Impermeable plastic covers for better winter survival of golf course putting greens: Ventilation under the covers during the winter 2020-2021

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SAMMENDRAG/SUMMARY:

Rapporten er fra et storskalaforsøk på fire norske golfbaner med kartlegging av ventileringsbehov og sammenlikning av metoder for ventilering av plastdekte greener gjennom vinteren. Se side 5 for norsk sammendrag.

This is a report is from a large-scale experiment on four Norwegian golf courses investigating ventilation requirements and ventilation methods on putting greens covered with impermeable plastic covers during winter. An English summary can be found on page 4.

LAND/COUNTRY:	Norway
FYLKE/COUNTY:	Viken
KOMMUNE/MUNICIPALITY:	Bærum, Asker, Lier
STED/LOKALITET:	Haga GC, Bærum GC, Asker GC, Holtsmark GC

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Preface

This report presents results from field trials conducted during the winter 2020-21 on greens at Haga, Bærum, Asker and Holtsmark Golf Course, south-east Norway, as part of the Norwegian Golf Federation (NGF)'s project 'ICE-BREAKER: 'Reducing the agronomic and economic impact of ice damage on golf courses and other grasslands'.

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Trygve S. Aamlid

Content

Summary

After severe ice and water damage during the winter 2017-18, Haga, Bærum, Asker and Holtsmark Golf Courses, all situated 10-30 km west/southwest of Oslo, successfully covered an increasing number of their greens with impermeable plastic covers during the winters 2018-19 and 2019-20. The covers minimized winter damage but also brought up the question about ventilation requirements and ventilation methods under the covers.

As part of the Norwegian Golf Federation's project ICE-BREAKER (2020-2023) it was decided to carry out a large-scale experiment on the four golf courses during the winter 2020-21. The experiment comprised the following five treatments, each replicated on three greens on each golf course: (1) No ventilation under the plastic covers (control); (2) Programmed ventilation every three weeks using 5 cm diameter drainage pipes; (3) Programmed ventilation every three weeks during the winter using 20 cm diameter flat inflatable tubes; (4) Sensor-based ventilation through drainage pipes every time the oxygen (O_2) concentration under the covers went under 12 % and/or the carbon dioxide (CO_2) concentration exceeded 4 % (40000 ppm); and (5) Sensor-based ventilation through flat inflatable tubes according to the same criteria as in treatment 4.

The protocol for coverage was; first, to install in treatments 1, 4 and 5 sensors that reported to the greenkeepers' computers or smart-phones hourly values for temperature, CO_2-concentration and O_2 concentration in the turfgrass thatch layers under the covers; second, to put out permeable spring tarps ('Evergreen' at Haga, 'Norgro klimaduk' at Bærum, Asker and Holtsmark) as undercovers in all treatments; third, to put out the ventilation systems in treatments 2-5 (usually three or four pipes or tubes distributed evenly on the greens); and fourth, to install the impermeable covers ('Green Jacket' at Haga, 20 m wide transparent plastic sheets, thickness 115 µm, at Bærum, Asker and Holtsmark) and secure them with sand bags and collars dug into the green area to prevent melting water from seeping in under the covers.

On all golf courses, the greens were covered between 26 and 30 Nov. 2020. December was mild with virtually no snow before Christmas. January and the first two weeks of February were cold with up to 40 cm of snow above the covers, while the second half February and the first half of March were unstable with new snow- and rainfalls and temperature fluctuations resulting in melting water and ice formation between the snow and the covers. Ventilation, notably through the inflatable tubes, became increasingly difficult from late January because of the snow and ice above the covers. The snow and ice melted naturally or was cleared from the greens in early to mid-March. The covers were removed in the last week of March after 110-120 days of coverage.

Assessments during the first month after cover removal showed practically no ice- or water damage on any of the golf courses or in any of the treatments. The average damage from microdochium patch under the covers varied from 3 % of the green acreage at Haga to 14 % at Holtsmark. Disease severity depended on the number of fungicide applications before winter and was not significantly affected by ventilation treatments. Observations of new and active mycelium at cover removal in March none-theless suggested that the disease was most active close to the drainage pipes in treatments 2 and 4.

Because of too low battery capacity and other technical problems, per cent of hours with successful data retrieval from the sensors during the cover period varied from only 36 % for temperature to 53 % for CO_2. Despite this unsatisfactory coverage, the sensors showed significantly lower CO_2 concentrations and a trend to higher O_2 concentrations in treatment 4 (drainage pipes) than in the unventilated control treatment, with the flat tubes (treatment 5) producing intermediate values. The number of ventilations in the programmed ventilation treatments was four at Bærum and five at Haga, Asker and Holtsmark. In treatments 4 and 5, ventilations were carried between zero and five times (mean 2.2) in response to the CO_2 or O_2 thresholds.

The project will continue with covers being reinstalled and new and improved sensors deployed during the 2021-22 winter season.

Sammendrag

Etter betydelige isskader gjennom vinteren 2017-18 startet Haga, Bærum, Asker og Holtsmark Golfbaner (alle 10-30 km vest/sørvest for Oslo) et vellykket prøveprosjekt der et økende antall greener ble dekket med tett plastduk foran vintrene 2018-19 og 2019-20. Prosjektet viste en kraftig reduksjon i vinterskadene, men det aktualiserte også behovet for ventilering av gresset under plastdukene gjennom vinteren.

Som en del av Norges Golfforbunds prosjekt ICE-BREAKER (2020-2023) ble det bestemt å gjennomføre et storskalaforsøk med ventilering under plastdukene gjennom vinteren 2020-21. Forsøket sammenliknet følgende fem behandlinger (forsøksledd) som hver ble gjentatt på tre greener på hver av de fire banene: (1) Ingen ventilering under plasten (kontroll); (2) Programmert ventilering hver tredje uke gjennom drensrør (5 cm diameter); (3) Programmert ventilering hver tredje uke gjennom oppblåsbare 'flat-tubes, (20 cm diameter); (4) Sensorstyrt ventilering gjennom drensrør hver gang oksygen (O_2) konsentrasjonen under duken gikk under 12 % og/eller karbondioksyd (CO_2) konsentrasjonen overskred 4 % (40000 ppm); og (5) Sensorstyrt ventilering gjennom oppblåsbare 'flat-tubes' i henhold til de same grenseverdiene som i ledd 4.

Før dekking med plast ble det på greenene i ledd 1, 4 og 5 montert sensorer som gjennom vinteren sendte timeverdier for temperatur, O_2 og CO_2-konsentrasjon til greenkeepernes PCer eller smart-telefoner. Deretter ble på alle greener lagt ut perforerte vårduker ('Evergreen' på Haga, 'Norgro klimaduk' på Bærum, Asker og Holtsmark) for å skape et lite luftlag og unngå at plasten skulle fryse fast i gresset. Ventileringssystemet som deretter ble lagt ut (dvs. mellom vårduken og plasten) i ledd 2-5 bestod av tre eller fire drensrør eller 'flat-tubes' på hver green. Som plastduk ble det brukt skreddersydde "Green Jacket' duker på Haga og en 20 m brei, gjennomsiktig plastfolie, tykkelse 115 µm, på Bærum, Asker og Holtsmark. Dukene ble sikret med sandsekker, og mot høyereliggende arealer utenfor greenene ble dukene felt inn under nedgravde krager for å hindre vann / smeltevann å trenge inn under plasten.

På alle fire baner ble greenene dekket i en kortvarig frostperiode mellom 26. and 30.november. Desember var mild og uten snø fram til jul, mens januar var stabilt kald med djup tele og inntil 40 cm snø. I februar fikk vi et værskifte med vekslende temperatur som førte til smeltevann og isdannelse mellom snø og plast. Fra slutten av januar ble ventileringa vanskeliggjort av tung snø og is oppå plasten, særlig på greener med 'flat-tubes'. Mesteparten av snøen og isen smeltet naturlig eller ble frest bort fra greenene i midten av mars. Plastdukene ble fjernet i siste uke av mars etter 110-120 dagers dekkeperiode.

Bedømming gjennom de første ukene etter at dukene var fjernet viste praktisk talt ingen is- eller vannskade på noen av banene eller i noen av behandlingene. Skader av mikrodochium-flekk like etter at dukene var tatt av utgjorde fra 3 % av samla greenareal på Haga til 14 % på Holtsmark; forskjellen skyldtes ulik soppsprøyting før dekking og hadde ingen statistisk sikker sammenheng med ventilering. Ved fjerning av dukene ble det likevel på noe av banene observert at microdochium-soppen var mest aktiv i nærheten av drensrøra i ledd 2 og 4.

På grunn av begrenset batterikapasitet og andre tekniske problemer varierte sensorenes dekningsgrad, dvs. andelen timer med rapporterte verdier, fra 36 % for temperatur til 53 % for CO_2. Til tross for denne utilfredsstillende datadekninga viste CO_2-sensorene signifikant lavere CO_2 konsentrasjon og en trend til høyere O_2 konsentrasjon i ledd 4 med ventilering gjennom drensrør enn i det uventilerte kontrolleddet. Ventilering gjennom flat-tubes kom i en mellomstilling. Antall ventileringer i ledd med programmert ventilering var fire på Bærum og fem på den andre banene. I ledda med sensorstyrt ventilering ble ventilering utført fra 0 til 5 ganger (middel 2,2).

Forsøket fortsetter med installering av forbedrede sensorer med større batterikapasitet og ny dekking av greenene foran vinteren 2021-22.

1 Introduction

Because of severe ice and water damage during the winter 2017-18 and thanks to inspiration from the Swedish golf course manager Torbjørn Pettersson, Sala Heby GC, Haga, Bærum, Asker and Holtsmark GC, all located 20-40 km west /southwest of Oslo (Figure 1), decided to cover some of their putting greens with impermeable plastic sheets before the 2018-2019 winter season. Six or seven of the ~20 greens at Bærum, Asker and Holtsmark, and six of the 28 greens at Haga were covered. The winter was stable with up to 1 m snow depth and few mild periods with melting water and ice formation. The winter challenges were therefore not as severe as the previous winter, but the experiences with plastic covers were nonetheless positive: The greens survived 140-150 days under the covers without anoxia or other types of winter damage. There was some microdochium patch depending on the number of preventative fungicide applications before winter, but not more than on uncovered greens. The importance of preventing water from seeping in or being pressed up under the plastic from deeper layers was very clear during this first winter (Aamlid et al. 2020).

Figure 1. Map showing location of the four golf courses

During the winter 2019-20, plastic coverage was extended to include all greens at Asker and Holtsmark and eleven greens at Bærum. The three courses used transparent plastic covers from the Swedish company SLIP AB. Haga ordered tailor-made covers for all greens from the Canadian company Green Jacket, but these covers did not arrive before the winter. Only 4 ½ greens were therefore covered at Haga during this winter.

The winter 2019-20 started early but soon turned into an on/off winter with fluctuating temperatures and ice formation of top of the covers. January and February 2020 were the mildest on record, thus resulting in early snow and ice melt except on shaded greens. The plastic covers at Bærum and Holtsmark were removed in February already, while most covers remained on the greens until late March at Haga and Asker. The experiences at Bærum which had almost the same number of covered and uncovered greens showed significantly better survival under the covers (Aamlid et al. 2020).

From January 2020, the trials with impermeable covers were included as Workpackage (WP) 3 in the Norwegian Golf Federation's project 'ICE-BREAKER: Reducing the agronomic and economic impact of ice damage on golf courses and other grasslands' (2020-2023). One of the objectives of this project is to introduce sensor technology to monitor the conditions at turfgrass crown level under ice encasement or impermeable plastic covers. While the proposal from August 2019 described a continuation of the comparison of uncovered greens and plastic-covered greens, the course managers in August 2020 expressed their confidence in the use of impermeable plastic covers and argued that WP3 should rather investigate the need for ventilation under the covers. Thus, we agreed on an experimental plan that included five experimental treatments, each replicated on three greens at each the four golf courses.

2 Materials and methods

2.1 Experimental treatments and division of greens into three blocks

The five ventilation treatments were tested at a whole green level on each of the four golf courses were:

1. NO_VENT: No ventilation under the plastic covers (Control)
2. DPIPE_3WK: Programmed ventilation every three weeks during the winter using 5 cm wide corrugated drainage pipes
3. FTUBE_3W: Programmed ventilation every three weeks during the winter using 20 cm diameter flat inflatable tubes.
4. DPIPE_SENS: Sensor-based ventilation through 5 cm wide drainage pipes (same as used in treatment 2) every time the oxygen (O2) concentration was less than 12 % and/or the carbon dioxide (CO2) concentration was higher than 4 % (40000 ppm) at crown level.
5. FTUBE_SENS: Sensor-based ventilation through 10 cm diameter flat inflatable tubes (same as used in treatment 3) every time the O2 concentration is less than 12 % and/or the CO2 concentration higher than 4 % (40000 ppm) at crown level.

The implementation of the treatments is described in detail in the following chapters from each golf course. Table 2 gives an overview of management common to all treatments.

2.2 Assignment of greens to five different treatments

The experiment had three replicates, thus comprising fifteen greens on each golf course. The greens were divided into three blocks (Table 1), the five greens in each block having as many common

Table 1. Characteristics of greens assigned to the three blocks on each golf course.

