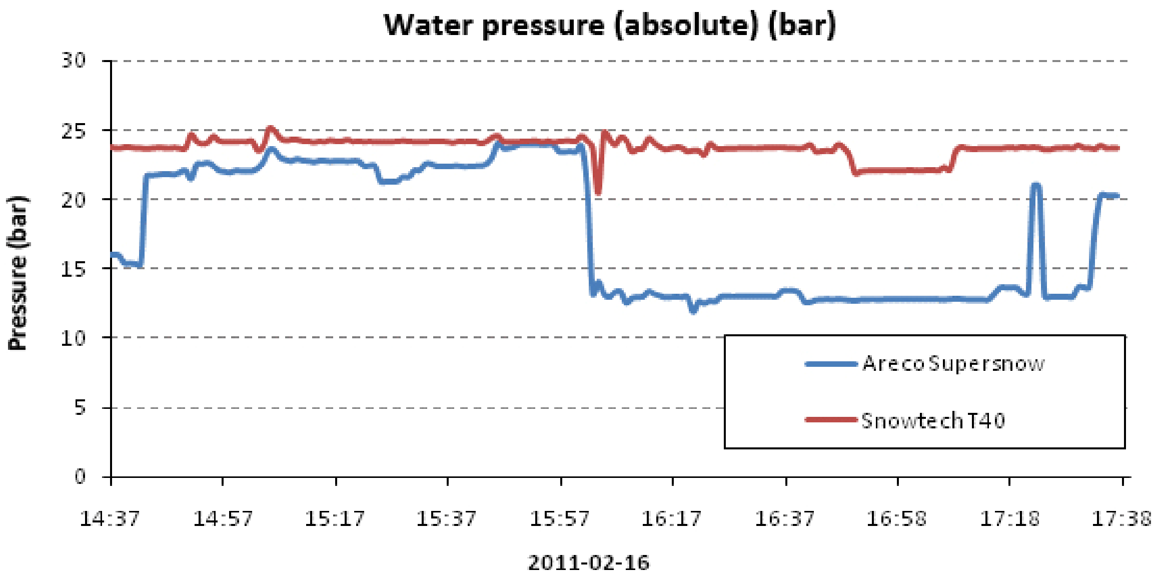


Figure 4-52: The graphs illustrate how the water pressure in each measuring tube varies during the test period.

Figure 4-52 illustrates the volume flow to each snowmaking unit. According to the graphs where the flow relatively similar for most of the test. However, the red graph in the figure (SnowtechT40) show that there was a greater flow of water around 05:00 pm. The large volume flow of about 300 liters per minute can explain the high snow density as the last snow sample illustrates in Figure 4-49.

Figure 4-53 declare the input power to each fan gun. This effect is the total electrical output, which thus includes the performance of the central pump.

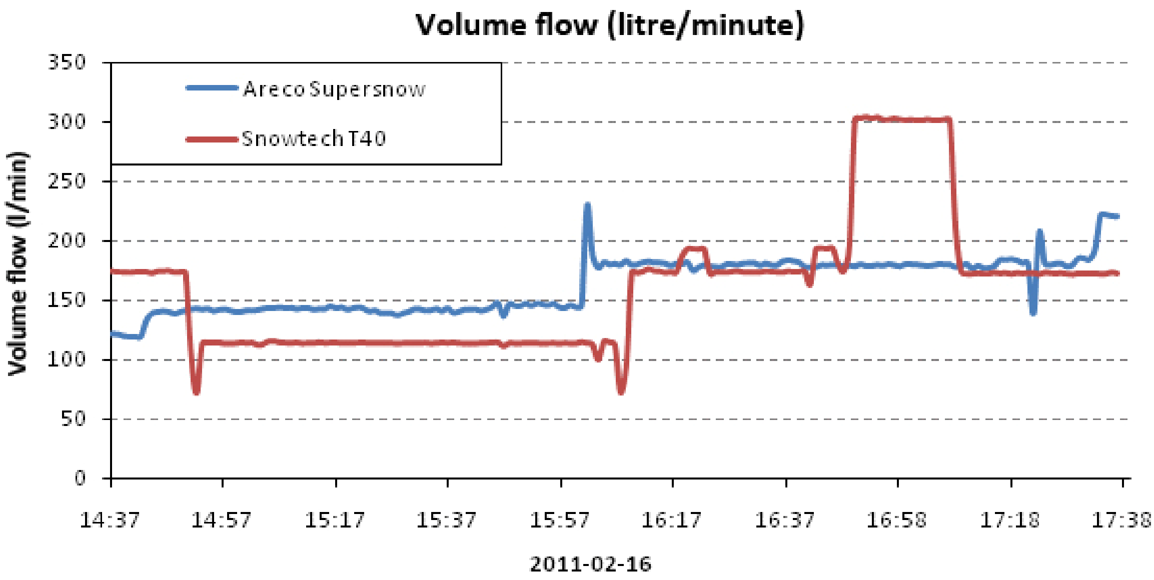


Figure 4-53: The graphs illustrate the volume flow of water to each fan gun.

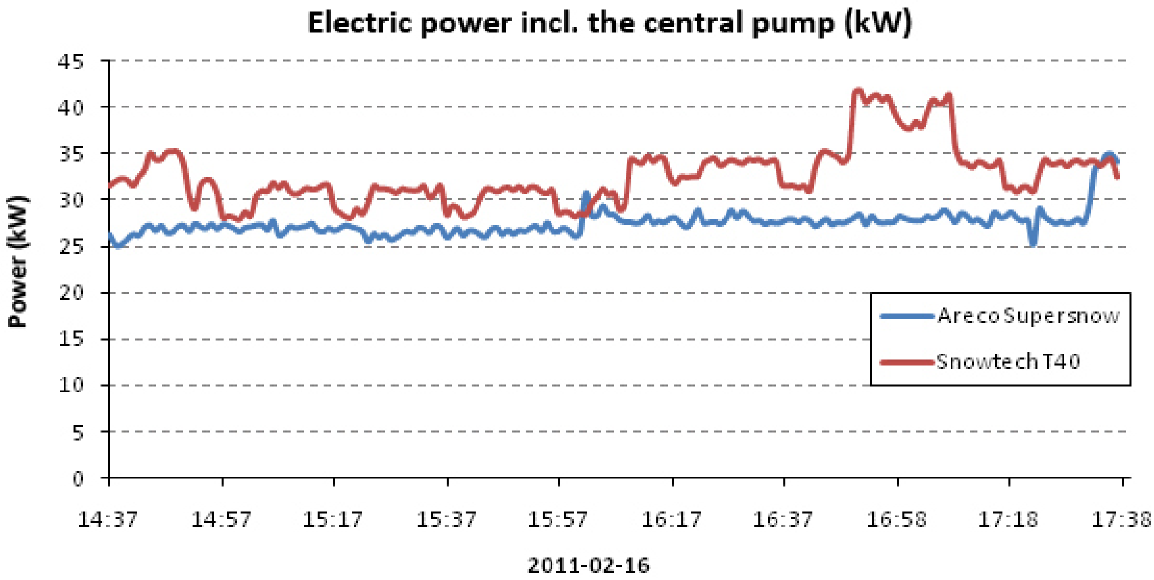


Figure 4-54: The figure illustrates how the input power to each fan gun varies during the measuring period.

Climate and weather data

Figure 4-54 below presents the ambient temperature and the corresponding dew point in the current period. As shown by the blue graph, where the ambient temperature more or less constant at just under -6° C. The relative humidity and ambient pressure is illustrated in Figure 4-55. According to the blue graph where air pressure unchanged during the test, while the humidity increased by about 2 percent.

The results of the measurements of wind speed and solar insulation are presented in Figure 4-56. The wind speed measured 0.5 m/s (light winds) in averaged over the period. The figure also shows that the solar radiation was most evident at the beginning of the test before the sun went down for the day. The solar radiation averaged was measured to about 100 W/m^2.

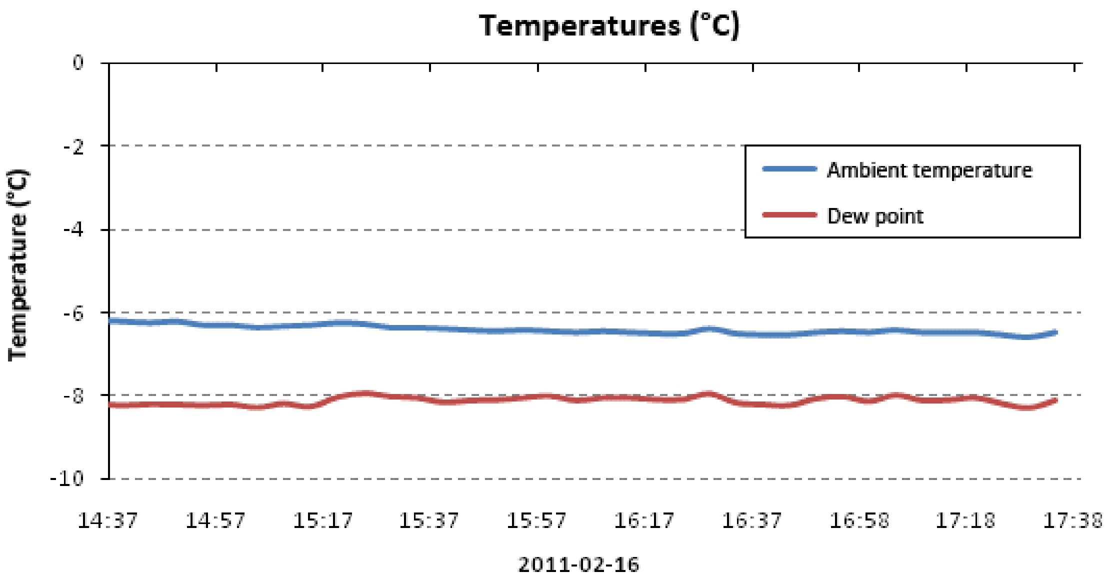


Figure 4-55: The ambient temperature and dew point as a function of time.

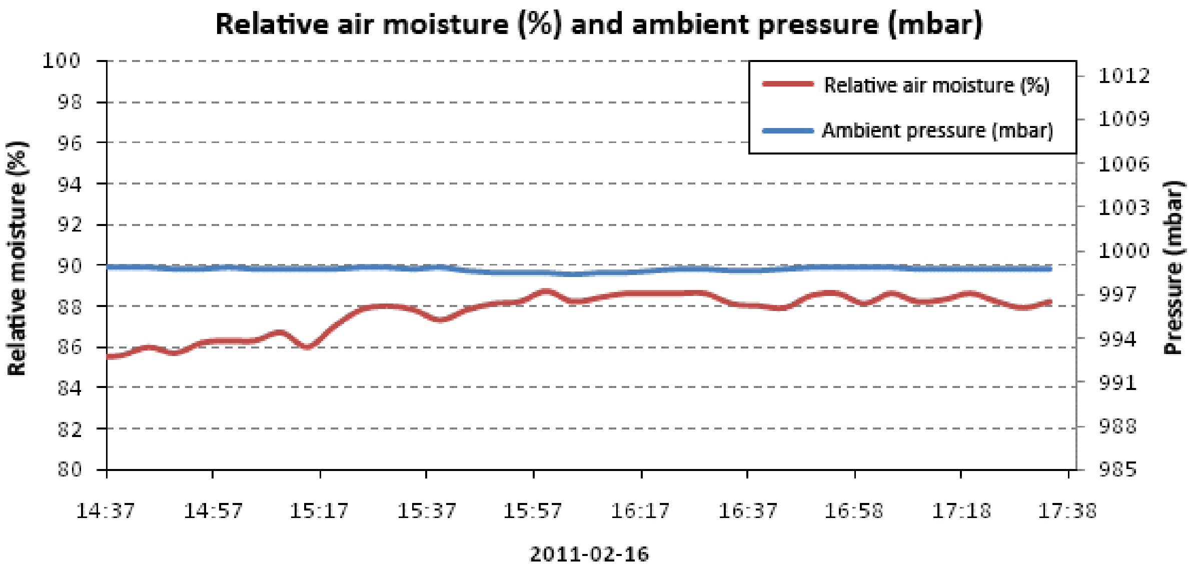


Figure 4-56: Relative humidity and ambient pressure as a function of time. The ambient pressure was more or less constant, while the humidity increased with around 2 percent.