	Block I	Block II	Block III	*P*-value for diff. in ignition loss between blocks
Haga GC	Rootzone depth 30 cm (others 50 cm). Average green size 406 m^2 (291-528 m^2). Thatch ignition loss 3.0 % (2.3-3.8 %). On average 41 % (15-70 %) annual bluegrass.	Elevated, sunny greens, average size 501 m^2 (416-665 m^2). Thatch ignition loss 4.0 % (2.8-4.4 %). On average 17 % (5-35 %) annual bluegrass.	Shaded greens, average size 403 m^2 (356-452 m^2). Thatch ignition loss 3.7 % (3.2-4.2 %). On average 47 % (20-80 %) annual bluegrass.	*P*=0.02
Bærum GC	Open, sunny greens, average size 455 m^2 (400-500 m^2). Thatch ignition loss 4.4 % (3.9-4.9 %). On average 83 % (80-90 %) annual bluegrass	Shaded greens, average size 424 m2 (360-500 m^2). Thatch ignition loss 3.8 % (3.0-4.2 %). On average 95 % (90-100 %) annual bluegrass	Mixed conditions, average size 638 m^2 (390-1300 m^2). Thatch ignition loss 4.8 % (4.0-5.7 %). On average 83 % (75-90 %) annual bluegrass	*P*=0.06
Asker GC	Shaded greens, average size 591 m^2 (312-1224 m^2). Thatch ignition loss 6.0 % (5.2-6.4 %).	Open, sunny greens, average size 494 m^2 (410-565 m^2). Thatch ignition loss 6.0 % (5.3-6.8 %).	Greens with early snow melt, average size 595 m^2 (467-660 m^2). High ignition loss (mean 7.3 % (6.4-8.4 %).	*P*=0.06
Holts-mark GC	High risk for winter damage. Average green size 537 m^2 (320-950 m^2). Thatch ignition loss 3.4 % (2.8-4.6 %). On average 40 % (20-60 %) annual bluegrass.	Medium risk for winter damage Average green size 599 m^2 (390-900 m^2). Thatch ignition loss 3.7 % (2.8-4.7 %). On average 17 % (10-25 %) annual bluegrass.	Least risk for winter damage. Average green size 558 m^2 (430-620 m^2). Thatch ignition loss 3.5 % (2.9-4.1 %). On average 15 % (5-30 %) annual bluegrass.	ns

characteristics as possible in terms of construction type, rootzone depth, thatch ignition loss and botanical composition (Table 1). The division of greens into blocks was done in collaboration with the course managers and after determination of per cent organic matter (ignition loss) in the top 3 cm on all greens in October 2020. Table 1 shows that the ignition loss varied significantly or almost significantly between the three blocks at Haga, Bærum and Asker, but not at Holtsmark GC.

2.3 Sensors

On 24 Nov. 2020 the company 7Sense delivered eight sensors to Bærum GC and nine sensors to the other golf courses to be used in treatments 1, 4 and 5 (Photo 1). The temperature, O_2 and CO_2 sensors were embedded in a plastic cup (70 mm diameter and 50 mm high) that was a mounted in a standard 100 mm wide hole cup via an adapter (Figure 2, Photos 1 and 2). Each sensor was connected to a battery / sender mounted above expected snow depth on a pole just outside of the green / plastic sheets. The fact that the length of the cable between the hole cup and the battery/sender was only 5 m implied that the that sensors had to be placed along the outskirts rather in the center of each green (Photo 3). The distance between a sensor and the nearest drainage pipe / flat tube used for ventilation was at least 2.5 m. The sensors were programmed to collect hourly values for temperature, O_2 and CO_2. The highest CO_2 concentration that could be recorded was 40000 ppm (4 %).

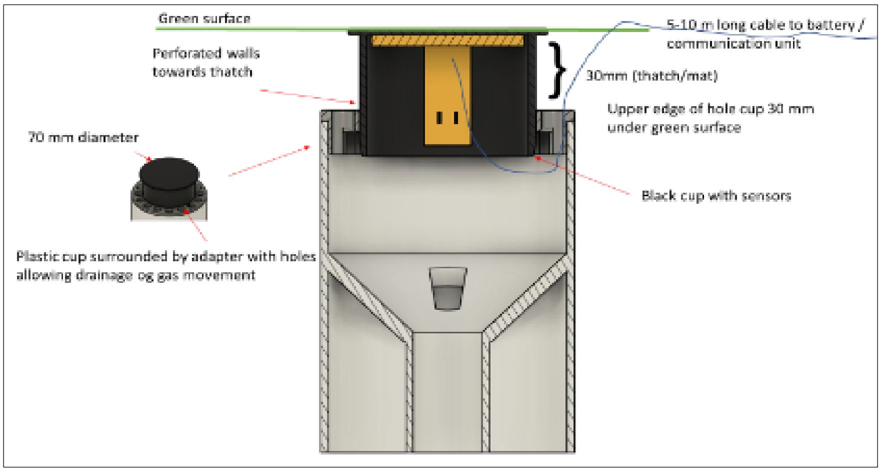


Figure 2. Sensors embedded in a black cup were mounted in a hole cup via a perforated adapter.

Photo 1. a) Max Tangen, 7Sense (to the left with sensor unit) delivered nine sensor nodes to Mads Thers, Holtsmark GC (to the right with battery/sender unit) on 24 Nov. 2020. b). Cup with sensors mounted in hole cup at Asker GC. Photos: Trygve S. Aamlid

Table 2. Botanical composition and management common to all treatments

	Haga GC	Bærum GC	Asker GC	Holtsmark GC
Grass species on greens	On average 57 % creeping bent-grass, 43 % annual bluegrass	15 % creeping bentgrass, 85 % annual bluegrass, highly variable	50 % annual bluegrass, 40 % rough bluegrass, 10 % creeping bentgrass	On average 76 % creeping bentgrass, 24 % annual bluegrass
Fertilizer after 1 Sep.	1.65 g N/m^2, last input 30 Sep.	5.1 g N/m^2, most of it on 28 Aug. last input 20 Oct.	2.46 g N/m^2, last time 2 Nov.	3.25 g N/m^2,last time 13 Oct.
Chemical growth regulators after 1 Sep.	No growth regulator	Primo Maxx II, 3 times, last time 0.3 L/ha on 2 Oct.	Primo Maxx II, 3 times, last time 0.3 L/ha on 13 Oct.	Primo Maxx II, 3 times, last time 0.3 L/ha on 13 Oct.
Last mowing in fall	5 Nov.	10 Oct.	23 Oct.	13 Oct.
Height at last mowing	4.0 mm	4.2 mm	5.0 mm	4.0 mm
Closure before winter	Blue and Yellow course: 19 Oct. Red course: 26 Oct.	20 Oct.	11 Oct.	18 Oct.
Fungicides against winter diseases	24 Aug.: Delaro, 0.3 L/ha 5 Oct.: Delaro, 0.3 L/ha 12 Oct.: Medallion, 0.3 L/ha	17 Sep.: Delaro, 0.1 L/ha 13 Oct.:Delaro, 0.1 L/ha 4 Nov.: Medallion, 0.26 L/ha 25 Nov.: Medallion, 0.26 L/ha	29 Sep. : Delaro, 0.2 L/ha 14 Oct.: Delaro 0.3 L/ha 30 Oct.: Medallion, 0.3 L/ha 17 Nov.: Medallion, 0.3 L/ha	24 Sep.: Delaro, 0.1 L/ha 16 Oct.: Delaro, 0.1 L/ha (Application of Medalllion not accomplished as planned)
Sand-dessing after 1 Sep.	Three times, 2 mm in total	Twice, 1.1 mm in total	Twice, 2.7 mm in total	Twice, 2.8 mm in total
Impermeable cover	Green Jacket (Canada) tailor-made for each green		Transparent covers, 20 m wide, thickness 115 µm. SLIP AB, Sweden	
Installation of covers	25-26 Nov.(most greens 26 Nov.)	29 Nov.	30 Nov.	28-29 Nov.
Removal of snow and/or ice on top of covers	Natural snow melt. Ice crushed with a rake and wiped off on 1 March in block I and II and on 22 March in block III.	Snow removed on 16 March. Then application of 'Black Earth' (coal) to melt the ice.	Snow cleared on 17 March.	Application of 'Black Earth' to melt snow on 10 March. Remaining snow (5-10 cm) cleared on 16 March
Impermeable cover off	29-31 March	29 March	29 March	23-24 March
Fungicides in spring	None	Tank mixture Delaro +Medallion except on greens 14 og 15	None	Tank mixture Delaro +Medallion on all greens
Permeable spring cover	'Evergreen' installed under the plastic sheets. Remained on the greens until ~20 April	'Norgro klimaduk' installed under plastic sheets. Remained on the greens until 19 April	'Norgro klimaduk' installed under plastic, removed on the same day as the plastic sheets.	'Norgro klimaduk' installed under plastic sheets. Remained on the greens until 17 April
Irrigation before 15 May	Not until 25 April (Irrigation pipes frozen)	Regularly since 16 April	5 times, first time 8 April. 30 mm in total	3-4 times per week, in total 10 mm per week, from 5 April
Fertilization before 15 May	5.6 g N/m2. Marathon Spring & Summer:	5 apps. of Liquid Turf Hardener and Greenmaster products totalling 3.6 kg N/m2	15 April + 29 April + 14 May : Andersons Nutri DG 6-0-12 + ICL WSF Spring/Summer, in total 2.3 g N/m2	14 Apr., 20 April and 9 May: Greenmaster/ Sportsmaster products totalling 7.2 g N /m2
First mowing	26-27 April: 5 mm	19-21 April: 4.7-5.0 mm	22 April: 6 mm	14 April: 4.5 mm
Overseeding in spring	Not until summer	Creeping bentgrass 'Riptide' + 'Luminary' on greens 9,11,17,18	Green 3, approach with ice/water damage: Rough bluegrass	6 Apr.: Creeping bentgrass '007'+ 'Riptide' on greens 9 and 11
Opening of golf course	14 May	7 May	8 May	1 May

Photo 2. The sensors were fitted into a hole cup. Top of hole cup was 3 cm from green surface, thus not inhibiting gases from the thatch layer to penetrate to the sensors. Photo: Trygve S. Aamlid

Photo 3. Sensor placement was limited to the 5 m wide outskirts of the greens due to cable length. Photo: Trygve S. Aamlid

2.4 Overall weather conditions

October, November and December 2020 were milder than in the two previous years and also when compared with the reference period 1991-2020 (Table 3, Figure 3). October and especially December had very high precipitation. Except for a thin and temporary snow layer at sensor installation at Bærum (cover photo) and during the last week of December, the entire precipitation in these months fell as rain.

The winter started with a sudden temperature fall shortly after New Year (Figure 3). January and the first two weeks of February were colder than in the two previous years and on level with or colder than the reference period. Snow depth varied with location (see later description of conditions on each golf course), but the snow layer was altogether rather thin, thus resulting in deeply frozen greens. The cold period culminated around 15 Feb. after which temperatures in late February and March were similar to the two previous seasons and far higher than during 2017-2018, the year with the most severe winter injuries on many golf courses.

April 2021 was very dry (Table 3), thus implying an early irrigation requirement.

Table 3. Mean monthly temperature and monthly precipitation at the Norwegian Meteorological Institute's weather station in Asker from October 2020 to April 2021 as compared with the two previous seasons and the 30-year normal values 1991-2020.

	Mean monthly temperature, °C				Precipitation, mm			
	2018-2019	2019-2020	2020-2021	Normal 1961-90	2018-2019	2019-2020	2020-2021	Normal 1961-90
October	6.9	4.9	7.2	6.1	50	164	214	115
November	2.5	0.1	4.7	1.7	149	205	111	115
December	-1.7	-0.4	1.2	-1.7	85	86	291	77
January	-3.0	2.5	-5.7	-2.5	44	70	80	81
February	-0.1	1.5	-4.1	-2.3	111	53	32	57
March	1.6	2.2	2.7	0.7	122	81	48	57
April	7.5	6.6	5.0	5.3	29	42	14	60
Mean / sum	2.0	2.5	1.6	1.0	590	701	790	562

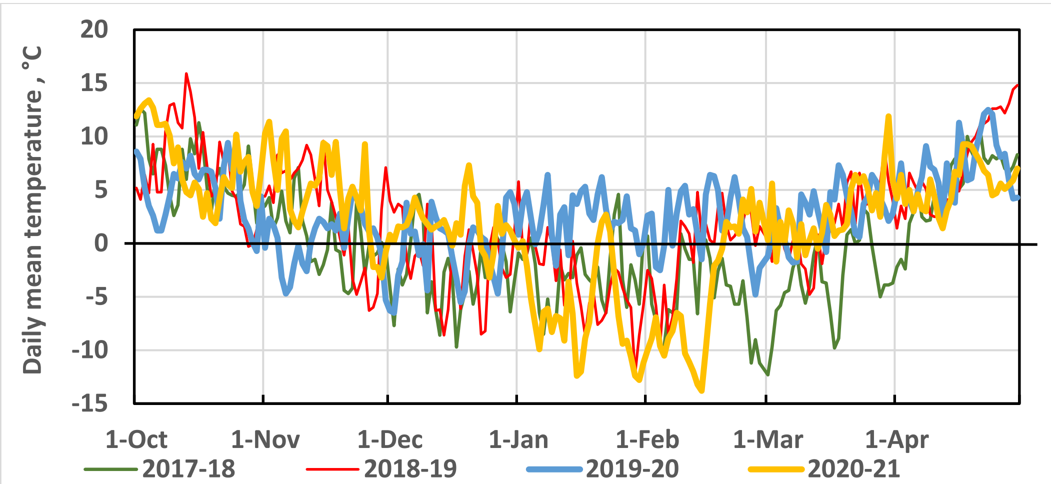


Figure 3. Daily mean temperatures October 2020 -April 2021 at Asker weather station as compared with the three preceeding winter seasons.

3 Implementation and results: Haga GC

3.1 Installation of ventilation pipe/tubes

The experimental greens at Haga were covered on 25-26 Nov., first with Evergreen permeable tarps, then with drainage pipes (treatments 2 and 4) or flat tubes (treatments 3 and 5) for ventilation, and finally with 'Green Jacket' covers tailor-made to each green. For ventilation, three or four unbranched drainage pipes or flat tubes were installed on each green (see example in Figure 4). At coverage, the surface was dry and firm, with frost in the top 2-3 cm and a soil water content of 13-18 %.

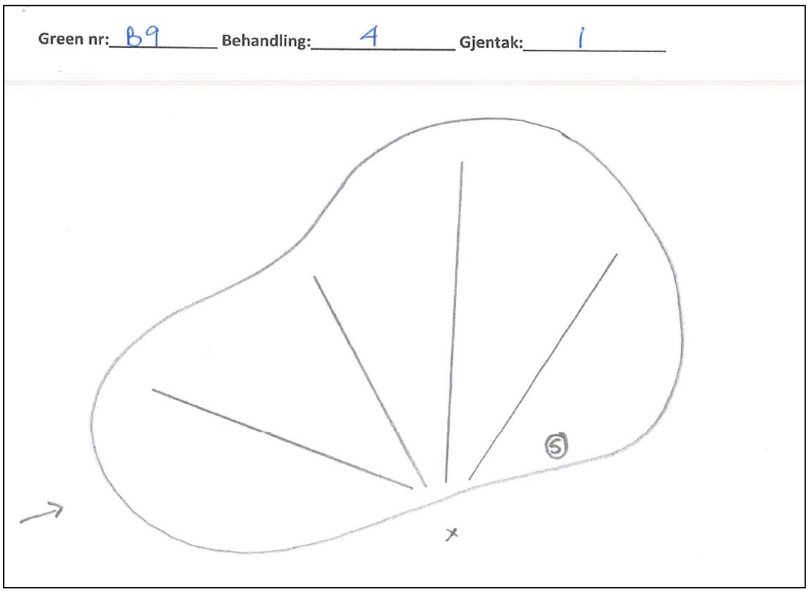


Figure 4. Sketch of drainage pipes installed on green 'Blue 9' at Haga GC. Placement of blower for ventilation (x) and hole cup with sensors (s) are indicated. Drawing: Gavin Jagger.

3.2 Snow and ice cover and consequences for ventilation

Of the four golf courses in this project, Haga is situated in the most open landscape and most exposed to wind. Some of the snow and sleet that came in late December soon turned into a porous ice layer that increased in thickness and compactness as some of the thin snow layer melted at the first mild spell around 20 January (Figure 5).

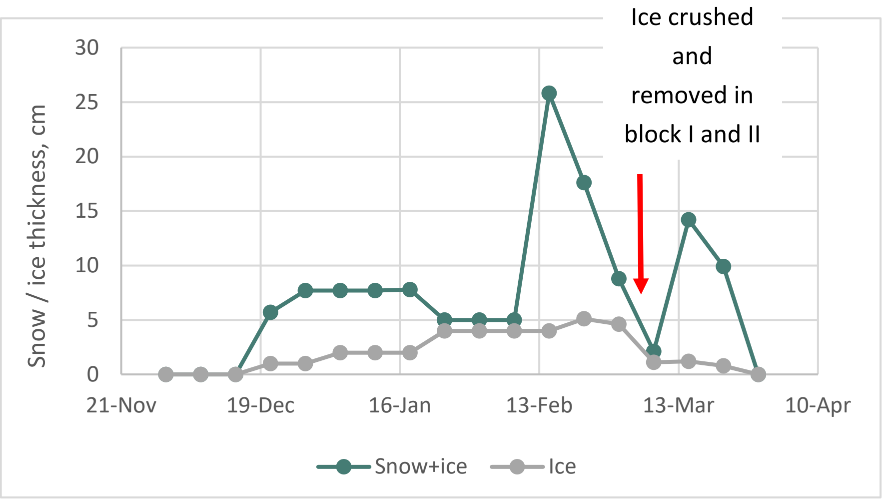


Figure 5. Average snow and ice thickness on the experimental greens at Haga GC. In block I and II, the ice was crushed and removed on 1 March, and the snow fall on 10 March did not result in any new formation of ice. In block III, the more shaded greens B2, Y7 and R5 were covered by ice until the last week of March.

The early formation of ice resulted in problems with ventilation under the 'Green Jacket' covers. In treatment 2 and 3 (ventilation every three weeks), the first ventilation on 14 Dec. went well (covers blowing up), but the following ventilations on 4 Jan., 25 Jan. and 15 Feb. were difficult because of the ice. The last ventilation on 1 March went well because most of the snow had melted and the ice crushed and removed on 1 March in block I and II. On the more shaded greens in block III, the ice was not crushed until 22 March. The 'Green Jacket' covers stayed on the greens until 29-31 March.

3.3 Temperatures and gas concentrations under the plastic covers

3.3.1 Sensor time coverage

Due to too low battery capacity or other reasons, data for temperature, CO_2 and O2 was only retrieved for 49-66 % of the hours from 28 Nov. to 28 March. The malfunction of sensors was most severe on green Y9 (Yellow 9) with only 12-14 % coverage for temperature and O2, Y2 with only 6 % coverage for CO2 and Y7 with only 5-8 % coverage for temperature and O2 (Table 4).

Table 4. **Per cent of hours, 28 Nov. – 28 March from which the sensors in sender unit and in the whole cup successfully recorded values for temperature, CO_2 concentration and O_2 concentration.**

Green no	Treat-ment	Block	Sensor no	% of hours with successful data retrieval			
				Air temperature in sender unit	In hole cup		
					Temperature	CO_2	O_2
B4	1	1	56	87	61	86	80
B1	1	2	63	96	74	55	94
B2	1	3	55	85	61	85	79
B9	4	1	61	97	65	34	78
Y9	4	2	57	12	13	59	14
R9	4	3	62	76	61	70	67
Y2	5	1	60	53	34	6	44
R2	5	2	59	84	71	47	76
Y7	5	3	58	8	5	35	5
Mean				66	49	53	60

3.3.2 Sensor-based ventilations and temperature and gas concentrations on ventilated vs. unventilated greens

On both unventilated and ventilated greens, temperatures under the covers were mostly above freezing until mid-January (Figures 6a and 7a). Because of no insulating snow but only ice above the covers, the mean daily temperatures went down to -13-15°C in mid-February.

On the unventilated Green Blue 2 (B2), the CO2 concentrations increased rapidly while the O2 concentrations decreased during the first weeks after coverage on 26 Nov. (Figure 6). Green B2 was a worst case with CO2 concentrations higher than 40000 ppm for about three months and O2 concentrations less than 5 % during the last month of coverage. The other unventilated greens had less extreme values, although a short period with O2 concentrations less the 10 % were recorded on green B4 as early as 16 Dec. (data not shown).

In the sensor-based ventilation treatments, the first warning about CO2-levels exceeding 40000 ppm came for green Y9 on 28 Jan. and for greens B9, R9 (Red 9), Y2 and R2 on 22 Feb. The total number of ventilations were three on Y9 and two on the other greens. Green Y7 was never ventilated because of poor data coverage. As with treatments 2 and 3, the greenkeepers had a feeling that the ventilation treatments in late January and February were in vain because of the ice layer above the covers. For green R9 this is confirmed by Figure 7 showing only a small, temporary and probably random drop in CO2 levels and rise in O2 levels two days after the first ventilation on 22 Feb. (red arrows in Figure 7). In contrast, the last ventilation on 4 March, after ice melt, was reflected immediately as a drop in CO2 concentration and a concomitant rise in O2 concentration (green arrows in Figure 7). O2 levels never went below 12 % on the ventilated greens at Haga.

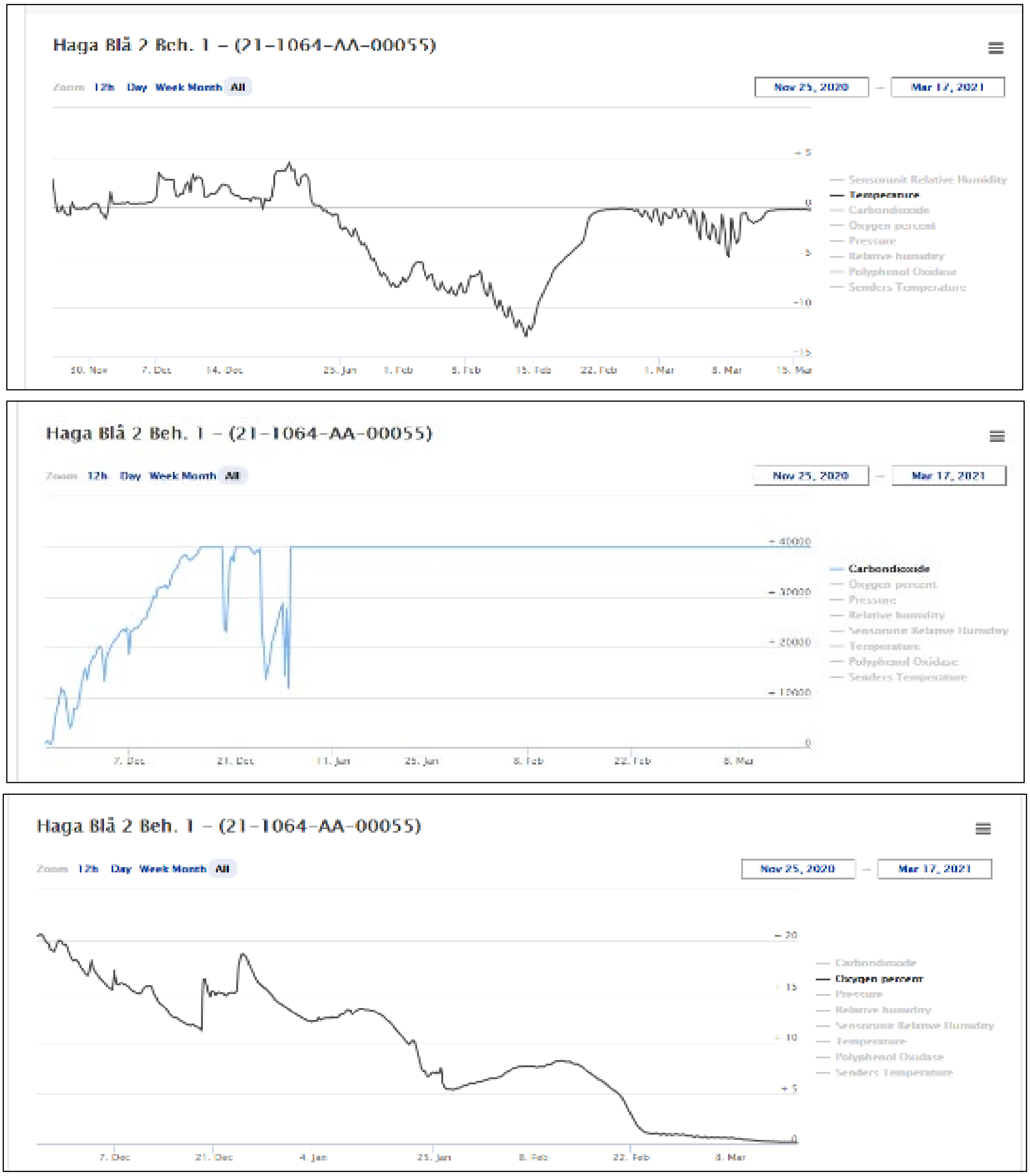


Figure 6a-c. Temperature and CO_2- and O_2 concentration in the hole cup on the unventilated green B2 at Haga.

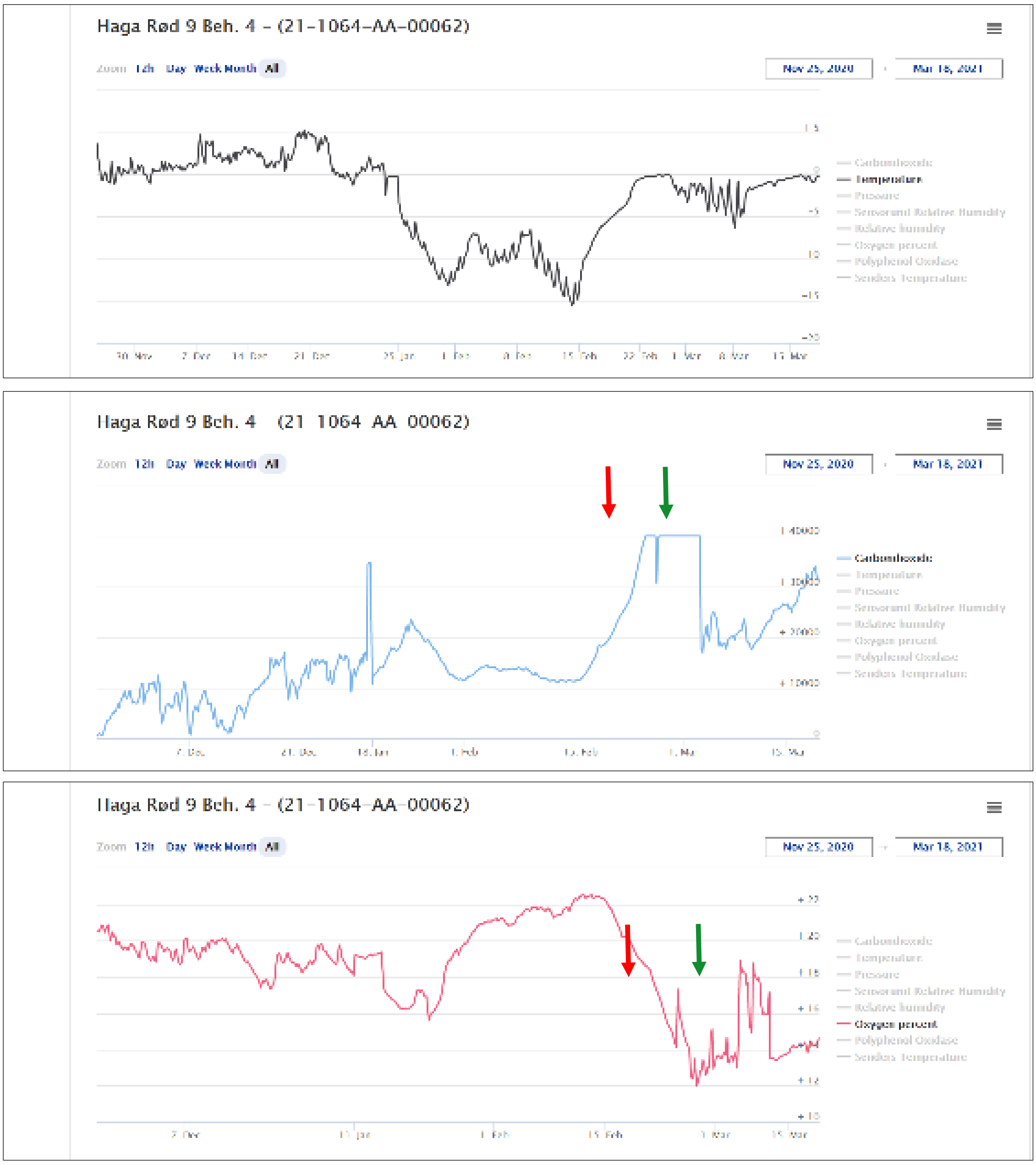


Figure 7a-c. **Temperature and CO_2- and O_2 concentration under the 'Green Jacket' covers on green R9 (treatment 4) at Haga. The criteria for ventilation were not reached until 22 Feb. when the CO_2 concentration exceeded 40000 ppm. Red and green arrows indicate unsuccessful ventilation on 22 Feb. and successful ventilation on 4 March, respectively.**

3.3.3 Summary of sensor data

In summary, the temperatures and gas concentrations at Haga were not significantly different among treatments (Table 5). On average for three greens per treatment, those without ventilation had the lowest temperatures, lowest O2-concentations and highest CO2-concentrations, but the variation within each treatment was to too high to allow significant conclusions.

Table 5. Mean and extremes for temperature, O_2 and CO_2 concentrations in treatments where sensors had been deployed at Haga. Mean of three greens per treatment.