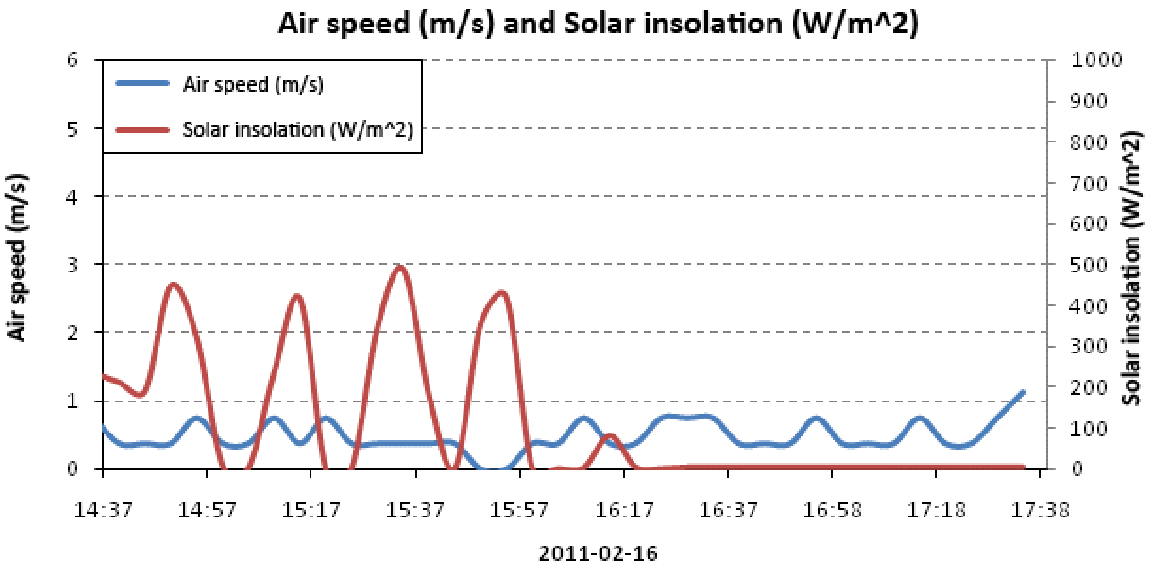


Figure 4-57: The figure show how the wind speed and solar insulation varies during the test period.

Compilation of results and key figures

Table 7 below presents the results and key figures that has been developed from the measurement data. As is clear from the table; was the ratio between net and gross snow volume almost 1. This means that the measured snow volume was similar to the estimated snow volume, which gives strong validity to the results.

Figure 4-57 describes the snow depth as a function of location/position of each snowmaking unit. According to the figure is the "hit rate" relatively centered in the middle of the range, which can be attributed to the low wind speed. Most of the produced snow has thus met within the designated area.

Table 7: Summary of results, second test February 16.

TEST 2.3: 2011-02-16 Kl. 14:37 to 17:37		Areco Supersnow	Snowtech T40
Used power (excl. central pump) [kWh]		64,0	81,0
Used power to the central pump [kWh]		26,5	26,2
TOTAL POWER USED [kWh]		**90,5**	**107,2**
Total used water volume [m^3]		29,6	29,2
Average density snow [kg/m^3]]		408,4	424,8
SNOW VOLUME GROSS [m^3]		72,4	68,7
SNOW VOLUME NET [m^3]		68,0	64,1
SNOW VOLUME AVERAGE [m^3]		**70**	**66**
TOTAL POWER PER GROSS VOLUME SNOW [kWh/m^3]		**1,25**	**1,56**
TOTAL POWER PER NET VOLUME SNOW [kWh/m^3]		**1,33**	**1,67**
TOTAL POWER PER AVERAGE VOLUME SNOW [kWh/m^3]		**1,29**	**1,61**
Other ratio			
Power to the central pump		29%	24%
Power to gun/lance		71%	76%
Power per volume amount water [kWh/m^3_water]		3,06	3,67
Proportion between net and gross volume of snow		0,94	0,93
	SUMMARY CLIMATE AND WEATHER DATA		
	At the start	Mean value	At the end
Ambient temperature [°C]	-6,2	-6,4	-6,5
Dew point [°C]	-8,2	-8,1	-8,1
Air moisture [%]	85,5%	87,7%	88,2%
Air speed [m/s]	0,76	0,49	1,1
Solar insolation [W/m^2]	236	109	4

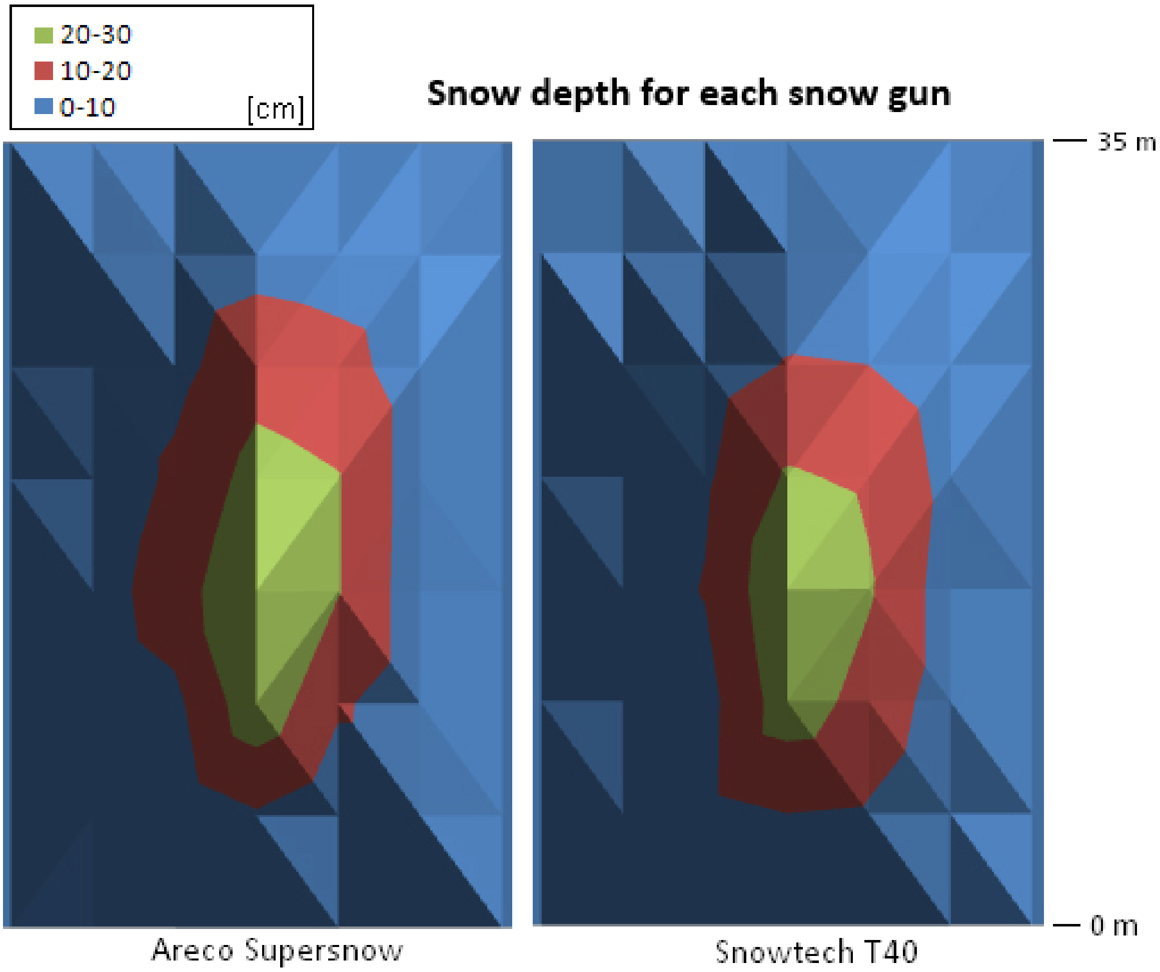


Figure 4-58: The illustrations show the snow depth as a function of positions within the measuring area.

4.2.6 Test 2.4 – Day 4, AM (February 17)

During the morning of February 17 the first test started at 09:20. Participants on this occasion was Snowtech(T40), Areco (Sufag) and Toppteknik(NESSy). The fan gun from Snow Tech, T40, started about 20 minutes later than other suppliers and ended therefore at 12:40 pm. Areco (Sufag) and Toppteknik(Nessy) completed the test at 12:20. In this way the performance period of three hours each was reached for all of the snowmaking units.

Performance of the snowmaking equipment

Figure 4-58 presents the results from the density measurements that were collected continuously during the test. The blue graph shows how the produced snow density by T40 varied during the test period. The graph illustrates that the density was within the range of 350-400 kg/m^3 for most of the test. The final density of the sample, however, showed a higher value which can be explained by an increased volume flow (see Figure 4-61). Toppteknik(NESSy) showed a density between 450-500 kg/m^3 while Areco (Surfag) were within the range of 390-460 kg/m^3.

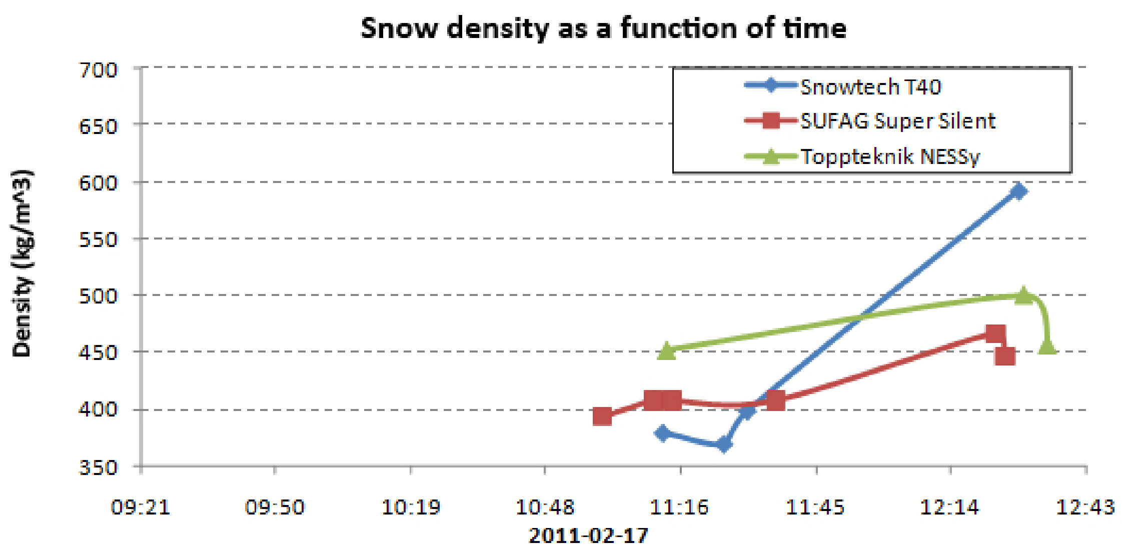


Figure 4-59: The illustration shows the snow depth as a function of positions within the measuring area.

Figure 4-60 and Figure 4-61 presents data from the temperature and pressure measurements that were carried out. Figure 4-60 shows that SnowtechT40 started at 09:40 in the morning as the water temperature at this time rose sharply in a short period. This is also reflected in the figure that illustrates how the pressure varied during the process. From the pressure graphs, it also appears that Snowtechand Toppteknik has produced snow with a relatively constant pressure while Areco have regulated the pressure.

Figure 4-61 describes how the rate for the volume flow varied during the measurement period. Comparing the figure with the density measurements carried out, it appears that an increased volume of water flow contributes to a higher density. This appears most clearly from the blue graph; increased volume of flow around noon contributes to the high density as shown in the graph above at the time of 12:30 pm. Figure 4-62 presented the use of electric power including the main pump for each fan gun and lance.