	Temperature, °C			O_2, %		CO_2, ppm[1]
Treatment	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Mean**
1. No ventilation	-2.3	-14.3	5.5	14.7	7.0	23234
4. DPIPE_sensor	-0.8	-11.7	6.6	18.3	11.1	16621
5. FTUBE_sensor	-1.5	-9.9	5.9	16.8	12.5	19039
Sign.	ns	ns	ns	ns	ns	ns

[1] The maximum CO_2- concentration that could be recorded by the -sensors was 40000 ppm. Since this maximum value was reached occasionally on all greens, these figures do not represent the true mean value

3.4 Winter damage on greens

All experimental greens at Haga GC survived the winter without ice or water damage. At the removal of the 'Green Jacket' covers, the average percentage of green area affected by Microdochium patch was estimated to 3 % with a maximum of 10 % on green R9, but there was no significant effect of ventilation treatments. Photos 4-10 give an impression of the putting greens in April.

Photo 4. Two greens in Block I at Haga GC shortly after removal of the Green Jacket covers. To the left B4 (treatment 1, see sensor in foreground) and to the right B3 (treatment 2, i.e. programmed ventilation through drainage pipes). Photos: Lee McAndrew.

Photo 5. Greens Y1 (left) and Y2 (right) in early April. Effects of Green Jacket winter cover and the Evergreen permeable spring cover were quite conspicuous along the edge of Y1. On Y2 there was a lower area with some damage, most likely because of water under the cover. Photo: Lee McAndrew.

Photo 6. One of the more open and sunny greens in Block II: Y5 (treatment 2) shortly after removal of the impermeable 'Green Jacket' cover. The 'Evergreen' spring that can be seen on the far side of the green was pulled back after the photo had been taken. Photo: Lee McAndrew.

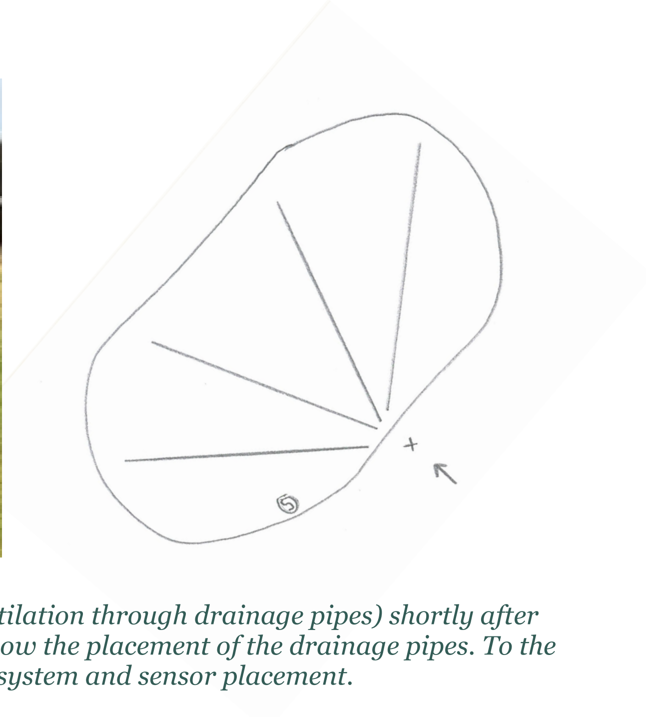


Photo 7. Green Y5 (treatment 2, i.e. programmed ventilation through drainage pipes) shortly after removal of the impermeable cover. The green lines show the placement of the drainage pipes. To the right he course managers drawing of the ventilation system and sensor placement.
Photo: Lee McAndrew. Drawing: Gavin Jagger.

Photo 8. The open and sunny putting green at Haga had ventilation treatment 5. When this photo was taken on 22 April, the green was still covered with the Evergreen Spring Tarp. Photo: Lee McAndrew.

Photo 9. Green B2 was one of the more shaded greens in block III. On this green, the sensors measured O2 concentration close to zero before cover removal in March (Figure 6). Photo: Lee McAndrew

Photo 10. Green R9 (treatment 4, block 3) suffered significant snow mold damage. Sensor values for this green are shown in Figure 7. Photo: Lee McAndrew.

4 Implementation and results: Bærum GC

4.1 Installation of covers and ventilation systems

Plastic collars to prevent water from seeping in under the plastic sheets were installed at Bærum GC shortly after the course had been closed for winter in late October (Photo 11). When 7Sense delivered sensors to the course on 24 Nov. the greens were mostly frozen and with a thin and coarse snow layer (Photo 12 and cover photo). However, the snow melted again, and the covers and ventilation systems were installed without problems during the weekend 28-29 Nov.

Photo 11. Preparations for coverage were made at Bærum GC in late October already. Old black and white plastic covers that had been used for coverage in 2018-19 were cut into long pieces and used as collars to prevent water from seeping in under the new covers. Photo: Trygve S. Aamlid

Photo 12. Max Tangen from 7Sense shows Course manager Guttorm Tuxen and his daughter Pia Tuxen how to install sensors at Bærum GC on 24 Nov. Photo: Trygve S. Aamlid

4.2 Snow and ice cover and consequences for ventilation

Apart from a couple of days before sensor installation in late November (Photo 12) there was no snow cover at Bærum until the last week of December. The winter started in Christmas week with a blizzard that blew off and partly teared apart the plastic sheets, flat tubes and undercovers on green 18 which had originally been assigned to treatment 5. Unfortunately, it was not possible to repair this damage before the winter since the storm was followed by 22 cm of heavy snow that froze to the ground. Photo 13 gives an impression of the mess that appeared on this green at snow melt in late March.

Photo 13. A Christmas blizzard destroyed the coverage of green 18. This photo was taken at snow melt on 24 March. Photo: Guttorm Ray Tuxen.

After the blizzard the temperature dropped and there was a cold and stable winter until mild spells resulted in starting formation of ice between the plastic sheets and the snow from mid-February onwards (Figure 8), i.e. more than one month later than at Haga GC. Photo 14 shows the change in thickness and consistency of the snow cover throughout the winter.

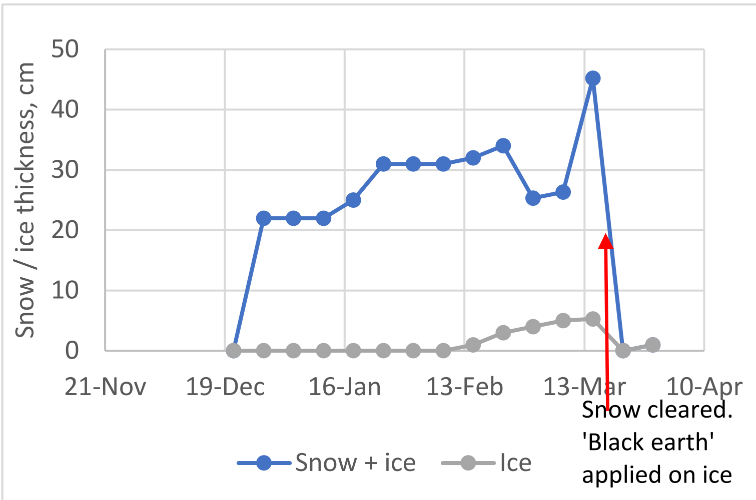


Figure 8. Average snow and ice thickness on the experimental greens at Bærum GC. The greens were cleared for snow and 'Black earth' added to melt the ice on 16 March.

Programmed ventilation in treatments 2 and 3 were carried out on 20 Dec., 19 Jan., 18 Feb. and 2 March. Because of no snow, the ventilation on 20 Dec. went well with the plastic covers lifting from the greens.

The greenkeepers at Bærum had a good feeling with the ventilation also on 19 Jan. when the snow was less than 30 cm thick and fluffy as there had been no mild spell so far. On 18 Feb. and 2 March there were more problems because of the heavy ice and snow layers above the covers. On 2 March, green no 8 (treatment 3, flat tubes) was an exception with the snow and ice layers lifting and cracking in response to the ventilation treatment (Photo 15).

Photo 14a-c. Snow depth and snow consistency at Bærum GC on a) 16 Feb., b) 22 Feb. og c) 12 March. A porous ice layer under the snow was not formed until a mild spell in mid February (b) The maximum ice + snow depth of about 40 cm was observed shortly before snow removal in mid-March. Photos: Guttorm Ray Tuxen.

Photo 15. The snow and ice on green 8 (treatment 3) were lifted and cracked in response to ventilation on 2 March. Photo: Guttorm Ray Tuxen

On 16 March, the greenkeepers at Bærum started to blow away the snow from all greens, and a couple of days later they applied 'Black Earth' on the remaining snow and ice (Photo 16a). The plastic sheets were removed between 22 and 28 March. On Green 17 (treatment 4), the plastic cover had to be cut into pieces because it was frozen to the ground and still covered by ice (Photo 16b).

Photo 16. a) Green 14 at Bærum GC on 19 March after snow removal and application of 'Black earth'. b) Green 17 on 22 March. The dark color of 'Black Earth' is visible, but the application had not been sufficient to melt the ice. The plastic sheets and flat tubes on this green had to be cut into pieces to remove them from the green. Photos: Guttorm Ray Tuxen.

4.3 Temperatures and gas concentrations under the plastic covers

4.3.1 Sensor time coverage

Eight sensors were delivered to Bærum GC instead of nine. Consequently, there was no sensor in treatment 1, block I (= Green 3). The average per cent data coverage for air temperature in the sender unit was higher than at Haga (84 vs. 66 %), while per cent data retrieval from the hole cup was on the same level, 44-66 % (Table 6).

Table 6. Per cent of hours, 30 Nov. – 28 March from which the temperature sensor in sender units and the temperature, CO_2 and O_2 sensors in the hole cups successfully recorded data at Bærum.

Green no[1]	Treat-ment	Block	Sensor no[1]	% of hours with successful data retrieval			
				Air temperature at sender	In hole cup		
					Temperature	CO_2	O_2
16	1	2	41	86	29	51	49
Big put	1	3	42	97	42	77	81
5	4	1	38	80	33	79	54
17	4	2	39	79	56	20	76
1	4	3	30	81	56	25	62
11	5	2	29	89	69	54	77
13	5	3	40	77	25	57	67
Mean				84	44	52	67

[1]Sensor 28 on green 18 has been excluded because the blizzard in Christmas week destroyed the covers on this green

4.3.2 Sensor-based ventilations and temperature and gas concentrations on ventilated vs. unventilated greens

Figure 9 show typical developments of temperature and CO2- and O2 concentrations on one of the unventilated greens (Green 16) at Bærum. Because of more snow cover, the minimum temperatures under the covers were higher and the maximum temperatures lower than at Haga. The CO2 concentration reached its maximum recordable threshold of 40000 ppm in early December and stayed at this level until about 15 Jan. O2-levels went down to 12 % in the first week of January and down to 10 % in the first week of March.

Figure 9a-c. Temperature and CO_2- and O_2 concentrations under plastic sheets on the unventilated Green 16 at Bærum.

Figure 10 shows the situation on the Big Putting green 'Store Putt' which also had no ventilation. Here the CO2 concentration exceeded 40000 ppm from early January until the plastic sheets were removed in late March. Unfortunately, the O2-sensor did not work on this green.

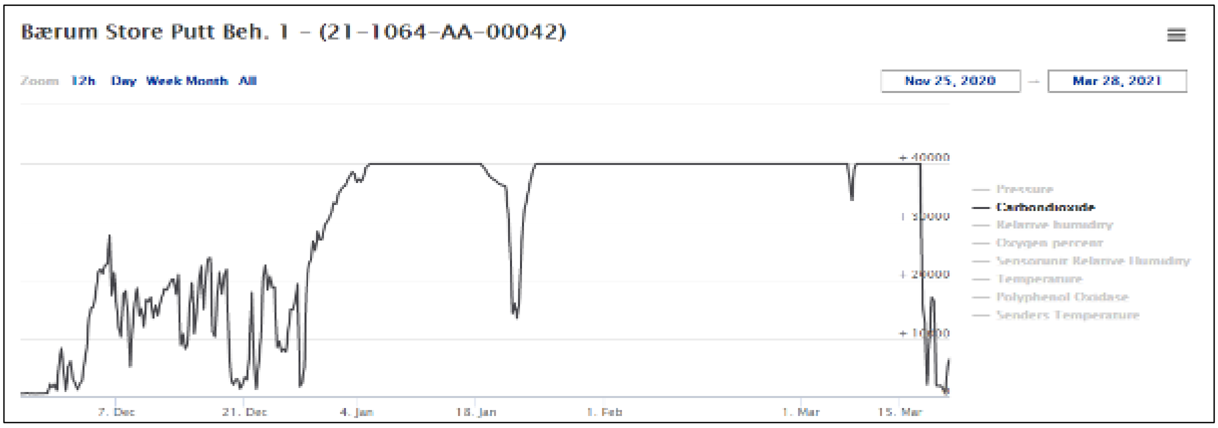


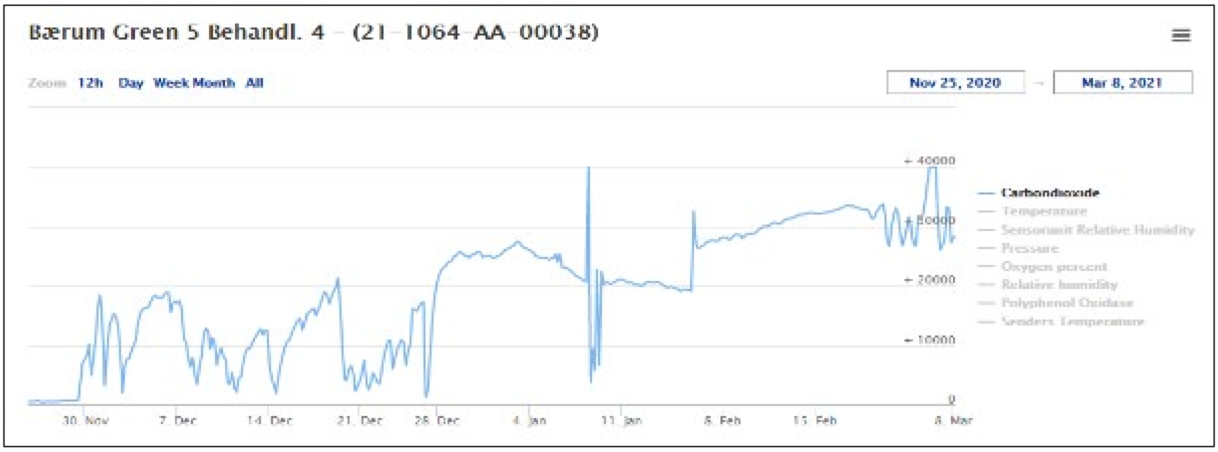
Figure 10. CO_2- concentration under the plastic sheets on the large unventilated putting green 'Store putt'

In the sensor-based ventilation treatments, the first warning of CO2-levels exceeding 40000 ppm came for green 17 (treatment 4) as early as 11 Dec. and was repeated on 20 Dec. and 21 Feb. (three ventilations in total). While the first two of these ventilations brought the CO2 levels down, there was no detectable effect of the ventilation on 21 Feb. (Figure 11b).

Figure 11a,b. Temperature and CO_2 concentration on green 17 (treatment 4 – drainage pipes) at Bærum GC. The green was ventilated three times (arrows) in response to CO_2- concentrations reaching 40000 ppm. The O_2 sensor did not work on this green.

The two other greens in treatment 4 were not ventilated at all. This was a mistake as the CO2-level reached 40000 ppm on 23 Feb. on Green 1 (Figure 12) and on 8 Jan. and 24 Feb. on Green 5 (Figure 13a). The O2 sensor on green 1 did not work, whereas the O2 concentration on Green 5 never went down to the ventilation threshold of 12 % O2 (Figure 13b).

Figure 12. CO₂ concentration on green 1 (treatment 4 – drainage pipes) at Bærum GC. By mistake, this green was never ventilated despite CO_2- concentrations reaching 40000 ppm on 24 February. The O_2 sensor did not report values on this green.



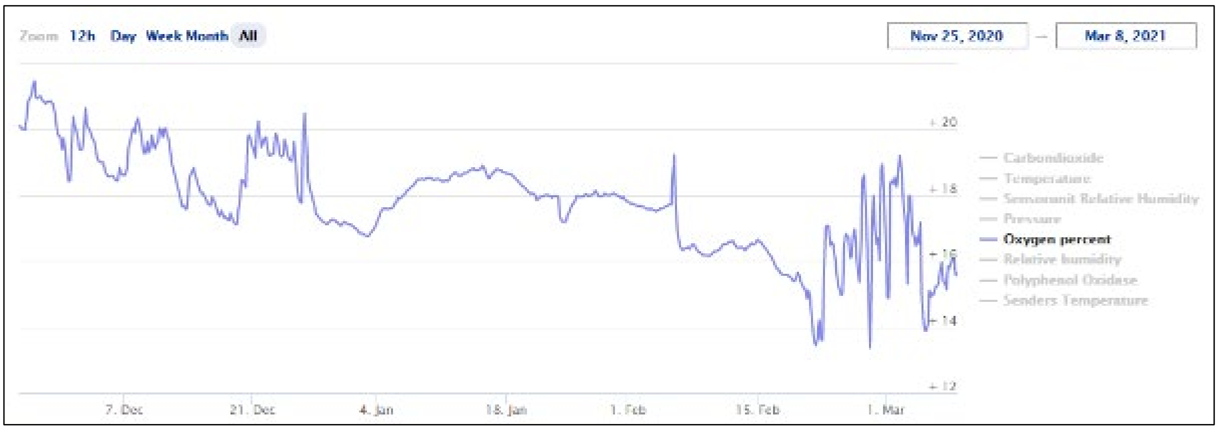


Figure 13a,b. CO_2 and O_2 concentration on green 5 (treatment 4) at Bærum GC. By mistake, this green was never ventilated despite CO_2- concentrations reaching 40000 ppm on 8 Jan. and 24 Feb.

In treatment 5, Greens 13 (Figure 14) and Green 11 (Figure 15) were both ventilated only once. In both cases, the ventilations resulted in lower CO2-level, whereas the effect on O2 concentration was less evident (Figure 14). According to the CO2 and O2 concentrations, both greens should have been ventilated for at least one more time, but this was not followed up by the greenkeepers.

Figure 14a-c. Temperature, CO_2 and O_2 concentration on green 13 (treatment 5 – flat tubes) at Bærum GC. This green was only ventilated once but should have received additional ventilations on 30 Dec. and 20 Feb.

Figure 15a,b. CO_2 and O_2 concentration on green 11 (treatment 5 – flat tubes) at Bærum GC. This green was only ventilated once. Because of falling O_2 concentration, it should have been ventilated also on 6 March.

4.3.3 Summary of sensor data

Despite ventilation of only one of three greens in treatment 4 and only one ventilation on per green in treatment 5, the summary in Table 7 shows an overall trend to a lower mean O2 concentration in the unventilated than in the ventilated treatments. The difference was accompanied by opposite, although not significant, differences in the average CO2-concentration. The minimum O2 concentration suggested that ventilation through drainage pipes was more efficient to avoid extremes than ventilation through flat tubes, but as for CO2, the difference was not significant.

Table 7. Mean and extremes for temperature, O_2 and CO_2 concentrations in treatments where sensors had been deployed at Bærum GC. Mean of two greens in treatments 1 and 5 and three greens in treatment 4.

	Temperature, °C			O_2, %		CO_2, ppm[1]
Treatment	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Mean**
1. No ventilation	-0.7	-4.8	3.8	13.0	6.0	32271
4. DPIPE_sensor	-0.6	-6.1	6.0	18.2	15.1	20473
5. FTUBE_sensor	-0.7	-5.0	4.5	17.1	9.1	20207
Sign.	ns	ns	*	(*)	ns	ns

[1] The maximum CO_2- concentration that could be recorded by the -sensors was 40000 ppm. Since this maximum value was reached occasionally on all greens, the figures may not represent the true mean value

4.4 Winter damage on greens

Historically, Green 9 is the green at Bærum that suffers most from microdochium patch. On this green which had been assigned to treatment 2, the course manager removed the plastic from about one third of the green area for a couple of hours on the day after the first programmed ventilation on 20 Dec. Despite the four fungicide applications prior to coverage, he then observed small patches of disease close to the drainage pipes (Photo 17). In spring, it was therefore not surprising that this green had more microdochum patch that any other green on the golf course (Photo 17c).

Photo 17a-c. The shaded Green 9 at Bærum is notorious for microdochium damage. Before the winter 2020-21, this green was assigned to treatment 2 (programmed ventilation through drainage pipes). On 21 December, the plastic sheets were removed briefly from part of the green to check for beginning signs of disease (a,b). The green had been ventilated one day earlier. Symptoms of microdochium patch could then be seen, mostly in the vicinity of the drainage pipes. At cover removal on 25 March, this green had by far the worst attack of microdochium patch – 25% of plot area. Photos: Guttorm Ray Tuxen.

Except of some light damage on Green 18 where the plastic cover had blown off (Photo 20), there was no ice or water damage on the greens at Bærum. Except on Green 9 which suffered 25% damage, the damage from microdochium patch varied from less than 1 % to 5 % (overall average 3.5 %). There was no significant effect of treatments on this biotic winter damage.

Photos 18-21 give some impressions from the greens at Bærum shortly after the removal of the plastic sheets and one month later.

Photo 18a,b. Green 8 (treatment 3) at the removal of the plastic sheets on 24 March (left) and six days later. The green was practically without any winter damage. Photos: Guttorm Ray Tuxen.

Photo 19. a) Pål Melbye from Norwegian Golf Federation (left) and Course Manager Guttorm Ray Tuxen (right) on Green 6 (treatment 3). b) Green 7 (treatment 2) with line after drainage pipe. Both photos taken on 22 April by Trygve S. Aamlid.

Photo 20. Green 3 on 22 April. The plastic sheets were too narrow to cover the entire green. Damage was seen where the sand bags had been placed to keep the covers in place. Photo: Trygve S. Aamlid.

Photo 21. From Green 18 which had been partly uncovered by the storm during Christmas week (cf. Photo 13). Green-up om the lower, uncovered part (to the right for Melbye and Tuxen) was much later than on the upper, covered part of the green to then left. Between the two parts there was a belt with severe damage from microdochium patch. Photo taken on 22 April by Trygve S. Aamlid.

5 Implementation and results: Asker GC

5.1 Installation of ventilation pipe/tubes

The sensor on Asker, Green 1 (treatment 5), was installed by Max Tangen, 7Sense, and course manager James Bentley on 24 Nov. Sensor installation on the other greens followed two days later. Spring tarps (‘Norgro klimaduk’) and ventilation systems (Figure 16) were put out on 28 Nov. and the plastic sheets on 29 Nov. (Photo 22).

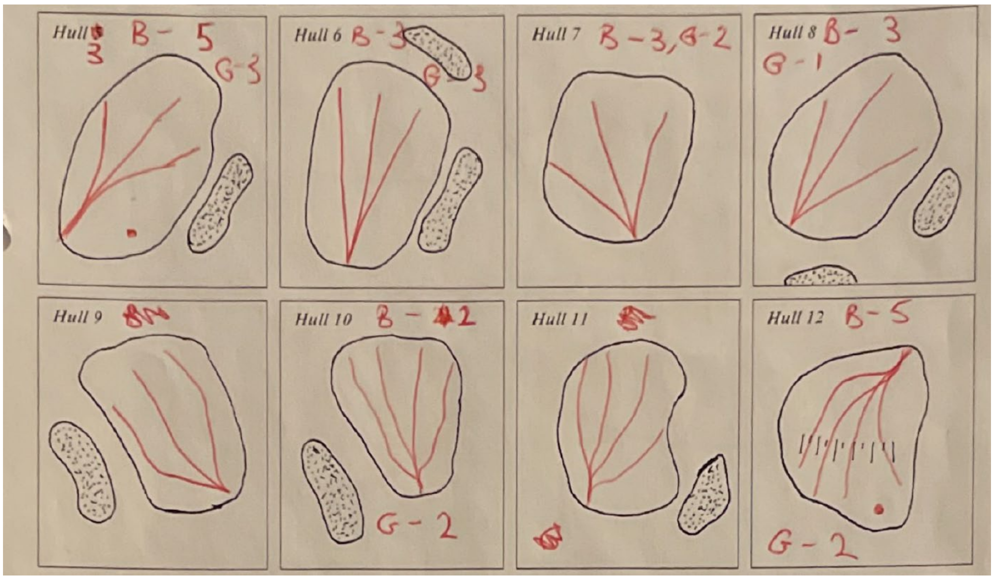


Figure 16. **Ventilation systems on some of the greens at Asker GC. (B=Treatment, G=Block (replicate)). Red dots on greens indicate sensor placement. Drawing: James Bentley.**

Photo 22. Plastic sheets are pulled over Green 15 (treatment 2) at Asker on 29 Nov. Climate tarp (undercover) and drainage pipes had been laid out on the day before. Sensor sending unit in the foreground. Photo: James Bentley

5.2 Snow and ice cover and consequences for ventilation

With snow depths up to 65 cm, Asker was the golf course that has the thickest snow cover of the four golf courses in this project (Figure 17).

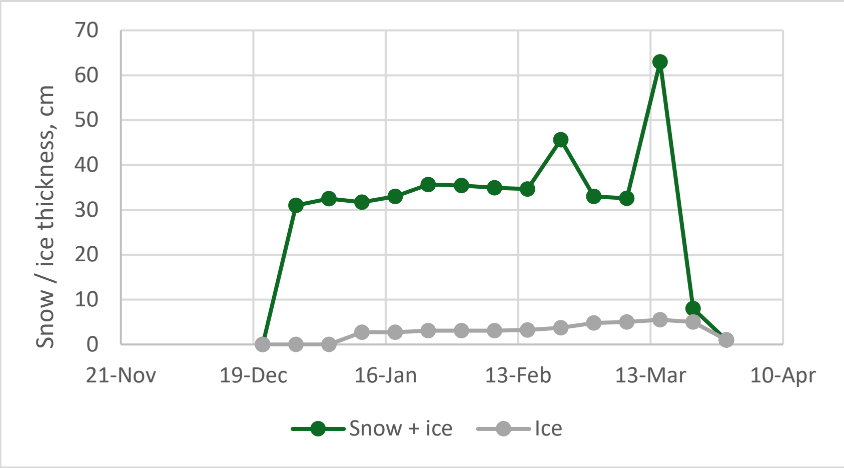


Figure 17. Average snow and ice thickness on the experimental greens at Asker GC. Most of the snow was cleared from the greens on 17 March.

Ice formation between the plastic sheets and the snow started later than at Haga, but earlier than at Bærum. In treatment 2 and 3, only the first ventilation on 21 Dec. (before snowfall) was undoubtedly successful. The following ventilations on 15 Jan., 8 Feb., 2 March and 22 March became more and more difficult due to the weight of the snow and ice. Unlike at the three the other courses, the plastic sheets and the undercover were removed on the same day – 29 March.

Photo 23a-c. Snow removal on Green 8 (a, b) and Green 6 (c) at Asker on 17 March. The tractor driver intentionally left 8-10 cm of snow in order not to destroy the covers. Photos: James Bentley.

Photo 24. After snow removal on 17 March, a 5-6 cm ice layer could be seen on some of the greens. Photo: James Bentley.

5.3 Temperatures and gas concentrations under the plastic covers

5.3.1 Sensor time coverage

Unfortunately, data capture by the sensors in the hole cups at Asker was rather fragmentary. (Table 8). All sender units were taken inside on 21 Dec. because of empty batteries or dysfunction. On 30 Dec., the entire unit on Green 1 was replaced and new batteries installed in the other units by 7Sense. Still, the incomplete data acquisition continued for the rest of the winter.

Table 8. Per cent of hours, 28 Nov. – 28 March from which the sensors in sender unit and in the whole cup successfully recorded values for temperature, CO_2 concentration and O_2 concentration at Asker.

Green	Treat-ment	Block	Sensor no	% of hours with successful data retrieval			
				Air temperature in sender unit	In hole cup		
					Temperature	CO_2	O_2
Chip	1	1	75	81	15	22	12
5	1	2	67	81	15	30	15
14	1	3	73	84	29	44	32
4	4	1	68	79	22	78	24
2	4	2	74	88	39	66	67
13	4	3	64	86	19	27	22
1	5	1	65/87*	62	0	37	62
12	5	2	72	86	18	27	42
3	5	3	76	77	17	20	35
Mean				80	19	39	35

*Sensor no 65 was replaced with no 87 on 30 Dec.

5.3.2 Sensor-based ventilations and temperature and gas concentrations on ventilated vs. unventilated greens

The most reliable data from the sensors at Asker were from December. During this month, the temperatures under the covers were mostly above freezing, with CO2 levels increased up to 40000 ppm between 12 and 16 December. A couple of days later, the O2 sensors that were operative showed values down to 11 % on the unventilated greens (treatment 1; Figure 18).