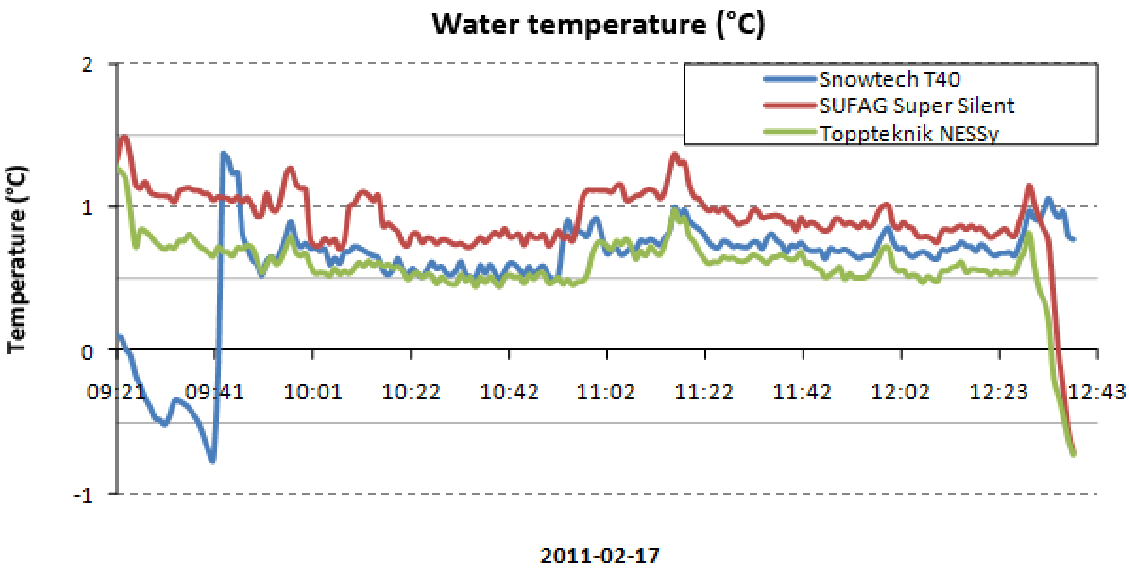


Figure 4-60: The water temperature in each measuring tube as a function of time.

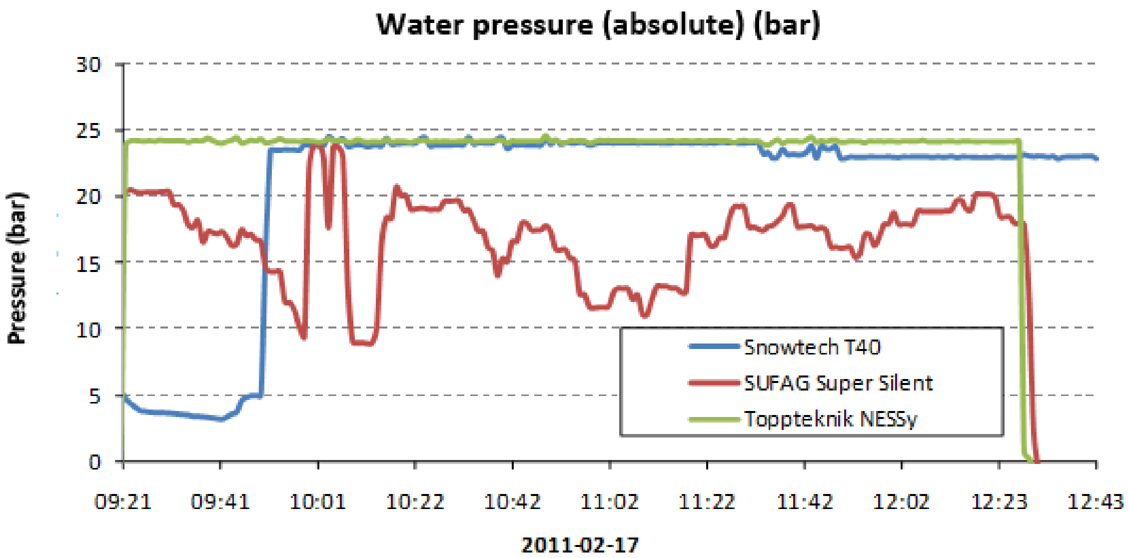


Figure 4-61: The figure illustrates how the water pressure varied during the measuring period.

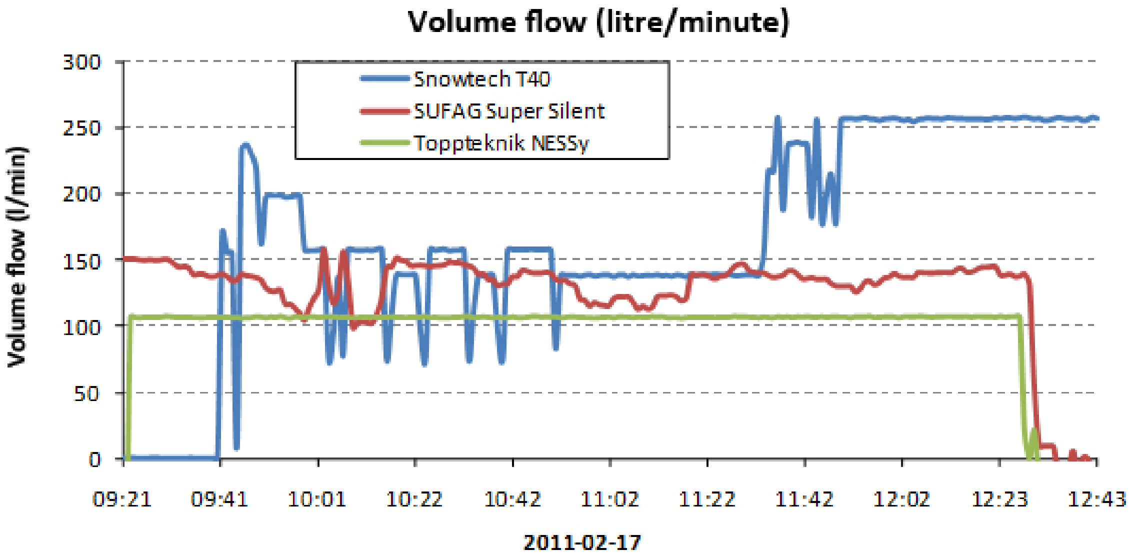


Figure 4-61: The figure shows how the volume flow varies during the measuring period.

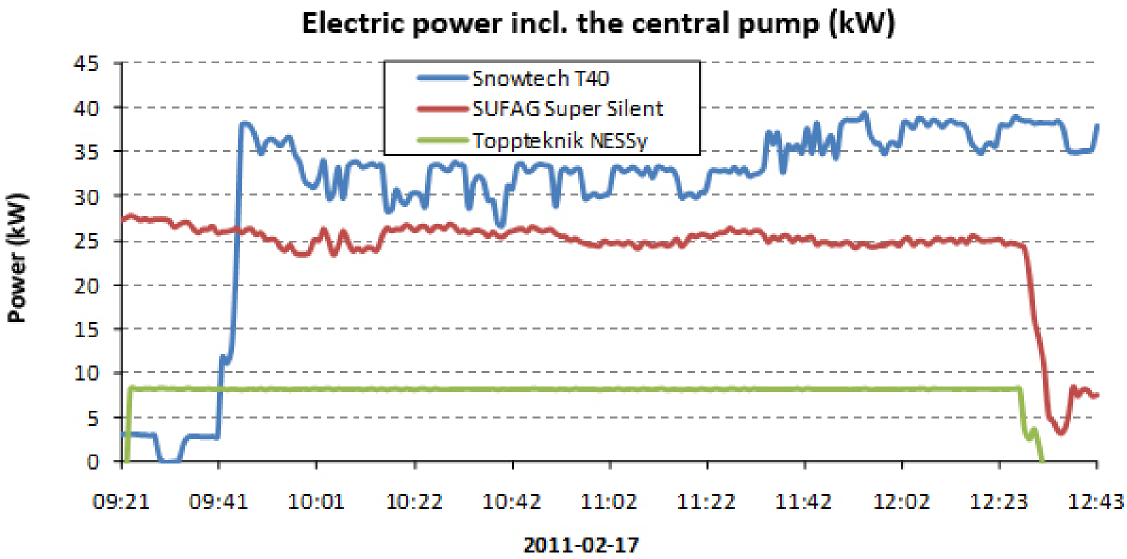


Figure 4-62: The graphs illustrate the input power to each snowmaking unit.

Climate and weather data

Figure 4-63 to Figure 4-65 illustrates the climate and weather data from the current test period. The ambient temperature ranged between - 8° C to -6° C, while ambient pressure was constant at about 1005 mbar. During the measurement period, the mean wind speed was a little over 0.8 mph (light winds) and the corresponding mean solar radiation was measured at 420 W/m^2.

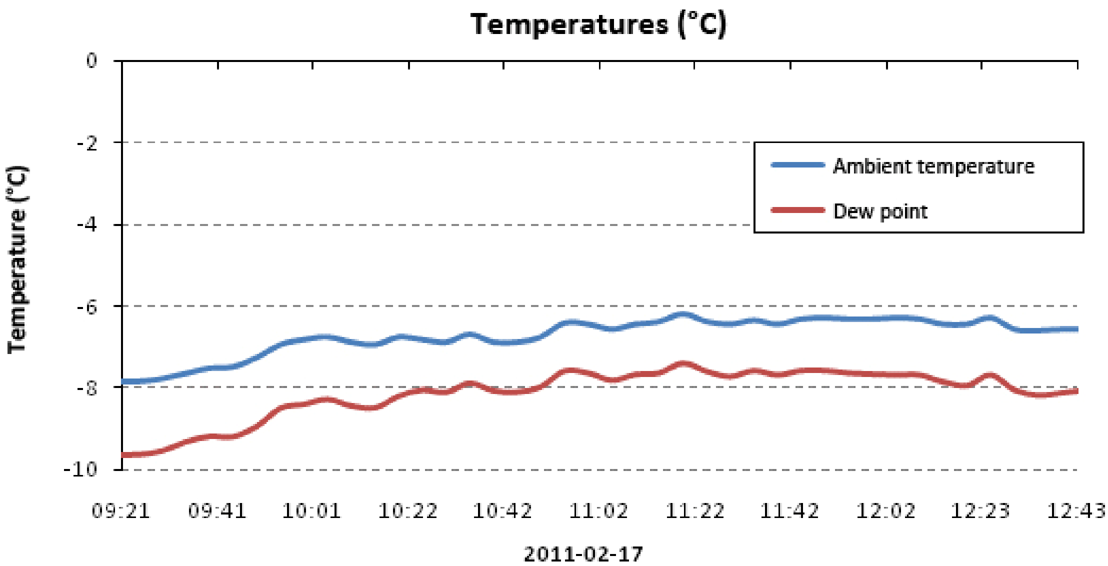


Figure 4-63: The graphs declare the input power to each snowmaking unit.