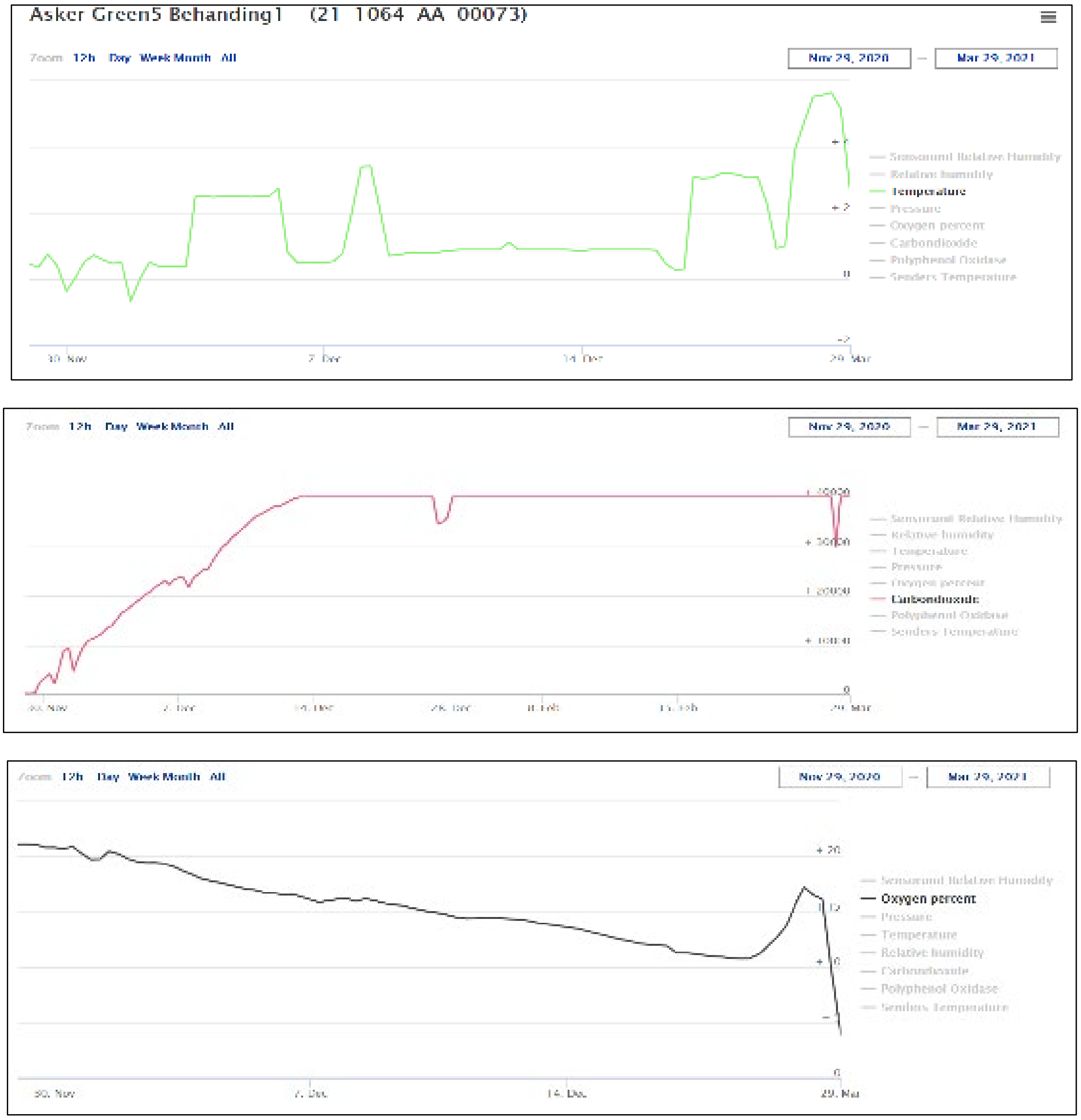


Figure 18a-c. Temperature CO_2- and O_2 concentration in the hole cup on the unventilated Green 5 at Asker.

In the sensor-based ventilation treatment 4, it was always the CO2-threshold that resulted in ventilation as the O2 concentration was never below 12 %. Green 2 was ventilated five times from 21 Dec to 2 March but should ideally have been ventilated at least one more time in March (Figure 19). Similarly, Green 4 was ventilated four times but should also have been reventilated in March (Figure 20). Green 13 with the same treatment was only ventilated on 21 Dec. as neither the CO2 nor the O2 sensors operative after December (data not shown).

Figure 19a-c. Temperature and CO_2- and O_2 concentration under the plastic sheets on Green 2 (treatment 4) at Asker GC. The CO_2-threshold (40000 ppm) resulted in five ventilations from 21 Dec. to 2 March. According to this criterion, the green should have been ventilated at least one more time in March, but that was not carried out. The O_2 concentration never went down to 12 %, but as indicated by the red arrows, the recorded responses to ventilation were far less evident than for CO_2.

Figure 20. CO_2- and O_2 concentration under the plastic cover on Green 4 (treatment 4) at Asker. The CO_2-threshold 40000 ppm for ventilation was reached four times from 21 Dec. to 2 March. According to this threshold, the green should also have been ventilated at least one more time in March. The O_2 sensor did not respond positively to ventilations and was not operative after 11 Jan.

In the sensor-based treatment 5 (flat tubes) no data were available for temperatures on green 1. After the replacement of the sender unit on 30 Dec., the CO2 and O2 concentrations were, however almost constantly higher than 40000 ppm and lower the 12 %, respectively (Figure 21). The green was ventilated on 21 Dec. (due not warnings for the other greens with the same treatment) and on 30 Jan., 3 Feb., 8 Feb. and 3 March, but except for 21 Dec., ventilation was difficult because of the heavy snow and ice cover. Small and temporary drops in CO2 concentration could be seen after some of the ventilations, but the O2-sensor did not react to the ventilations at all (Figure 21).

On Green 12, also treatment 5, the CO2 levels exceeded 40000 ppm and O2 levels were down to less than 10 % around 20 Dec. (Figure 22). The resulting ventilation on 21 Dec. was detected by the CO2 sensor but hardly by the O2-sensor. For the rest of the winter, this green and Green 3 (also treatment 5) were ventilated according to the gas concentration in the same treatment on green 1. The CO2-sensors did not work, and ventilations were not detected by the O2-sensors.

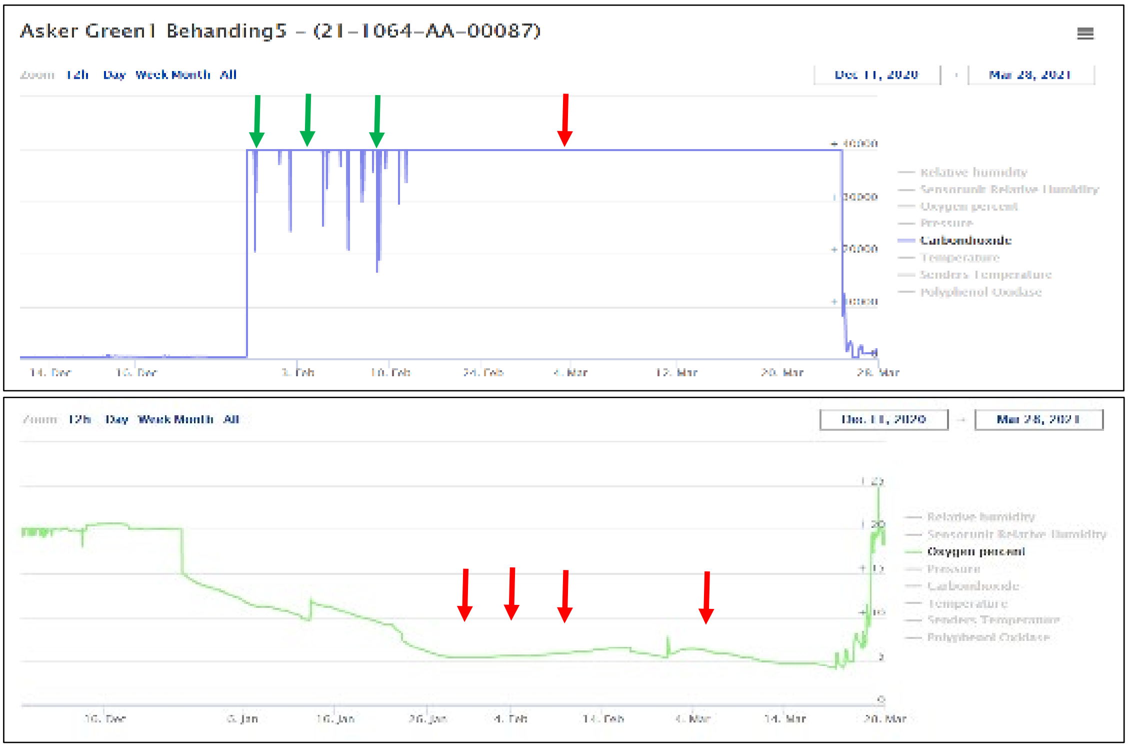


Figure 21. CO_2- and O_2 concentration on Green 1 (treatment 5) at Asker GC. The CO_2-threshold 40000 ppm was exceeded and the O_2-concentration went below 10 % a period for more than 60 days. Responses in gas concentration to ventilations were absent for O_2 (red arrows) and, at the very best, transient for CO_2 (green arrows). This green was also ventilated on 21 Dec., but then there was no sensor in operation.

Figure 22. CO_2- and O_2 concentration under plastic sheets on green 12 (treatment 5) at Asker GC. The green was ventilated on 21 Dec. in response to the high CO_2-concentrations and low O_2-concentrations, but a change in concentrations was detected only by the CO_2-sensor.

5.3.3 Summary of sensor data

The temperature and gas concentrations at Asker must be interpreted in light of the poor data coverage, especially during the cold period in January and early February. Despite the ventilation problems, it is still noteworthy that the drainage pipes, with a fixed form, gave a bigger and more durable response than the inflatable flat tubes (Table 9).

The difference between the unventilated control treatment and treatment 5 is suspicious and must probably be interpreted as a random effect due to sensors being in operation in different periods.

Table 9. Mean and extremes for temperature, O_2- and CO_2 concentrations in treatments where sensors had been deployed at Asker. Mean of three greens per treatment.

	Temperature, °C			O_2, %		CO_2, ppm[1]
Treatment	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Mean**
1. No ventilation	1.8	-2.0	14.7	14.7	9.9	33164
4. DPIPE_sensor	0.7	-1.2	3.6	16.3	12.9	27971
5. FTUBE_sensor	1.1	-1.2	4.6	10.0	4.4	30488
Sign.	**	ns	(*)	*	*	ns

[1] The maximum CO_2- concentration that could be recorded by the sensors was 40000 ppm. Since this maximum value was reached occasionally on all greens, these figures do not represent the true mean value

5.4 Winter damage on greens

Turfgrass samples taken inside from Green 2 (treatment 4) on 2 Feb. (i.e. approximately half way through the winter) showed healthy turf with no damage thus far (Photo 25). This was also confirmed when the plastic sheets and undercovers were taken off on 29 March (Photo 26). Except on Green 3 which had a small area where where ice and melting water had been trapped partly on the green and partly just outside (Photo 27), there was no ice or water damage at all. The most damage from microdochium patch was seen on parts of Green 6 (treatment 3) where the plastic had blown off due to the blizzard between Christmas and New Year (Photo 28).

Photo 25. Samples taken inside on 2 Feb. under the plastic cover on Green 2 showed no winter damage so far.

Photo 26. Green 13 (treatment 4) shortly after cover removal on 29 March. Photo: James Bentley.

Photo 27. Green 3 (treatment 5) shortly after the removal of covers on 29 March. A small area suffered damage from ice and melting water. Photo: James Bentley.

Photo 28. Green 6 (treatment 3) shortly after the removal of covers on 29 March. There was sever damage from microdochium patch on a part of the green that had been uncovered by the storm on 28 Dec. Photo: James Bentley.

Photo 29. Course manager James Bentley on Green 14, 22 April. Excellent winter survival despite no ventilation on this green. Photo: Trygve S. Aamlid.

Assessments of winter damage at cover removal on 29 March and about two weeks after showed no significant difference between the ventilation treatments (Table 10).

Table 10. Winter damage (mainly microdochioum patch) in the various treatments at Asker GC. Mean of three blocks.

	Winter damage, % of plot area	
	29 March	15 April
1. Unventilated control	4.7	4.0
2. Programmed ventilation through drainage pipes every 3 weeks	6.0	4.3
3. Programmed ventilation through flat tubes every 3 weeks	4.7	3.0
4. Sensor-based ventilation through drainage pipes	7.0	4.7
5. Sensor-based ventilation through flat tubes	3.0	2.7
	ns	ns

6 Implementation and results: Holtsmark GC

6.1 Installation of covers and ventilation pipe/tubes

Collars had been dug into the upper surrounds and bags with sand placed along the edges of the greens (Photo 30) when Max Tangen handed over sensors to course manager Mads Thers in the morning on 24 Nov. (Photo 1). On this morning the greens could not be walk on because the surface was frozen. Instead, the undercovers, ventilation systems and plastic sheets were installed on the milder days 28-29 Nov.

Photo 30. Putting green at Holtsmark in the morning on 24 Nov. Photo: Trygve S. Aamlid

Figure 23. Examples of the simple, unbranched ventilation systems laid out under the covers at Holtsmark GC. N=green nr, b=treatment, G=block. Drawings: Mads Thers.

6.2 Snow and ice cover and consequences for ventilation

Snow and ice during the winter followed the same pattern as on the other golf courses. The plastic covers on Green 3 (treatment 1), 9 (treatment 1) and 16 (treatment 4) blew off due to the storm on 28-29 Dec, but the snow was cleared and the covers reinstalled on 12-13 January. On Green 3 the reinstallation was not successful as melting water started to seep in under the plastic. The plastic cover on this green was therefore removed in early February and the observations discarded from the experiment.

'Black Earth' was applied to melt snow on 9 March but buried by a moderate snow fall a couple of days later. Seven of the fifteen experimental greens were practically without snow and ice on 15 March, on the others between 5 and 15 cm of snow was removed on 16 March. The thickest and most persistent ice layers were found on Green 1 (treatment 1), Green 14 (treatment 5) and Green 17 (treatment 3).

Ventilations in treatments 2 and 3 were carried out on 18 Dec., 8 Jan., 2 Feb, 18 Feb, and 9 Dec. The ventilations in December and January were successful, but the ventilations in February and March were difficult with the air coming in return rather than being distributed under the covers.

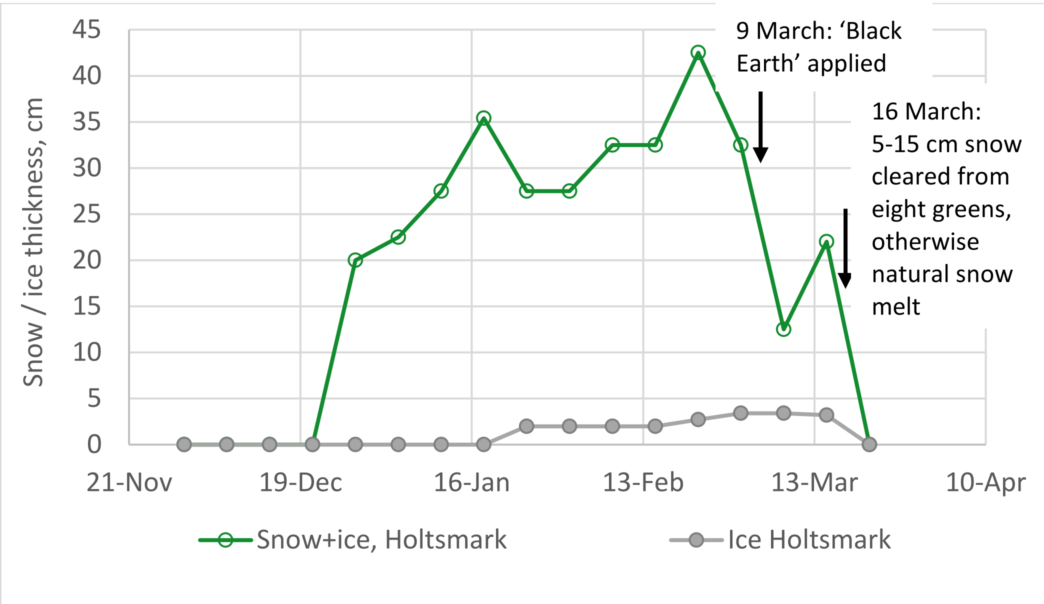


Figure 24. Average snow and ice depth on the experimental greens Holtsmark GC.

6.3 Temperatures and gas concentrations under the plastic covers

6.3.1 Sensor time coverage

Sensor data coverage on Holtsmark was at the same unsatisfactory level as on the other golf courses. (Table 11). Batteries were replaced several times and alle sender units repaired by 7Sense and reinstalled on 14 Jan., and for Green 11 also on 2 Feb., but the unstable data acquisition continued, notably for temperature.

Table 11. Per cent of hours, 30 Nov. – 22 March from which the sensors in sender unit and in the whole cup successfully recorded values for temperature, CO_2 concentration and O_2 concentration.

Green no	Treat-ment	Block	Sensor no	% of hours with successful data retrieval			
				Air temperature in sender unit	In hole cup		
					Temperature	CO_2	O_2
1	1	1	45	85	37	78	63
9	1	3	49	85	45	46	83
4	4	1	50	34	25	25	62
10	4	2	43	86	83	86	69
16	4	3	53	63	42	43	63
14	5	1	54	54	23	23	25
12	5	2	51	49	16	16	35
11	5	3	48/89	40	11	22	45
Mean				62	35	42	56

6.3.2 Sensor-based ventilations and temperature and gas concentrations on ventilated vs. unventilated greens

CO2 concentrations varied between the two unventilated greens that kept the covers in place during most of the winter. On Green 1 the concentration exceeded 40000 ppm from about 20 Feb. (Figure 25), but on Green 9 the concentration was always less than 20000 ppm (Figure 26). The O2 sensors did not report reliable data on Green 1, but showed values that were always higher than 14 % on Green 9.

Figure 25a,b. CO_2 and O_2 concentrations under the plastic sheets on the unventilated Green 1 at Holtsmark GC. Red arrows indicate the period when parts of the green were uncovered after the storm around Christmas has been indicated. The O_2 sensor did not work on this green.

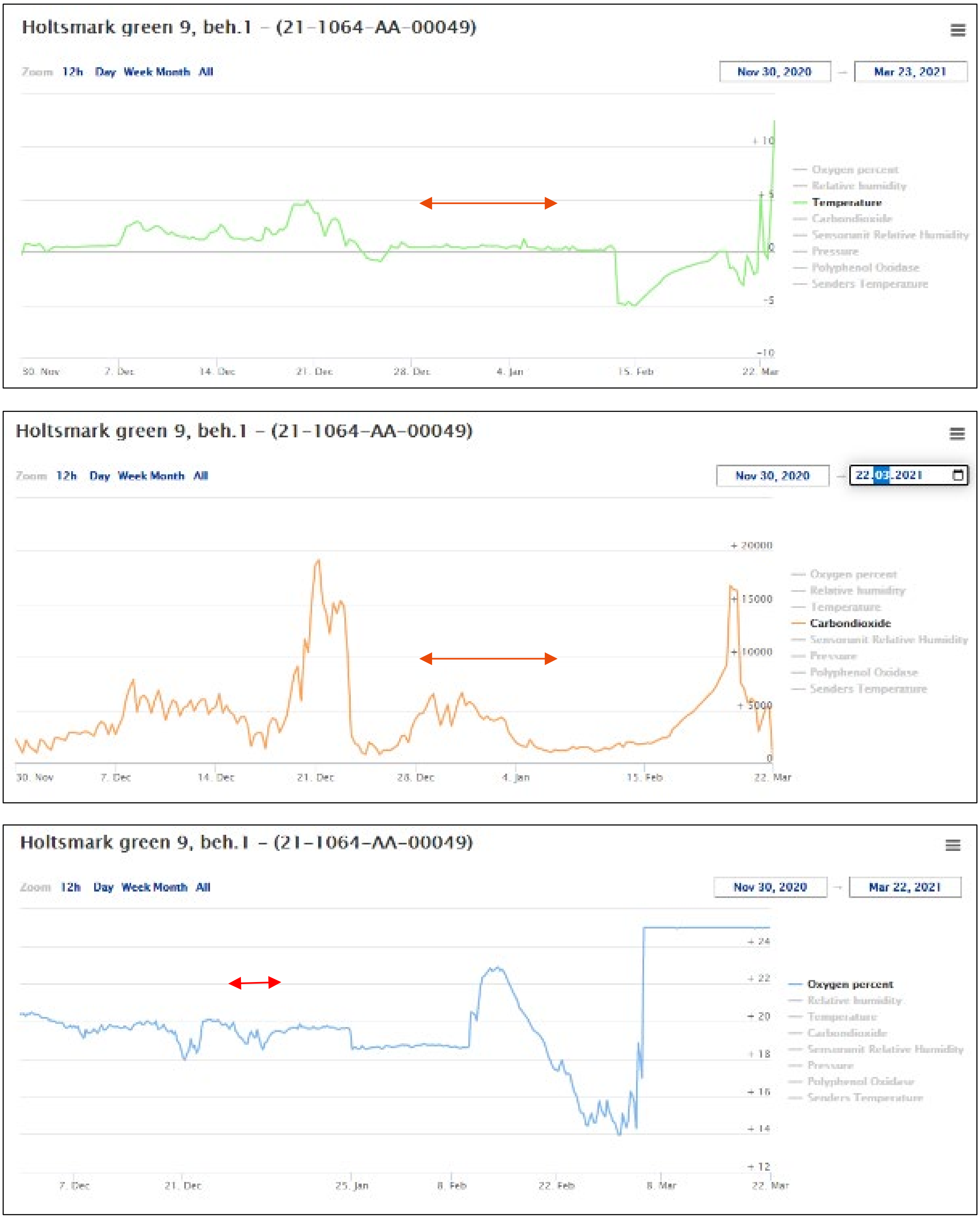


Figure 26a-c. Temperature, CO_2 and O_2 concentrations under the plastic sheets on the unventilated green 9 at Holtsmark GC. The period 28 Dec.-11 Jan. when the green was partly uncovered after storm around Christmas has been indicated.

In treatment 4 with sensor-based ventilation through drainage pipes, on Green 10 there was a good response in both CO2 and O2-levels to the first ventilation triggered by the CO2 concentration on 18 Dec. (Figure 27). The next ventilation on the same green was on 23 Feb., also in response to high CO2 levels, while the last two ventilations on 2 March and 9 March were in response to O2-concentrations approaching 12 %. In large, these ventilations produced detectable changes in the gas concentrations under the covers, although less precise and in some cases with couple of days' delay in response.

Also in treatment 4, Green 4 was never ventilated as the sensors were operative in December only and then never reached the threshold values (data not shown). Green 16 was, in contrast, ventilated on 18 Dec. and on 23 Feb. in response to the CO2 threshold, and on 2 March according to the O2 threshold as the CO2 sensor was not in operation any more (Figure 28).

Figure 27a-c. Temperature, CO_2 and O_2 concentrations under the plastic sheets on green 10 ventilated through drainage pipes at Holtsmark. Green arrows indicate ventilations followed by a detectable change in CO_2 or O_2 concentration, while red arrows indicate apparently unsuccessful ventilations.

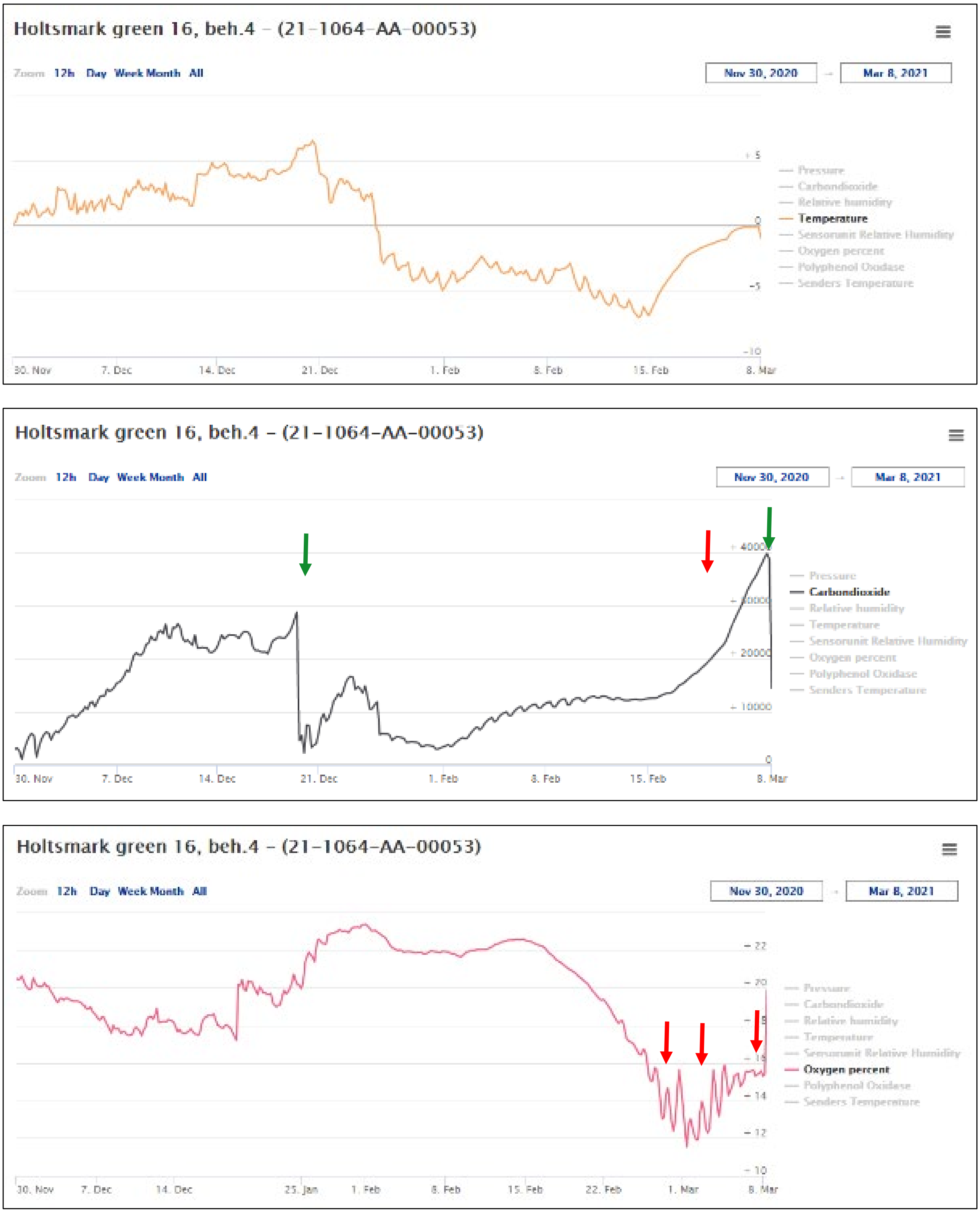


Figure 28a-c. Temperature, CO_2 and O_2 concentrations under the plastic sheets on green 16 ventilated through drainage pipes at Holtsmark. Green arrows indicate ventilations followed by a detectable change in CO_2 or O_2 concentration, while red arrows indicate apparently unsuccessful ventilations.

In treatment 5 (flat tubes), Green 11 was never ventilated despite CO2-concentrations reaching 40000 ppm on several occasions after the sensor had been replaced on 2 Feb. (Fig 29). Green 12 was ventilated on 18 Dec. because CO2 had reached 40000 ppm., and this ventilation showed a temporary increase also in O2-values (Figure 30). Late ventilations were not carried out on this green as the CO2 sensor went out of work while the O2 sensor showed values above 12% O2.

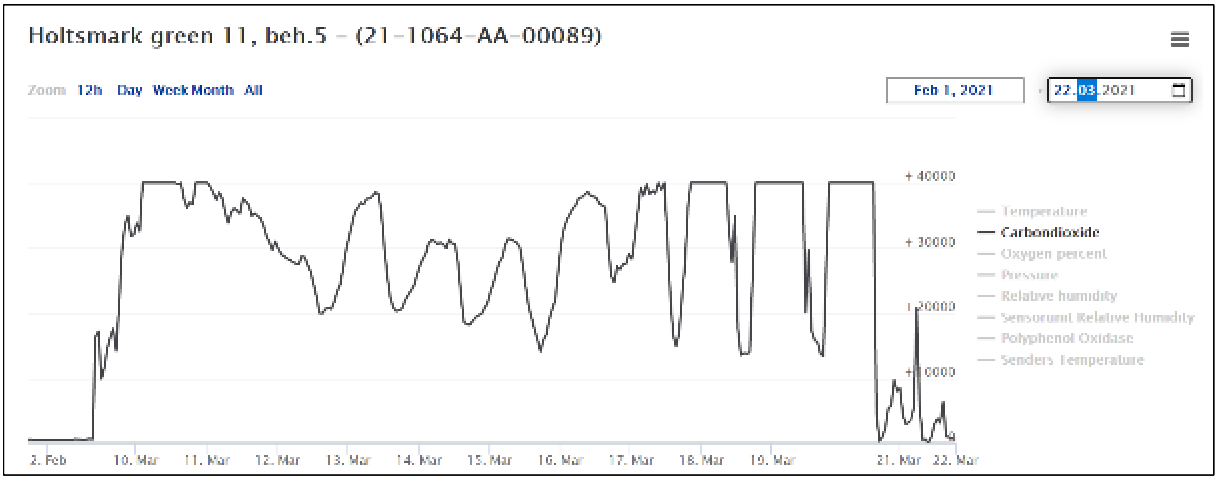


Figure 29. CO_2-consentration under the plastic sheets on green 11 (treatment 5) at Holtsmark GC. This green was not ventilated despite CO_2 concentrations reaching 40000 ppm in March.