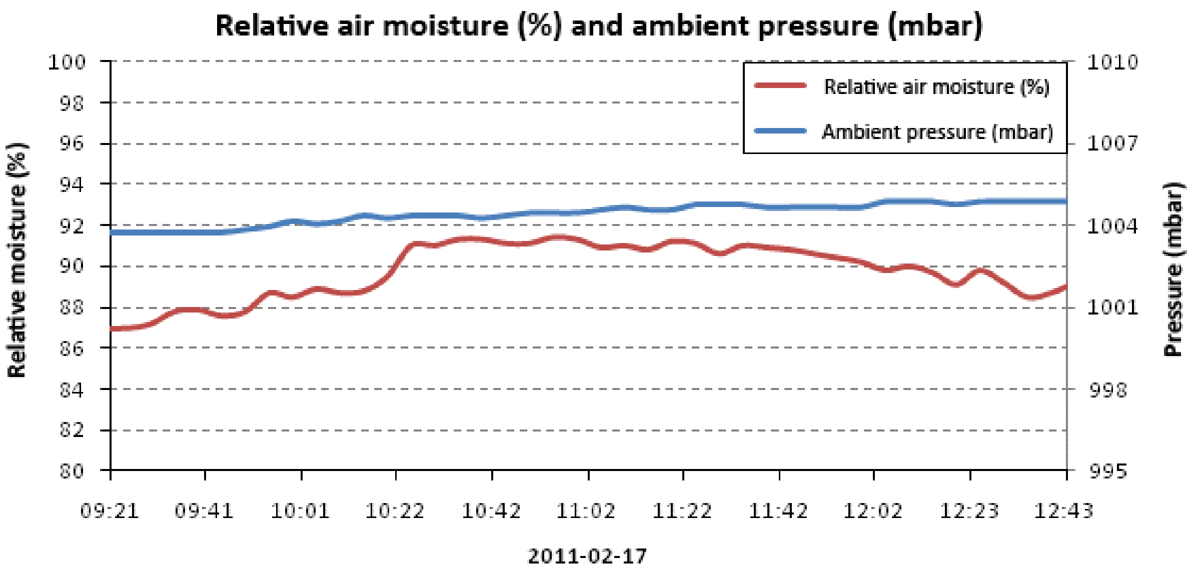


Figure 4-64: Relative humidity and ambient pressure.

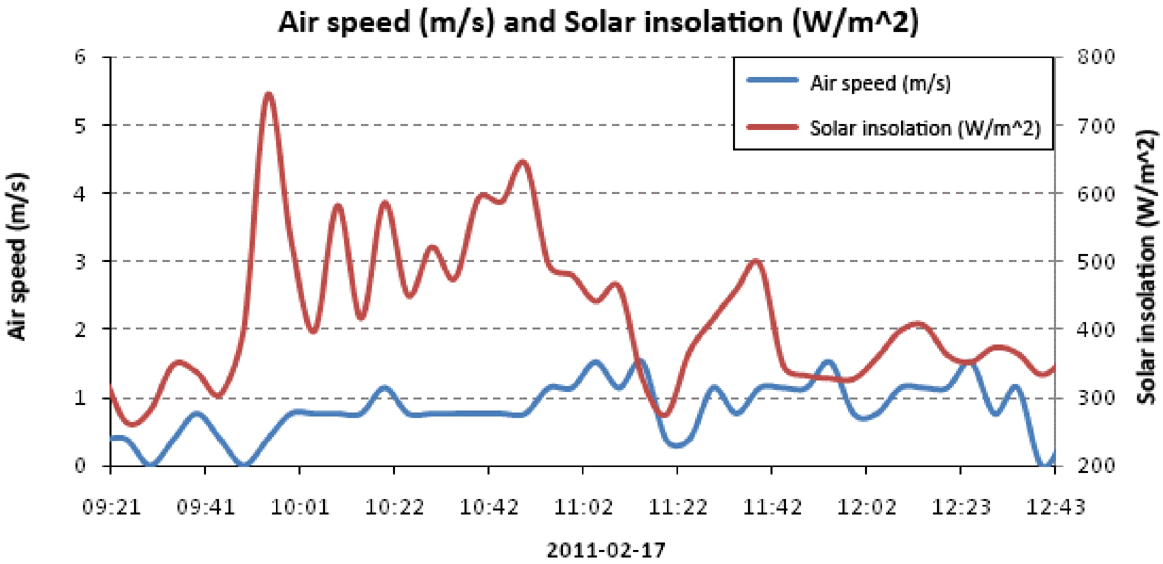


Figure 4-65: The wind speed and solar insulation as a function of time.

Compilation of results and key figures

The following table summarizes the results and key figures of the first test February 17. From the table it appears that the ratio between net and gross volume of snow ranged from 0.7-0.9 between the participants. Figure 4-66 shows how the produced amount of snow was distributed in the target area.

Table 8: Summary of results, first test February 17.

TEST 2.4: 2011-02-17 Kl. 09:20 to 12:20 (12:45)	Snowtech T40	Areco SUFAG Super Silent	Toppteknik NESSy
Used power (excl. central pump) [kWh]	75,0	62,0	9,0
Used power to the central pump [kWh]	30,6	23,0	17,3
TOTAL POWER USED [kWh]	**105,6**	**85,0**	**26,3**
Total used water volume [m^3]	34,1	25,7	19,3
Average density snow [kg/m^3]]	434,5	421,5	469,3
SNOW VOLUME GROSS [m^3]	78,6	60,9	41,1
SNOW VOLUME NET [m^3]	58,7	55,1	28,9
SNOW VOLUME AVERAGE [m^3]	**69**	**58**	**35**
TOTAL POWER PER GROSS VOLUME SNOW [kWh/m^3]	**1,34**	**1,40**	**0,64**
TOTAL POWER PER NET VOLUME SNOW [kWh/m^3]	**1,80**	**1,54**	**0,91**
TOTAL POWER PER AVERAGE VOLUME SNOW [kWh/m^3]	**1,54**	**1,47**	**0,75**
Other ratio			
Power to the central pump	29%	27%	66%
Power to gun/lance	71%	73%	34%
Power per volume amount water [kWh/m^3_water]	3,09	3,31	1,36
Proportion between net and gross volume of snow	0,75	0,90	0,70
	SUMMARY CLIMATE AND WEATHER DATA		
	At the start	Mean value	At the end
Ambient temperature [°C]	-7,8	-6,7	-6,5
Dew point [°C]	-9,6	-8,1	-8,0
Air moisture [%]	87%	90%	89%
Air speed [m/s]	0,38	0,81	0,38
Solar insolation [W/m^2]	334	420	356

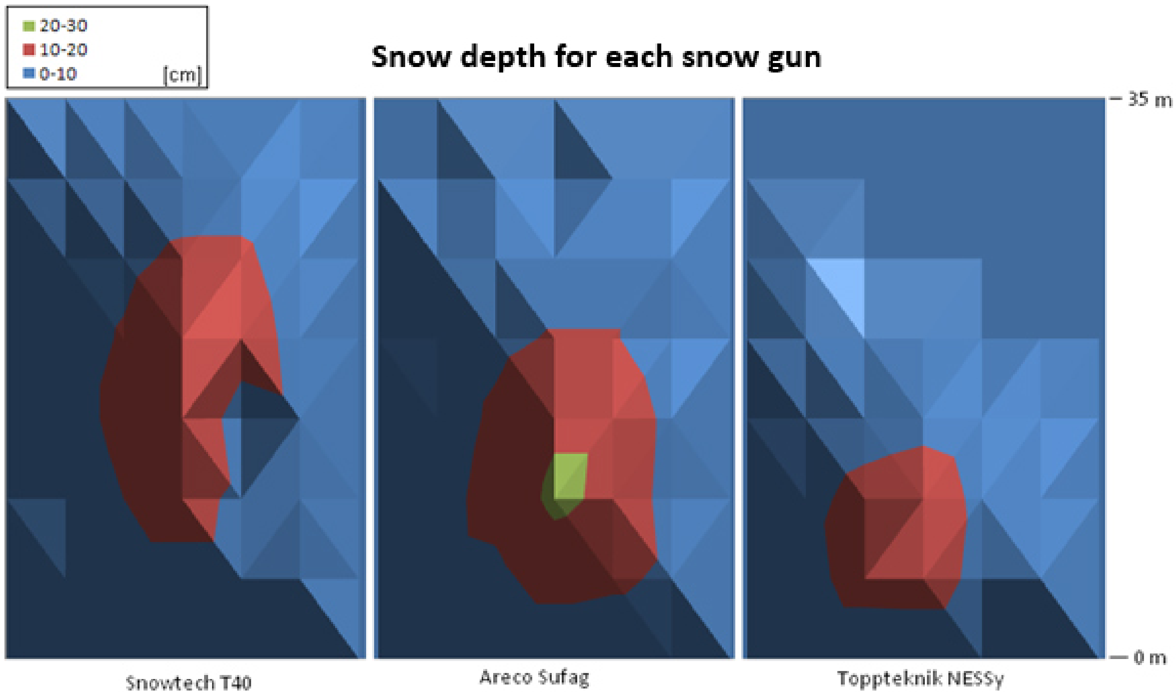


Figure 4-66: Snow depth as a function of time.

4.2.7 Test 2.4 – Day 4, afternoon (February17)

The final test for the week took place during the afternoon of February 17. The test started at 02:50 pm and ended according to plan three hours later. The participating suppliers in this test were Snowtechfan gun, T40 and T60, and Toppteknik lance, NESSy.

Performance of the snowmaking equipment

Figure 4-67 shows the results from the collected snow density samples. The fan guns T40 and T60 had an average density of 400 kg/m^3, while the lance NESSy had a density of about 450 kg/m^3 in average during the test period.

The water temperature during the test is shown in Figure 4-68. The graphs in the figure indicate that the temperature was relatively similar between the participating units during the test. However, after 05:00 pm the water temperature begins fall to NESSy, which is illustrated by the green graph. The temperature reduction can be explained with the reduced volume flow, as shown in Figure 4-70. A lower flow rate means that the water is cooled to the surrounding environment over a longer period compared with a higher flow.

The water pressure to each fan gun and lance were virtually equal between the participants, as shown in Figure 4-69. However did the water flow very as illustrated in Figure 4-70. The present figure illustrates clearly how the flow of water to NESSy (green graph) is reduced towards the end of the test, which gives rise to the falling water temperature.

The current electrical power to each snow gun and lance are presented in Figure 4-71. Comparing the fan guns (T40 and T60) with the lance (NESSy) shows that the fan guns use a higher proportion of electricity than the lance. Nevertheless, this must be related to the amount of snow each unit produced during the test. The snow volumes are reported separately in Table 9.

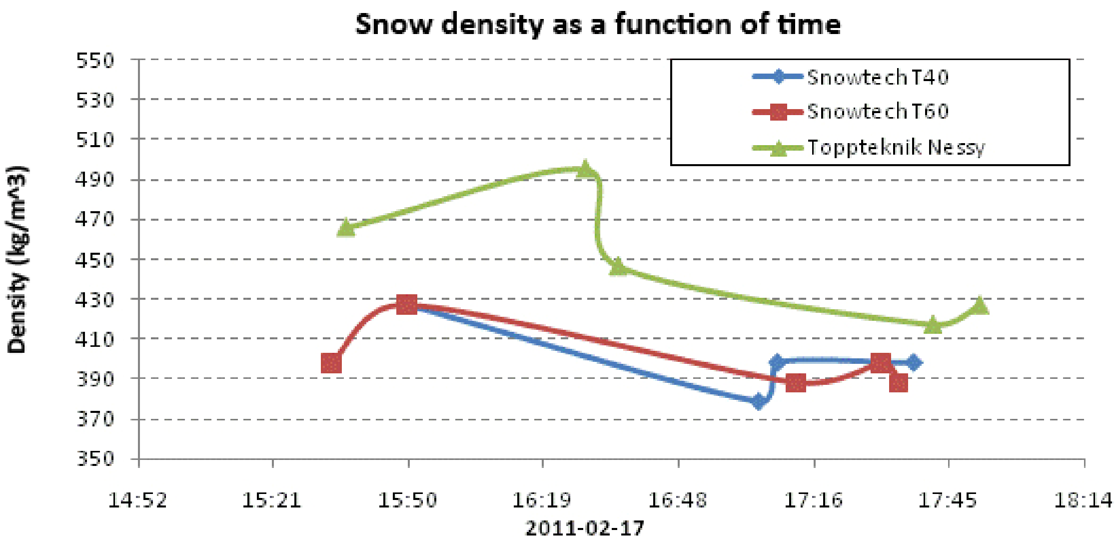


Figure 4-67: The figure illustrates the density as a function of time during the current measuring period.

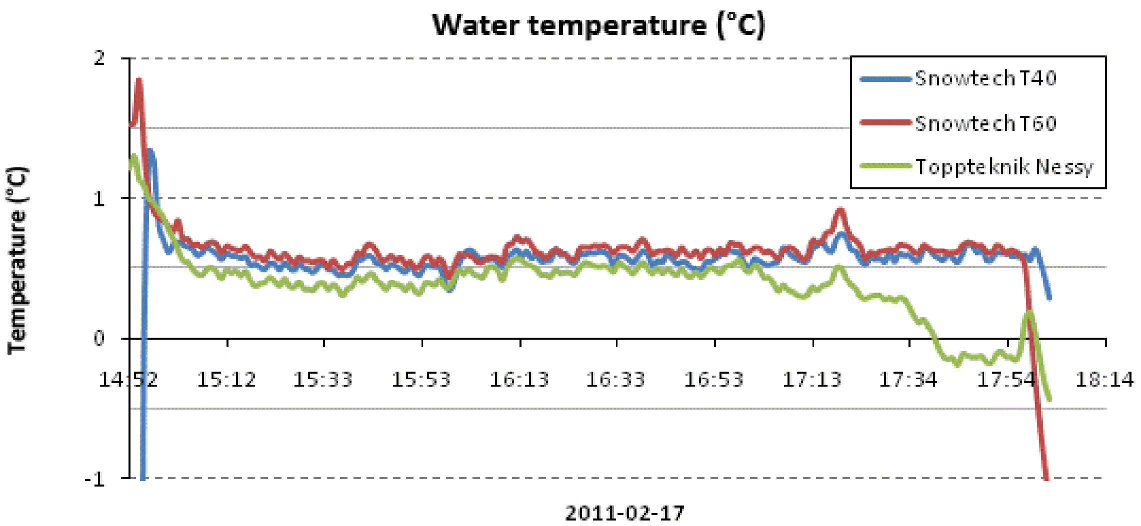


Figure 4-68: The graphs present the water temperature during the test.

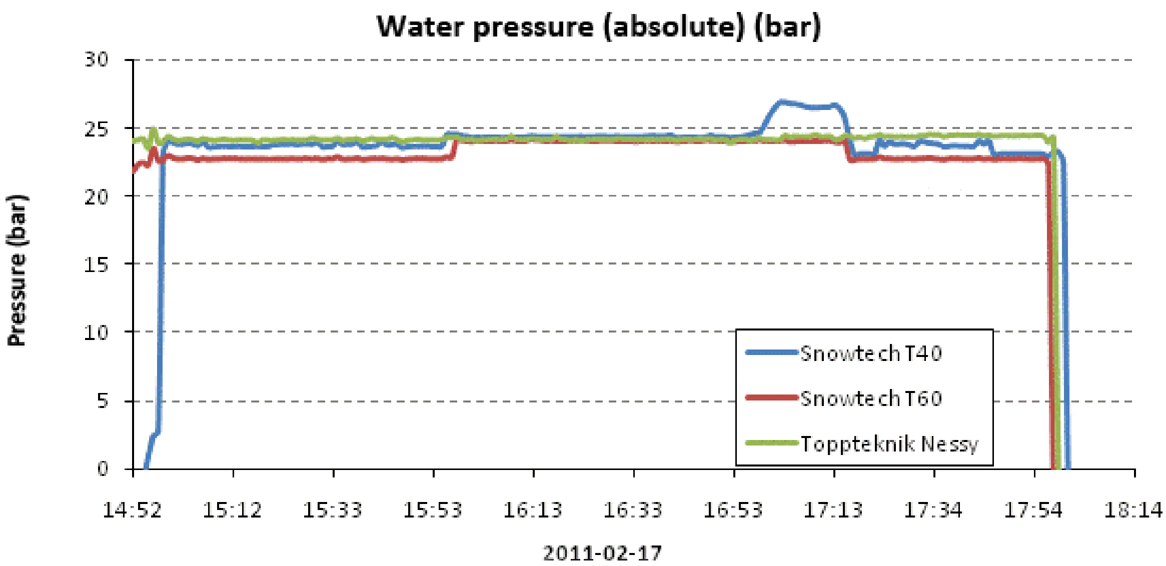


Figure 4-69: The figure shows the water pressure and how it varied during the measuring period. As the graphs indicate was the pressure relatively stable for all participants.

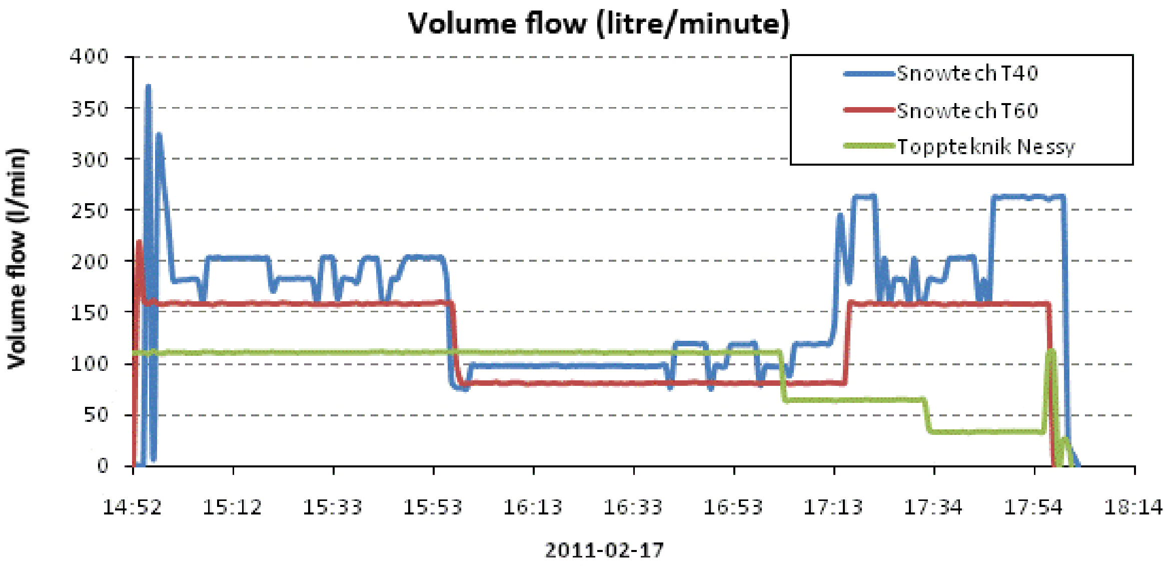


Figure 4-70: The figure illustrates water pressure to each snowmaking unit.

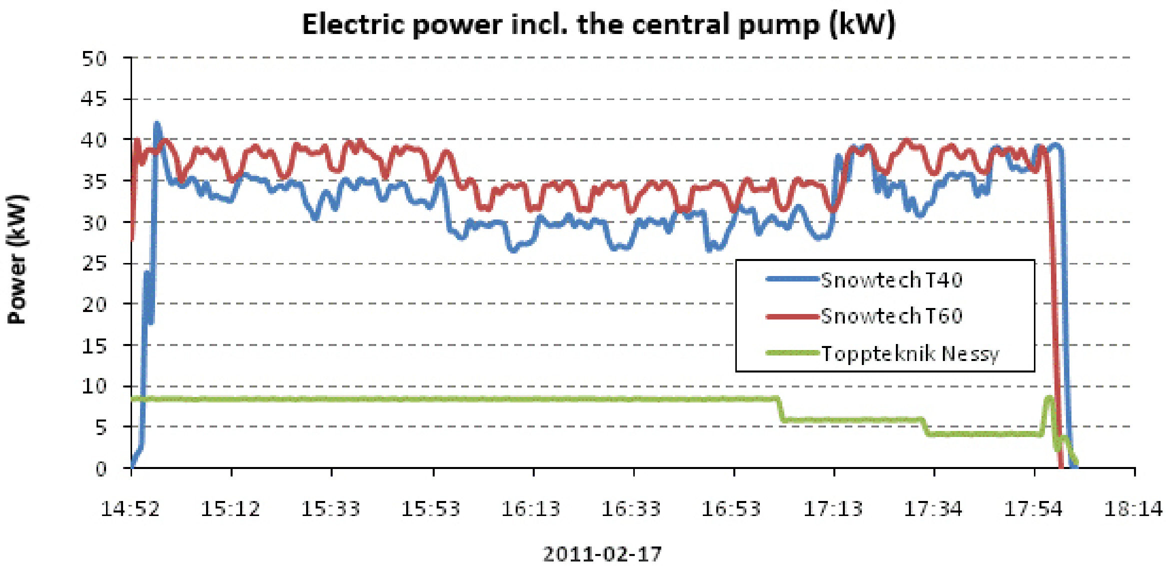


Figure 4-71: The input power to each snowmaking unit, the central pump included.

Climate and weather data

Figure 4-72 to Figure 4-74 presents the weather conditions that were present during the measuring period. Figure 4-72 illustrates the ambient temperature and the corresponding dew point during the test. The relative humidity and ambient pressure are presented in Figure 4-73, while the wind speed and solar radiation are presented in Figure 4-74. As it appears from the latter figure was the solar radiation most noticeable during the first part of the test. The wind speed was measured at 0.7 m/s in average during the period (light winds).

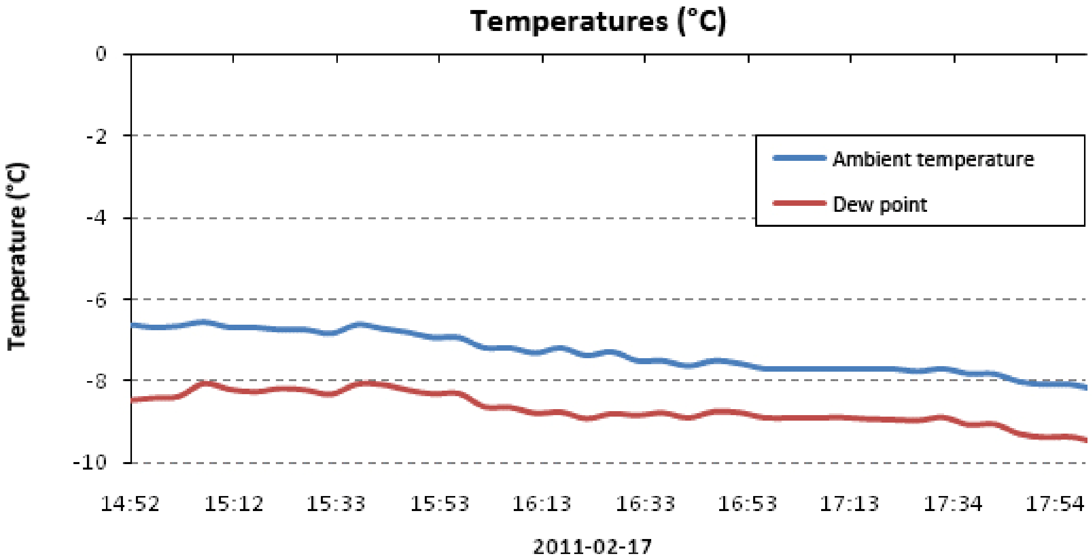


Figure 4-72: The ambient temperature and corresponding dew point during the test period.

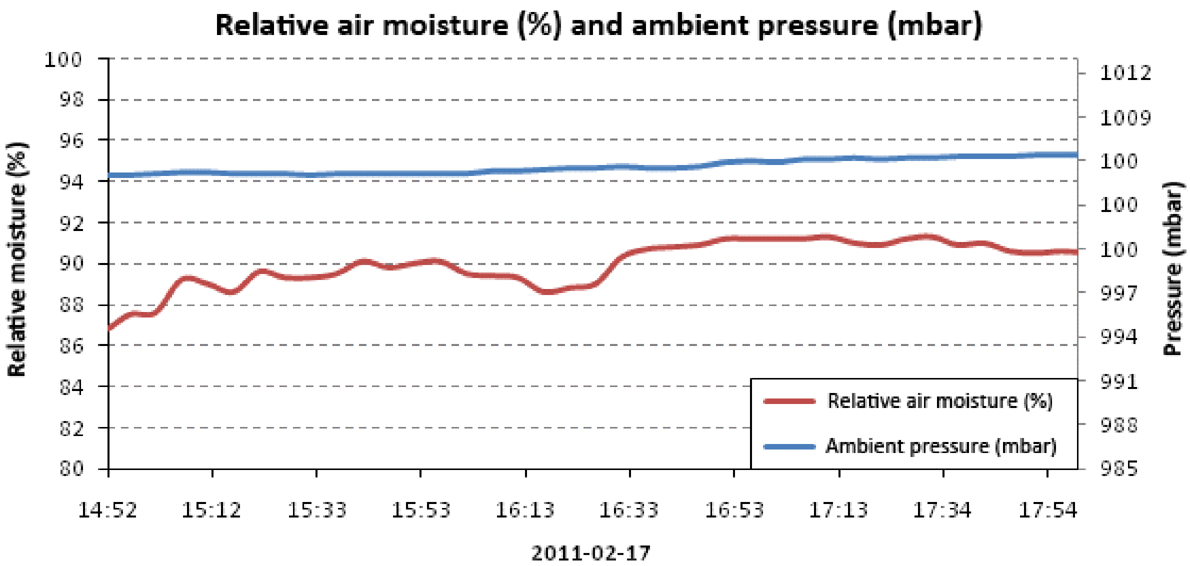


Figure 4-73: The relative humidity and the ambient pressure.