Figure 30a,b. CO_2 and O_2 concentrations under the plastic sheets on green 12 ventilated through flat tubes at Holtsmark. This green was ventilated only on 18 Dec. because the CO_2 sensor failed after 21 Dec. whilst the O_2 sensor never showed concentrations below 12 %.

Green 14, also representing treatment 5, was ventilated on 11 Feb. in response CO2 reaching 40000 ppm., but at this point there was hardly any detectable response in either CO2 or O2 concentration (Figure 31). Ventilation was repeated also on 18 Feb., 23 Feb., 2 March and 9 March although none of the sensors were working on these dates.

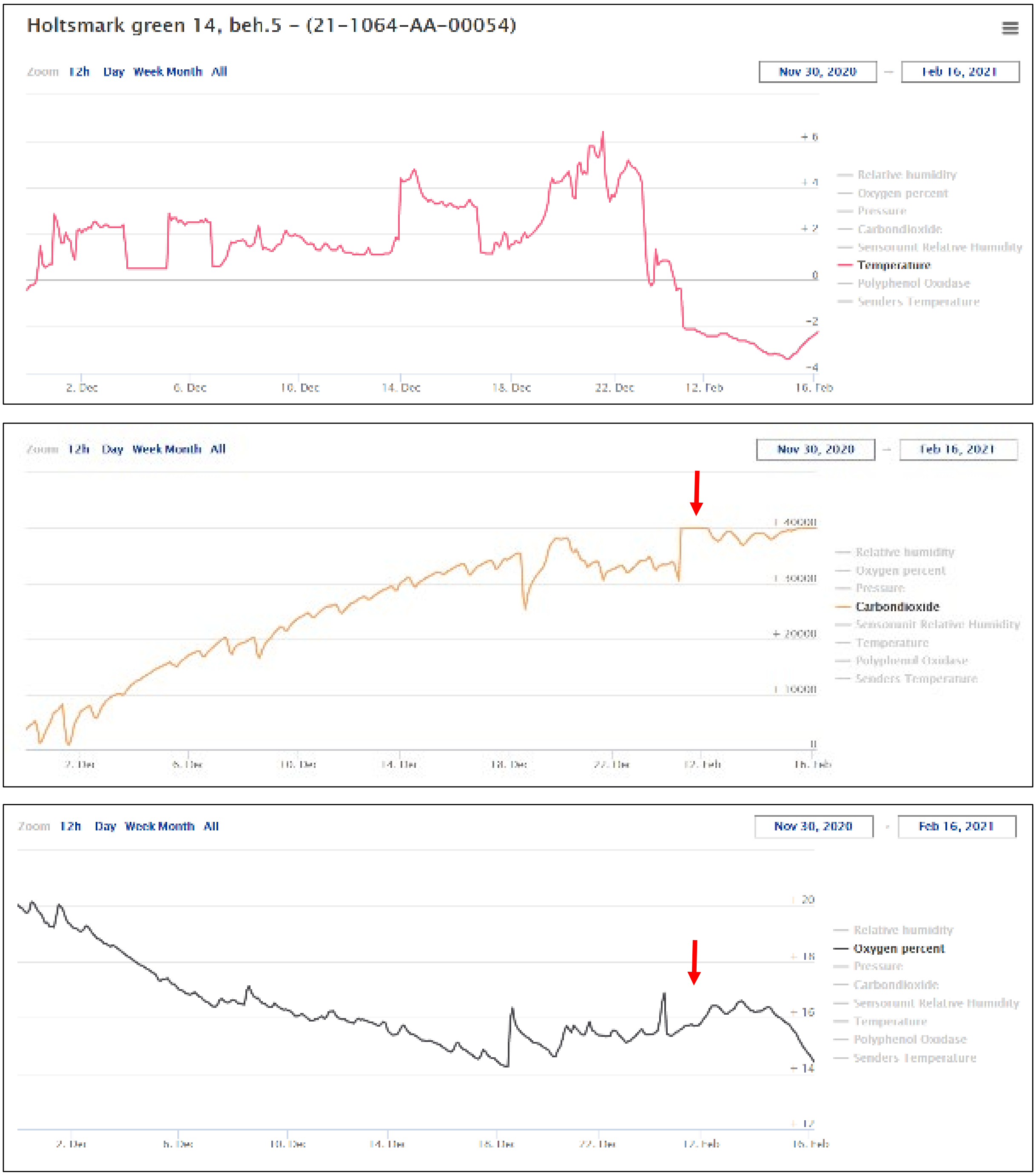


Figure 31 a-c. **CO_2 and O_2 concentrations under the plastic sheets on green 14 ventilated through flat tubes at Holtsmark GC. CO_2 and O_2 concentrations responded to ventilation on 18 Dec. but not on 11 Feb. The green was ventilated also on 18 Feb. 23 Feb., 2 March and 9 March despite sensors did not work after 16 Feb.**

6.3.3 Summary of sensor data

The summary of temperature and gas concentrations in treatments 1, 4 and 5 at Holtsmark (Table 12) must be interpreted in light of the fragmentary data coverage. Differences for temperature and CO2 concentration were not significant and for O2 it is hard to explain that the average concentration was lower in treatment 5 than in the unventilated control treatment.

Table 12. Mean and extremes for temperature, O_2 and CO_2 concentrations in treatments where sensors had been deployed at Holtsmark. Mean of two reps for treatment 1 and three reps for treatment 4 and 5.

	Temperature, °C			O_2, %		CO_2, ppm[1]
Treatment	Mean	Minimum	Maximum	Mean	Minimum	Mean
1. No ventilation	0.9	-3.4	7.7	18.3	12.6	18460
4. DPIPE_sensor	0.3	-4.6	6.0	17.8	11.4	18662
5. FTUBE_sensor	2.0	-2.2	10.0	16.5	10.1	22922
Sign.	ns	ns	ns	**	ns	ns

[1] The maximum CO_2- concentration that could be recorded by the -sensors was 40000 ppm. Since this maximum value was reached occa sionally on all greens, the figures may not represent the true mean value

6.4 Winter damage on greens

With an average of 13 % of the green acreage infected with microdochium patch, winter damage was more severe at Holtsmark than at the three other golf courses. The difference can be explained by the fact that Holtsmark missed the last fungicide application before winter (Table 3). More surprising was the observation was that there, on average for treatments, was more disease (16 %) in block III which had the highest dominance on creeping bentgrass than in block I which had the highest infestation of annual bluegrass (10 %). With 14, 16, 17, 12 and 11 % disease in treatments 1, 2 , 3, 4 and 5, respectively, the differences between ventilation treatments were not significant. Green 3 which was uncovered during most of the winter was excluded from the analysis of winter disease; this green had only 7 % microdochium patch, but spring growth was much slower than on the greens which had the covers in place throughout the winter. Photos 31-33 give some impressions form the greens at Holtsmark in spring.

Photo 31a,b. From Holtsmark shortly after cover removal on 22-24 March. Green 11 (to the left, 10 % annual bluegrass) was severely infected by microdochum patch, but there was very little disease on green 14 (to the right, 20 % annual bluegrass). Photos: Mads Thers.

Photo 32a,b. Close up from Greens 18 and 15 on 24-25 March. There were patches of micordochium patch all over these greens, but the disease appeared to be most active (new mycelium) close to the drainage pipes. Photos: Mads Thers.

Photo 33. First mowing using walk-behind mowers on Green 12, 14 April. Photo Mats Thers.

7 Discussion and revision of the experimental plan for 2021-22.

Although the experimental plan for 2021-22 did not include an uncovered control, the results with practically no ice or water damage on any of the four golf courses confirm our positive experiences with impermeable covers from the two previous winters (Aamlid et al. 2020). Many Norwegian greenkeepers are now convinced that coverage with plastic is a key to better winter survival, and about 20 courses will try coverage of one of more of their greens during the winter 2021-22.

The winter 2021-22 was short and not too challenging. With December constantly mild and January and first half of February (almost) constantly cold, the relatively few and moderate temperature fluctuations resulted in an ice layer, but not thicker than 5-6 cm and not for more than 6-7 weeks. The plastic sheets stayed on the greens for up to 120 days, of which the first 25-30 days had no burden of ice or snow on top of the covers. Together with the use of a permeable climate (spring) tarp that created more room under the plastic, it appears that the period under the plastic sheets was too short to result in anoxic conditions, even in the unventilated control treatment. This may well be different with a longer period of coverage, e.g. 150-160 days. It is therefore too early to reject the need for ventilation under the covers based on the results from 2020-21 only.

One argument that has been raised against ventilation under plastic covers is that microdochium patch will develop more profusely in response to more aerobic conditions. Such an argument may perhaps be plausible based on Photos 17 and 28, but the greenkeepers' assessment at cover removal showed very little difference between the ventilated and unventilated treatments. What made the difference in microdochium development was whether the greens had been sprayed three or four times, including a last application of fludioxonil (Medallion) shortly before coverage, as at Haga, Bærum and Asker, or whether they had received the early applications of a systemic fungicide only, as at Holtsmark. Photo 28 nonetheless suggests an effect of gas concentration on mycelium development, so a systematic study into the effect of decreasing O_2 / increasing CO_2 concentrations at various stages through the life cycle of *M.nivale* would probably be useful.

Table 13. Per cent of green areal showing symptoms of microdochium patch at cover removal in March on Haga, Bærum, Asker and Holtsmark GC and on average for the four courses

	Microdochum patch, % of green area				
	Haga	Bærum	Asker	Holtsmark	Mean
1. Unventilated control	3	2	5	14	6
2. Programmed ventilation through drainage pipes	3	9	6	16	8
3. Programmed ventilation through flat tubes	2	1	5	17	6
4. Sensor-based ventilation through drainage pipes	4	1	7	12	6
5. Sensor-based ventilation through flat tubes	3	3	3	10	5
	ns	ns	ns	ns	ns

The CO_2 threshold that was used as criterion for when to ventilate under the covers was a pragmatic decision based on the fact that 40000 ppm was the maximum concentration that could be measured by the CO_2 sensors. For the next winter, the CO_2 sensors ought to be replaced by new ones that are able to measure higher concentrations. Based on the normal atmospheric concentrations of 21 % O_2 and 0.04 % (400 ppm) CO_2, and the assumption that aerobic respiration produces one molecule of CO_2 per molecule of O_2 consumed, it is not surprising that the 4 % CO_2 threshold was usually reached before the O_2 concentration had decreased to 12 %. However, in line with Rochette et al. (2006) and Castonguay et al. (2009), none of these thresholds appeared to be critical for turfgrass winter survival.

Table 14 gives at summary of temperatures, CO2 and O2 concentrations under the covers on average for the four golf courses. Despite the incomplete and unsatisfactory data coverage, the mean temperatures under the covers were close to 0 °C as expected. Although statistically not significant, what is perhaps equally interesting is the lower maximum temperatures in the treatments with than without ventilation. Except for a few cases at Asker and Holtsmark where the maximums were recorded on the day before cover removal in March, these maximums were usually recorded around 20 December, i.e. shortly after the first ventilations in treatment 4 and 5. It therefore appears that ventilations have a role in avoiding temperature rise under the plastic in periods with not snow or ice above the covers.

Table 14. Mean and extremes for temperature, O_2 and CO_2 concentrations in treatments where sensors had been deployed at Holtsmark. Mean of two reps for treatment 1 and three reps for treatment 4 and 5.

Treatment	Temperature, °C (37 % data coverage)			O_2, % (50 % data coverage)		CO_2, ppm[1] Mean (53% data coverage)
	Mean	Minimum	Maximum	Mean	Minimum	
1. No ventilation	-0.1	-6.0	10.2	14.5	8.0	29810
4. DPIPE_sensor	-0.1	-5.9	5.6	17.6	12.6	20932
5. FTUBE_sensor	0.4	-4.6	6.8	15.1	9.0	23164
P-value	>0.20	>0.20	>0.20	0.14	0.14	<0.01

[1] The maximum CO2- concentration that could be recorded by the -sensors was 40000 ppm. Since this maximum value was reached on most greens, the figures do not represent the true mean value

As for gas concentrations, there were significantly higher mean CO2 values and trends to lower mean and minimum O2 values in the unventilated control treatment than in the treatment 4 with ventilation through drainage pipes. The inflateable flat-tubes were less efficient and this is also in agreement with the greenkeepers' frustration that the tubes did not blow up if there were heavy layers of snow or ice above the covers. For the remainder of this project, we have therefore decided to omit the flat tubes and rather base our investigation into turfgrass responses to ventilation on drainage pipes placed under the covers. We will also study the function of the spring tarp in creating a more favorable environment under the covers.

The treatments to be compared during the winter 2021-22 are therefore as follows:

1. Impermeable plastic sheets with spring tarp (Norgro/Evergreen) under the plastic. No ventilation. Sensors placed under the covers (= treatment 1 in 2020-21)
2. Impermeable plastic sheets with spring tarp (Norgro/Evergreen) under the plastic. Programmed ventilation through drainage pipes every 3 weeks. No sensors. (= treatment 2 in 2020-21)
3. Impermeable plastic sheets with spring tarp (Norgro/Evergreen) under the plastic. Sensor-based ventilation through drainage pipes whenever CO2 > 40000 ppm or O2 < 12 %. (= treatment 4 in 2020-21)
4. Impermeable plastic sheets with no spring tarp under the plastic. No ventilation.
5. Impermeable plastic sheets with no spring tarp under the plastic. Sensor-based ventilation through drainage pipes whenever CO2 > 40000 ppm or O2 < 12 %.

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