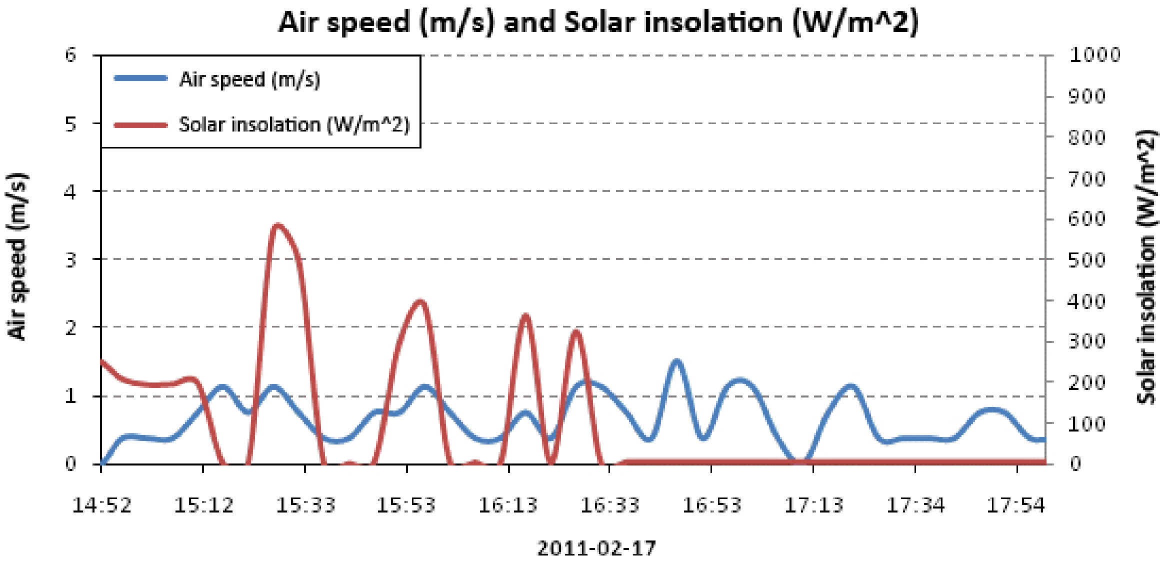


Figure 4-74: The wind speed and the solar insulation during the test period.

Compilation of results and key figures

In table below is a compilation of results and key figures from the second test, February 17th, presented. The ratio between the measured snowfall and the estimated output ranged from 0.76 to 1.00, which indicates a high accuracy of measurements. Figure 4-75 presents the results from measurements of the snow depth.

Table 9: Summary of results, second test February 17.

TEST 2.4: 2011-02-17 Kl. 14:53 to 17:53	Snowtech T40	Snowtech T60	Toppteknik NESSy
Used power (excl. central pump) [kWh]	73,6	91,1	8,0
Used power to the central pump [kWh]	26,8	20,7	15,6
TOTAL POWER USED [kWh]	**100,4**	**111,8**	**23,5**
Total used water volume [m^3]	29,9	23,1	17,3
Average density snow [kg/m^3]]	400,5	400,0	450,5
SNOW VOLUME GROSS [m^3]	74,6	57,7	38,5
SNOW VOLUME NET [m^3]	56,8	47,4	38,7
SNOW VOLUME AVERAGE [m^3]	**66**	**53**	**39**
TOTAL POWER PER GROSS VOLUME SNOW [kWh/m^3]	**1,35**	**1,94**	**0,61**
TOTAL POWER PER NET VOLUME SNOW [kWh/m^3]	**1,77**	**2,36**	**0,61**
TOTAL POWER PER AVERAGE VOLUME SNOW [kWh/m^3]	**1,53**	**2,13**	**0,61**
Other ratio			
Power to the central pump	27%	19%	66%
Power to gun/lance	73%	81%	34%
Power per volume amount water [kWh/m^3_water]	3,36	4,84	1,36
Proportion between net and gross volume of snow	0,76	0,82	1,00
	SUMMARY CLIMATE AND WEATHER DATA		
	At the start	Mean value	At the end
Ambient temperature [°C]	-6,7	-7,3	-8,2
Dew point [°C]	-8,6	-8,7	-9,5
Air moisture [%]	86,5%	89,8%	90,5%
Air speed [m/s]	1,14	0,67	0,38
Solar insolation [W/m^2]	252	99	4

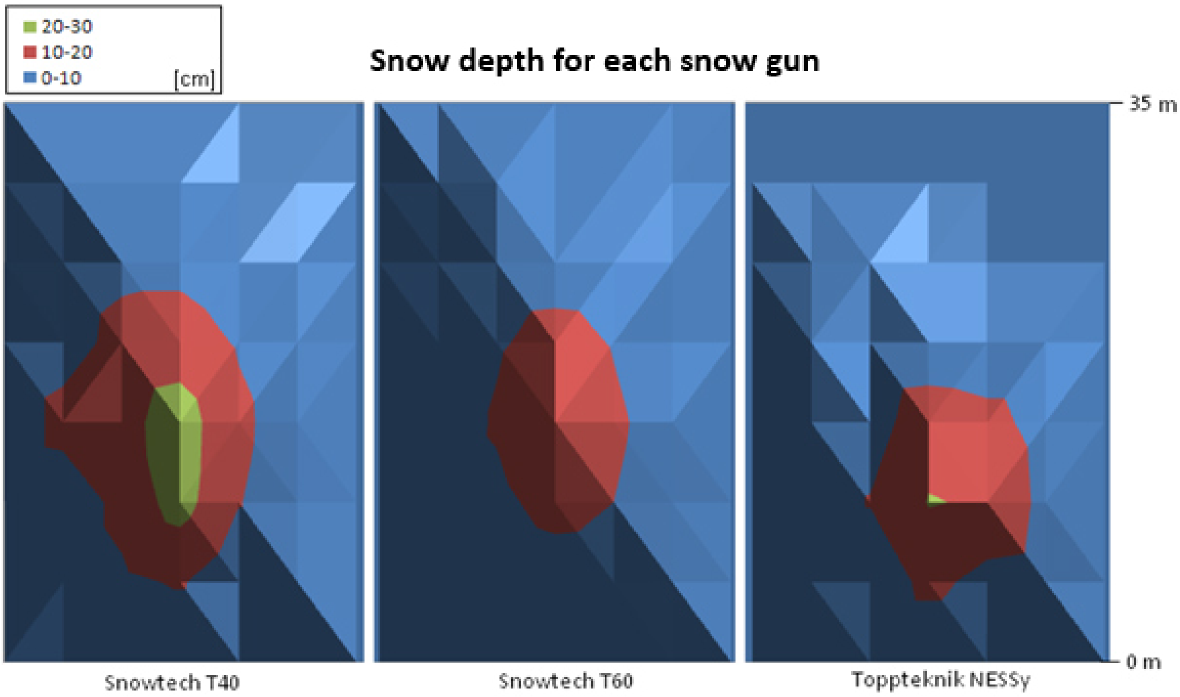


Figure 4-75: Snow depth for each fan gun and lance.

4.3 Summary of test results

Figure 4-76 to Figure 4-79 compiles the results from all the tests. Since no measurable snow was produced at the first testing opportunity, during week 5, these results have not been included in the figures.

Figure 4-76 and Figure 4-77 shows the capacity of the snow making equipment. The term capacity refers to how much snow each unit produces per hour. The snow volume used in calculating the key figure is the gross volume. This means that the key figure is specified in produced snow volume (gross) per hour. The key figure has then been compared with the dew point temperature, as illustrated in the figure. Consequently is the y-axis snow volume per hour while the corresponding dew point is the x-axis.

Figure 4-76 presents the results from the fan guns. For the fan guns that were tested on several occasions, a linear regression line (corresponding to dashed line) is developed to show any correlation between the values. In cases where there have been more than two measurements “the least squares method” have been used.

Figure 4-76 shows that Areco, Sufag, only was tested on one occasion. The corresponding point on the chart is found in the same paragraph as the SnowtechT40. As shown in the graphs in the figure is the slope of each regression line relatively similar between the participants, with the exception of Areco Standard. This has a point which indicates a capacity of over 15 m^3/h at a dew point temperature of about -9° C. The low capacity (15 m^3) of this paragraph may be coupled with the low volume of water flow in this particular test (see Figure 4-43).

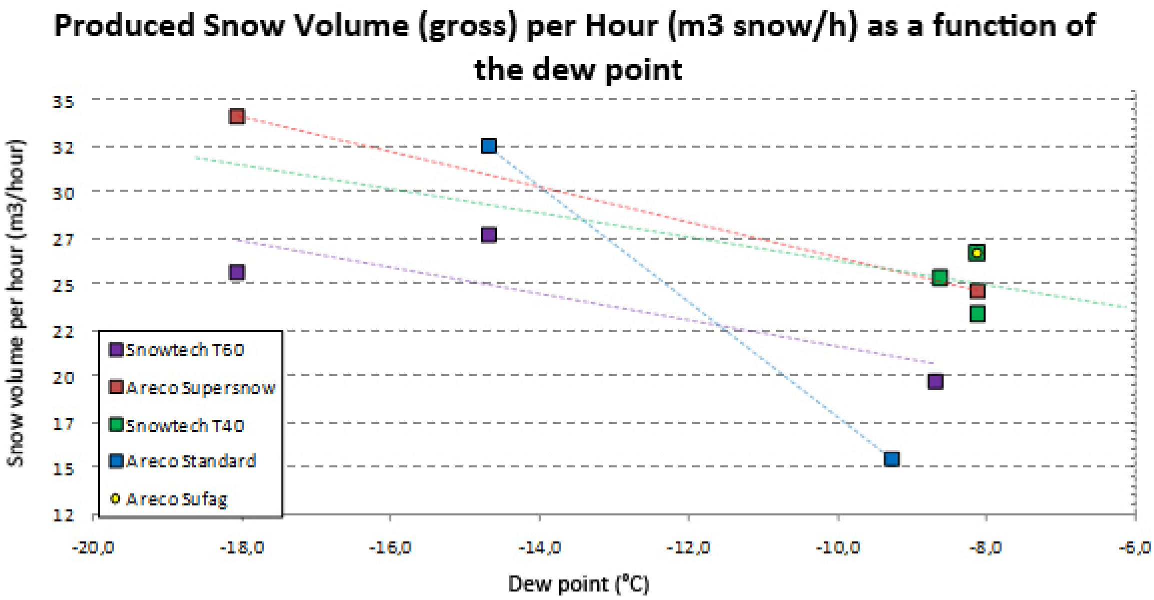


Figure 4-76: The Figure above illustrates the capacity of the fan guns. The key figure is measured as produced snow volume, and is put in relation to the wet temperature for each test.

Figure 4-77 presents the corresponding results for the lances. The lance of Snowtech and the sled of Toppteknik were only tested once, whereby no regression line could be established.

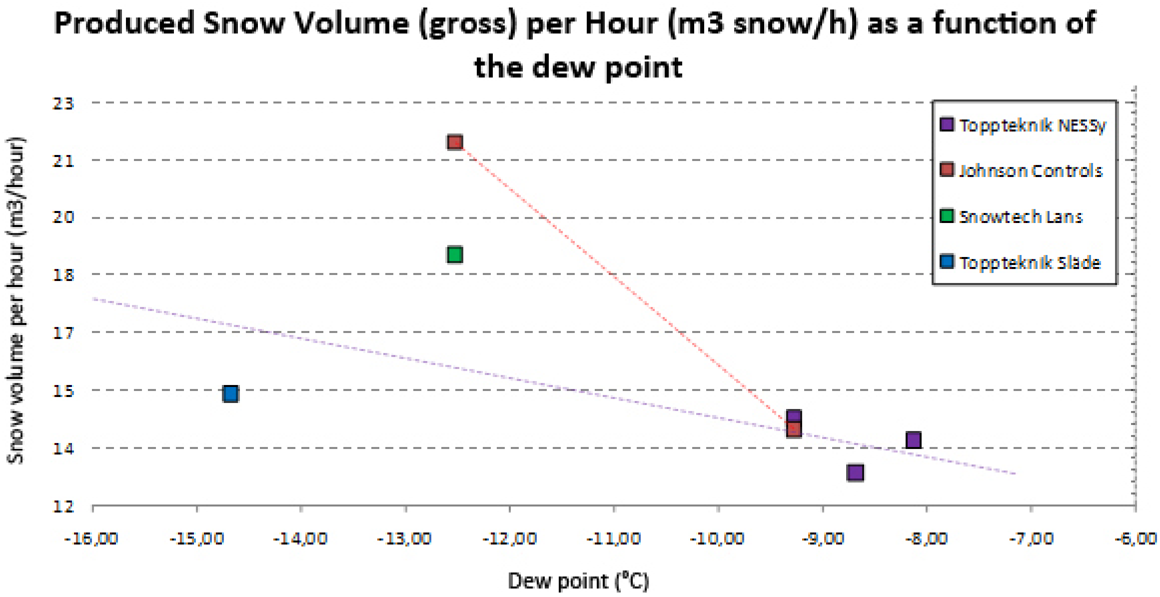


Figure 4-77: The figure above illustrates the capacity of the lances. The key figure is measured as produced snow volume, and is put in relation to the wet temperature for each test.

Figure 4-78 and Figure 4-79 account for the quantity of electrical energy per gross volume of snow (y-axis) in relation to the dew point temperature (x axis). Figure 4-78 presents the results of the fan guns, while Figure 4-79 presents the results of the lances. The graphs in Figure 4-78 shows that the slope of the regression line associated with Snow Tech, T40, (green graph) is steeper than the others. This when the x-values of the measurements are clustered around about - 8° C in dew point temperature. Had there been data from tests where the dew point was about - 18 ° C the slope would probably have been different.

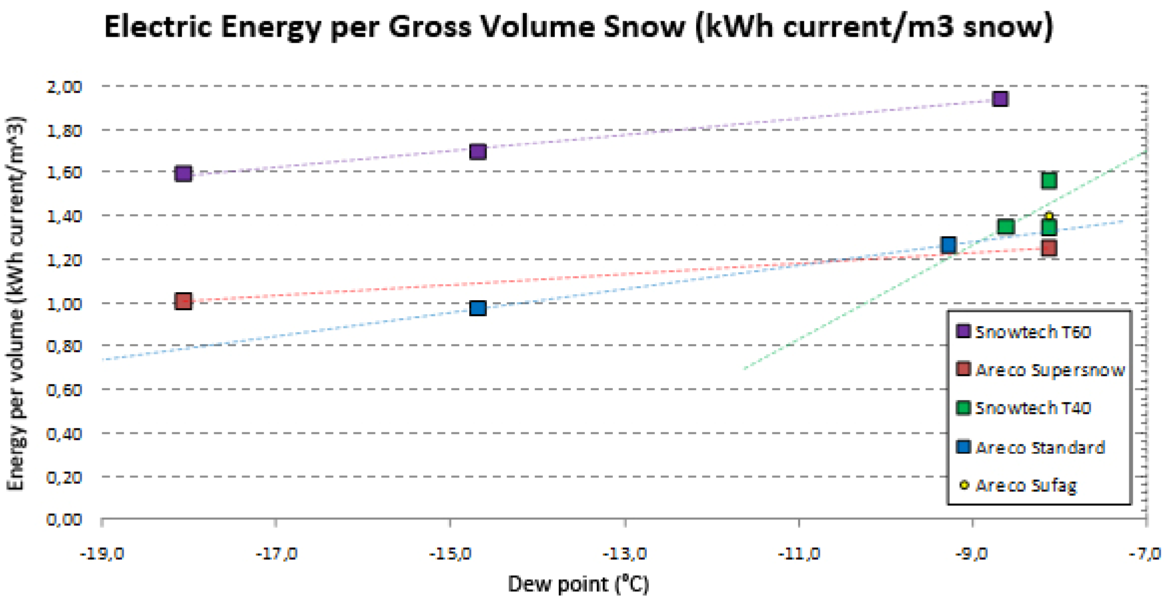


Figure 4-78: Electric power per gross volume of snow for each fan gun.

Figure 4-79 illustrates the electrical energy use for each lance. At one point, two points coincide, making it difficult to distinguish them. At the dew point of - 12.5°C does both Johnson Controls and Snowtech show a value of 0.68 kWh/m^3 of energy per volume amount of snow. The figure is this illustrated only as a green square cursor.

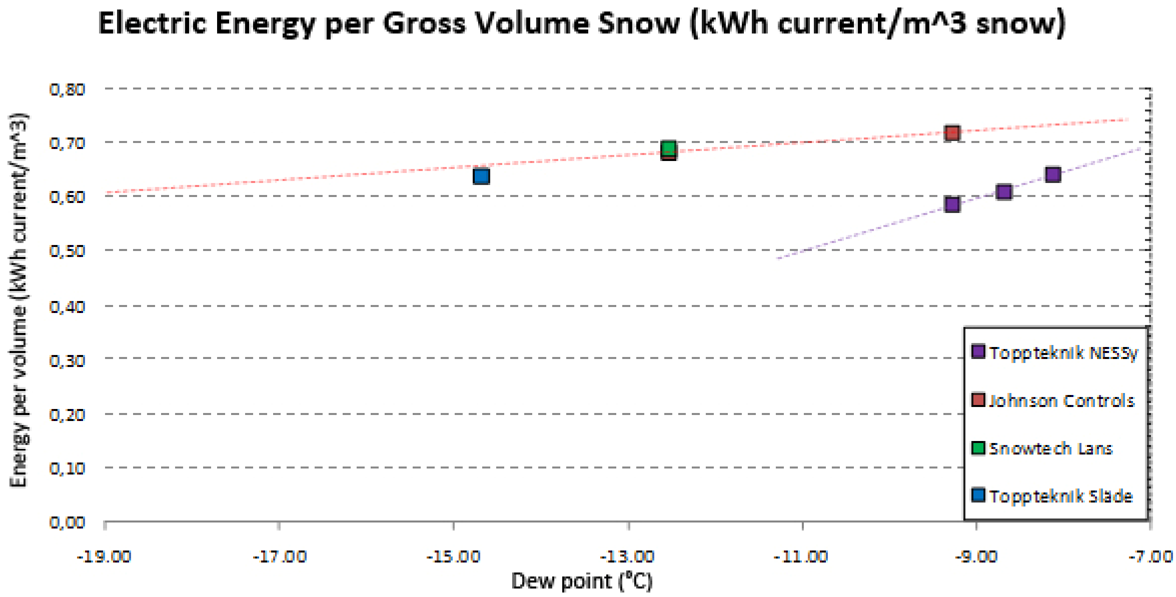


Figure 4-79: The electric energy per gross volume of snow for each lance.

5 Discussion

In this chapter presents a discussion of test performance and the data produced. It should be noted that the tests were carried out under the conditions offered by the ski stadium Lugnet in Falun, which has not always proved to be optimal for each snowmaking unit. Some “experiments” with the settings of the equipments were done during the tests, which could have led to divergent values.

5.1 Test performance and results

As described previously was the tests of the mobile snowmaking equipment performed at Lugnet Ski Arena in Falun. The snowmaking system on the ski arena is constructed with a central pump that delivers a water pressure of about ~ 22-23 bar for each snowmaking unit. This pressure rise was not optimal for all participants in the test in which a higher pressure would have been desirable. There was a possibility of regulating the pressure for each snowmaking unit by cutting off the flow of water with a hydrant valve. However, it appeared that it was not so easy for some suppliers to connect to the hydrant because of the pipe connections that were in place. By that did not the pressure control function for some guns work out.

The gross volume snow were used in the production of key figures in the results presented in Chapter 4.3, "Summary of test results". The reason that the gross volume was used rather than the net volume has to do with measurement accuracy. Gross volume of snow is based on the volume of water which in turn is recorded and measured continuously by flow sensors. This method is however dependent on the density of the snow, which leads to some uncertainty in the results. From the graphs that shows the density it is illustrated that the density at some courses have varied across a wide range leading to a high standard deviation for these tests. Comparing the net volume with the gross volume of snow - a value is recieved that describes the deviation between the measured amount of snow (net volume) in relation to the estimated output (gross volume). Looking at the entire test series is the difference between these volumes about 10 percent, indicating a relatively good accuracy in volume measurements (Figure 5-1).

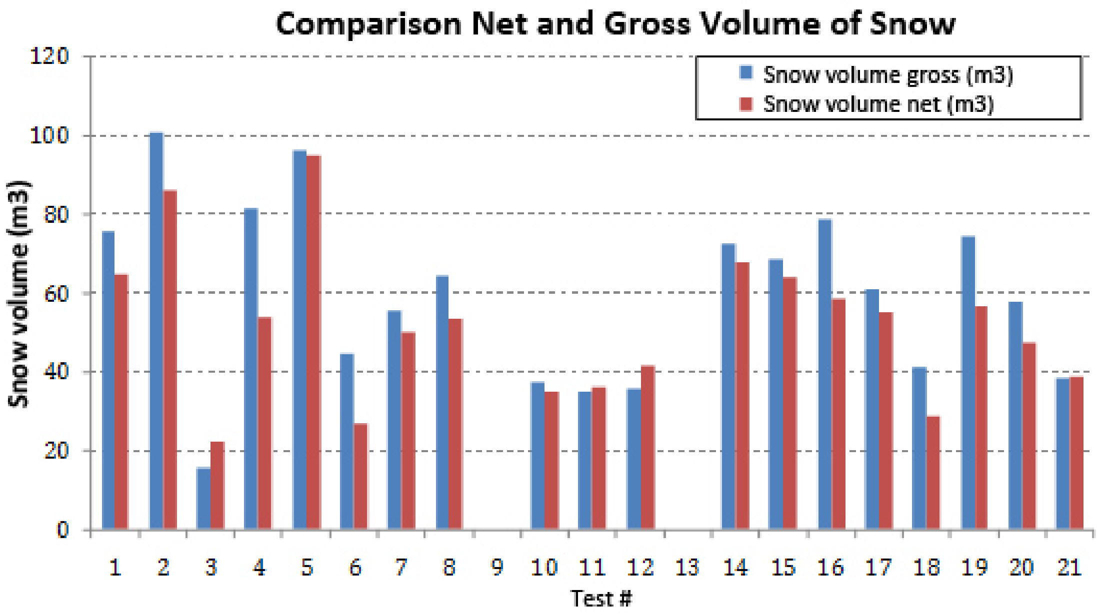


Figure 5-1: Comparison of snow volumes.

5.2 Snow quality

The concept "snow quality" proved to be a difficult concept to assess. The project intended to evaluate the quality of the produced amount of snow after each completed test. It appeared, however, relatively early in the test series, that only density was not sufficient to describe the snow quality. Snow of the same density could have completely different characteristics such as dry or wet. A snow sample with a certain density might to its appearance have a characteristic "powder snow" structure, at the same time as snow of the same density could have a more "wet" texture.

The predetermined target with produced snow of a density of 380 kg/m^3, was found early to be an inadequate approach to achieve the desirable type of snow. According to information given, would that density provide good snow for cross country skiing. This aim had to be overlooked as a result of the above reasoning on the dry and wet snow at the same density. It also turned out to be difficult to produce snow with this low density. The desired low density also affected energy use per unit gross volume of snow, especially for fan guns. This because a lower density resulted in a reduction in the gross volume of snow, while energy use is affected to a lesser extent.

5.3 Potential energy savings - the regulation of the central pump

The central pump and the feed water system at the ski arena were designed for about 22-23 bar. As described in chapter 5.1, is this pressure level likely not optimal for all snowmaking units. In the energy evaluation has all units been treated equally in terms of electrical output to the main pump, in the sense that the same pressure increase has been used. The pump power will only be driven by the outlet flow according to the equation below. In fact, the pump in this case not regulated by needs of the snowmaking equipments. Nevertheless, this is an opportunity that can save energy in a snowmaking system.

To regulate the pressure to a snowmaking unit by cutting off the flow is not optimal from an energy perspective. However, energy saving can be made when it is possible to reduce the pressure by controlling the central pump by frequency regulation, and adjust it after the unit which has the highest pressure need.

$$\dot{E}_{pump} = \frac{\dot{V} \cdot \Delta P}{\eta_t} \quad \text{Ekvation 1.}$$

$\dot{E}_{pump}$ – Pump power [W]
$\dot{V}$ – Volume flow [m3/s]
ΔP – Pressure increase [Pa]
η_t – Overall efficiency [~0,65]

To illustrate the possibility to save energy in a system by regulating the pressure from the main delivery pump, have the tests where this have been done then been analyzed further. Figure 5-2 shows how the pressure to Areco Standard in practice has varied (flex pressure) as opposed to the available pressure (fixed pressure). The red graph shows how the fan gun regulates the pressure by cutting off the flow. The difference in pressure between the two graphs represents the potential energy savings.

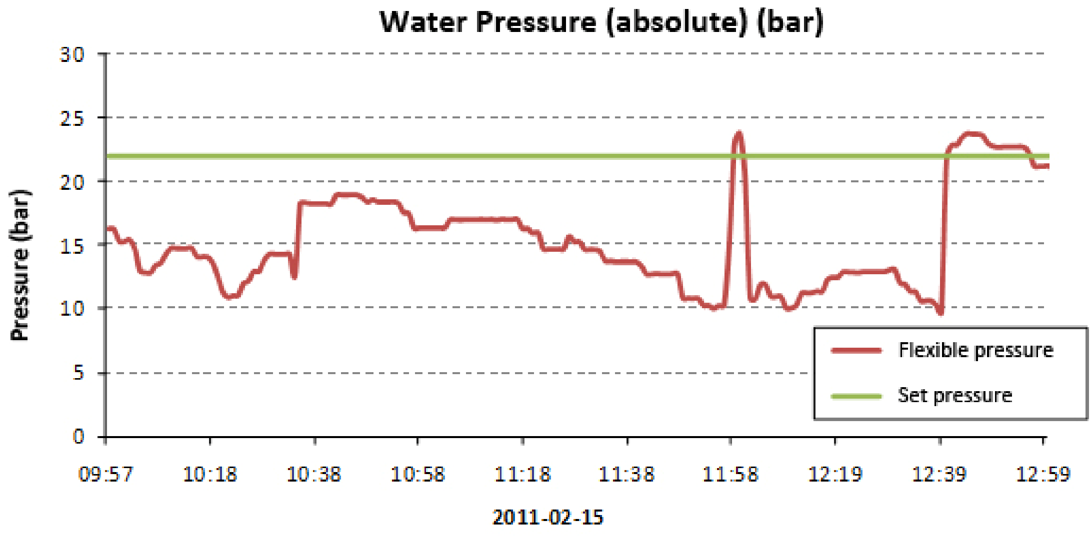


Figure 5-2: The fixed pressure of the system and the regulated pressure to Areco Standard.

Figure 5-3 shows the electrical output contribution from the main pump to the fan gun for the two cases discussed. The top curve (fixed pressure) shows the power at the case when it first raises the pressure at a fixed level in the system and then strangle it to a desired level. The lower curve shows the case where the central pump is regulated to just the pressure that the fan gun demanded. The difference in energy supplied to the pump in this specific case was 27.9 kWh, which represents a reduction of 32 percent interest in pumping energy.

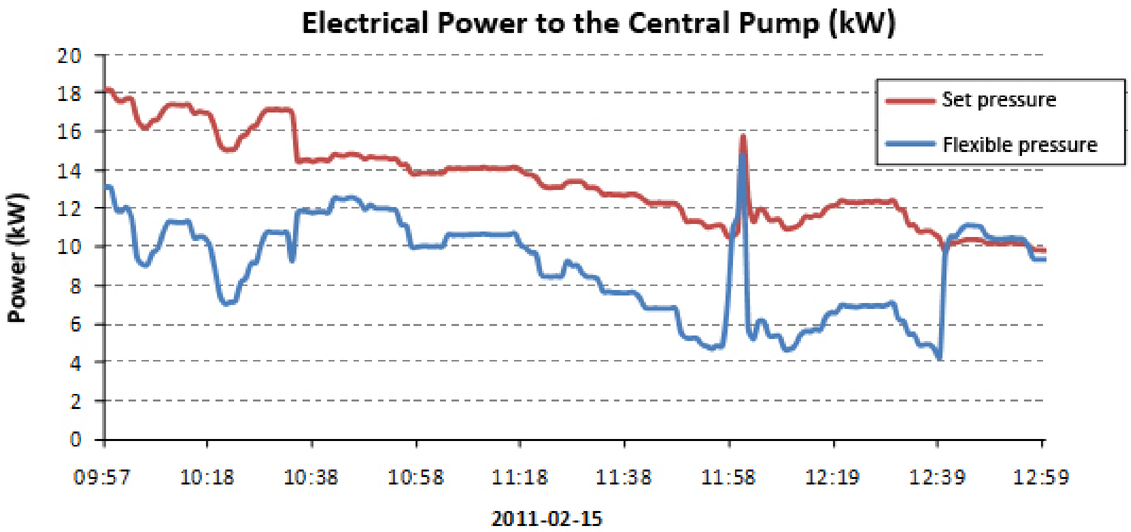


Figure 5-3: The power input to the central pump at fixed and regulated pressure level.

The impact on the total electricity output to the fan gun can be seen in Figure 5-4. It is of course slightly less since the reduction is compared to the electric power needs. In the present case, the total energy use decreased from 93.3 kWh to 79.9 kWh, corresponding to about 14 Percent.

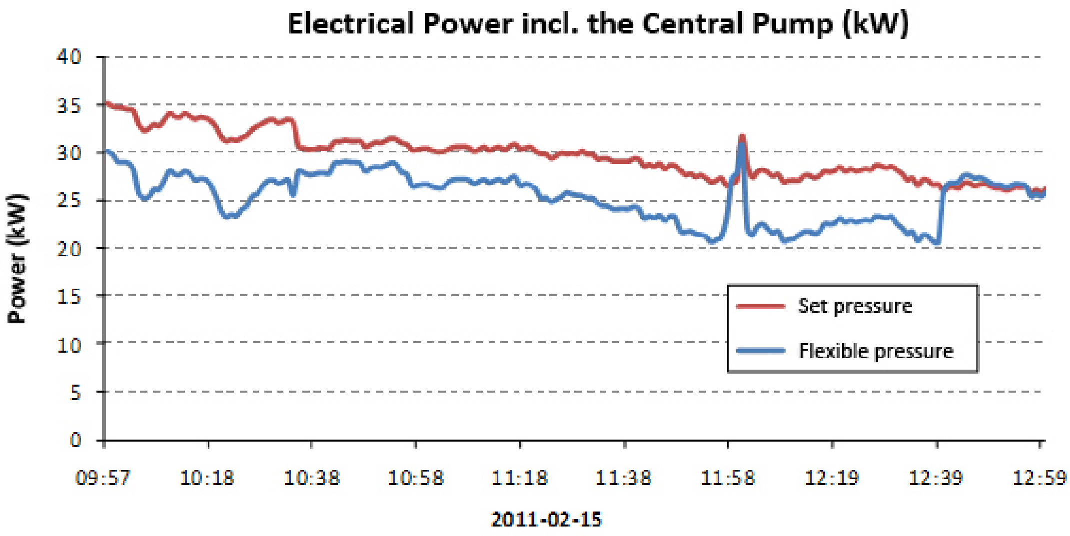


Figure 5-4: The difference in input power at fixed and regulated pressure level.

Table 10 shows a summary of the tests that were carried out with the regulated pressure to the snowmaking equipment. The comparison is made for the estimated energy of the central pump with a fixed (solid) and regulated (flex) pressure. All results and comparisons earlier in the report are made with an assumed fixed pressure. This comparison is done to highlight the potential for energy savings with a "good" regulation of the central pump. The regulation should aim to keep as low pressure as possible in the feedwater system.

Table 10: The results from the tested snowmaking with regulated pressure.

	Test nr.	1	2	3	4	5
Pump	E pump - Set (kWh)	38.8	41.3	14.5	26.5	23.0
	E pump - Flex (kWh)	31.2	27.9	8.3	20.4	17.8
	Difference (kWh)	7.6	13.4	6.2	6.2	5.3
	Difference (%)	19.6%	32.4%	43.0%	23.2%	22.8%
Total	E pump - Set (kWh)	**101.3**	**93.3**	**47.3**	**90.5**	**85.0**
	E pump - Flex (kWh)	93.7	79.9	41.1	84.4	79.8
	Difference (kWh)	7.6	13.4	6.2	6.2	5.3
	Difference (%)	7.5%	14.4%	13.2%	6.8%	6.2%

The results of this analysis show that with a "theoretically perfect regulation" so would it be possible to reduced the added energy to the central pump by between 20 and 40 percent. The total energy to the snowmaking equipment in these tests could then be reduced by between 6 and 14 percent.

6 Conclusions

General conclusions:

- Density itself is not a good measure of snow quality, since the snow texture depends on several factors such as the structure of the snow crystals.

- Snow with a low density (~ <380 kg/m^3) is not always equivalent to "dry" snow.

Conclusions regarding energy usage:

- Energy consumption per gross volume of snow decreases with a falling dew point temperature. It is therefore more energy efficient to produce snow at a lower temperature. The results of these tests suggest that energy use (kWh/m^3) in average decreases by 3.4 percent per declining °C (dew point). The averages from the Lech-tests were slightly higher, at approximately 7 percent in energy reduction per decreasing degree.

- A lower supply pressure to the snowmaking unit reduces the performance of the central pump and decreases the energy use; provided that the unit produce equivalent snow at a lower pressure level. The energy might be reduced by about 6 - 14 percent if the central pump is managed perfectly .

- Generally does the lances in the test consume less energy per m^3 of snow, compared to the fan guns in the test. If instead capacity is compared – then the fan guns produce more snow per hour compared to the lances. These findings apply to the specific equipment tested under these specific prevailing conditions. Factors such as water pressure and mast length also has an effect in which increasing pressure and length normally increases capacity.

- A lower snow density will most of the time (not always) lead to a higher energy consumption per gross volume of snow. This is because electrical power to the fan guns (fan work) are not significantly altered by a decreased density, while water flow is reduced the more (less water for the same amount of energy).

- The prestudy gave information that an average snowmaking unit at a cross country ski area in Sweden uses between 3.4 to 4.3 kWh electricity per m^3 of snow. The same average ski area produces approximately 7500 m^3 of snow per season. Test results from Lugnet, Falun, suggest that a modern snowmaking unit uses around 1.1 kWh/m^3. For a single ski area, this would mean an energy saving equivalent to 17 250 – 24 000 kWh per year, or about 70 percent reduction. With an assumed price of electricity of 1.2 SEK/kWh, could this imply a cost reduction of between 21 000 - 29 000 SEK per year.

- In terms of a national perspective (all 100 cross-country ski areas in Sweden with snowmaking), this represents a saving of between 1.8 - 2.4 GWh / year.

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