Report on the NEEM 2012 balloon trench experiment.

Copenhagen, 10th September 2012. Jørgen Peder Steffensen, Centre for Ice and Climate, Niels Bohr Institute, University of Copenhagen. (Updated 5th June 2014).

Introduction: At NEEM 2012 an experiment was conducted to investigate the possibility to construct future drilling, science, inclined trenches and overwintering garages without the use of wood as roofing.

The rationale behind this investigation is to limit the amount of wood (or corrugated steel) to be purchased, transported and left behind at the site after the projects are over. In short: To save money, to reduce the emission by transport and to reduce the environmental impact of the projects by reducing materiel left behind.

The overall idea is to use only snow as construction material. Taking advantage of the observation that snow processed by a snow blower sinters to a very hard and compact material in few days, we proceeded to make a test of the concept at NEEM to full scale. We plan to revisit the trench in the coming years to measure deformation and strength as the trench ages. It is necessary to know the stability of the trench over time before we will plan to use this construction in future ice coring projects.

In Figure 1 a sketch of the test cross section is shown.

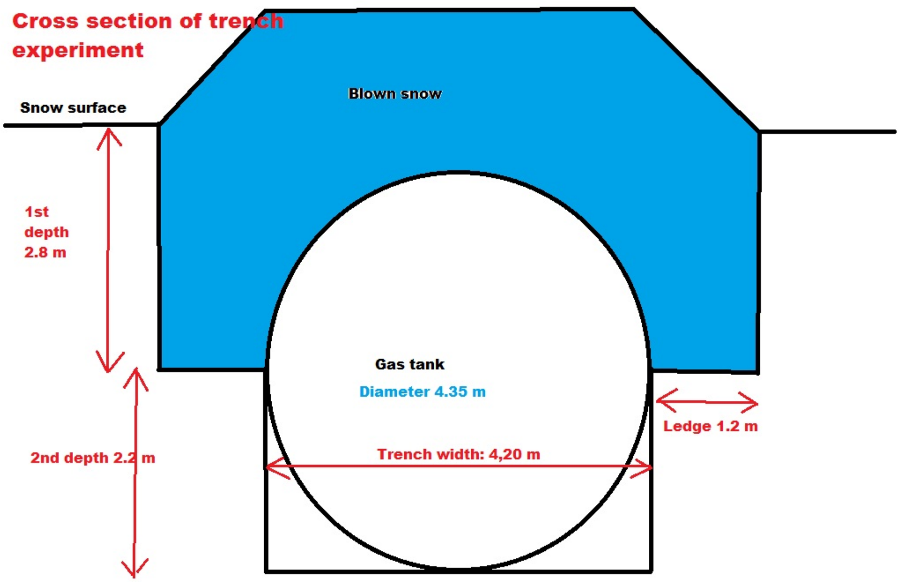


Figure 1: Cross section of the test trench.

One of the key parameters is the roof thickness versus width of the trench. Going through literature (CRREL reports) and talking to experienced Icelandic glacier drivers, there is a rule of thumb for the capacity of natural snow bridges across crevasses to carry vehicles: The thickness of the snow bridge must be larger or equal to the width of the crevasse.

As seen in the above sketch, this rule is obeyed almost everywhere.

Also, based on observations in the past, we knew that sintered snow from a snow blower does not attach itself well to a vertical wall of undisturbed snow, so in order to make the roof strong and to distribute the load of the roof on a large surface of stronger and deeper undisturbed snow, we included 1.2 m wide ledges along each wall. As an alternative, a wedge shaped (wider at the top) trench could be considered.

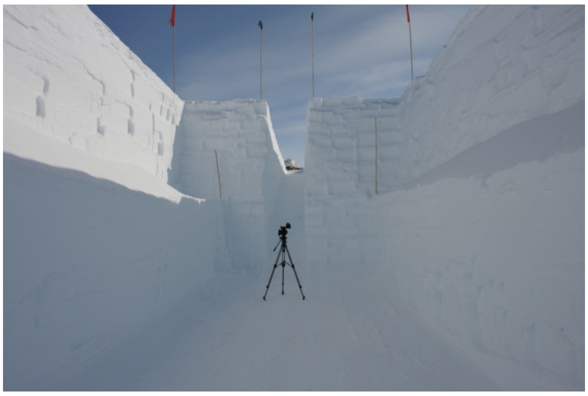
The tank / balloon:

We purchased a cylindrical PVC gas tank from the company Presenco (www.presenco.dk). It was 4.85 m diameter and 14.85 m long including 2.5 m long torpedo shaped tapering in each end. It was made from white PVC guaranteed to stay soft down to -30 C. Supplied with the tank (balloon) was 10 m 1 ¼ inch air hose with counter valve and a hand held air blower. Fittings and plugs were plastic camlocks. The tank had a 1 ¼ inch camlock fitting and a 10 mm diameter pressure gauge fitting.

The price of the complete kit was DKK 75,000. The weight of the complete kit was 180 kg.

Observation: In future purchases we should aim at having balloons with an off-white color.

Excavation of trench:



As our balloon had slightly different dimensions than shown in Figure 1, we proceeded to adjust our measurements.

The top part of the trench was a rectangle, 7.0 m wide and 15.2 m long. At one end we marked a 1.2 m wide entrance of the inclined trench in the center. The top part of the trench was excavated to 3.1 m depth using two Yanmar snowblowers.

The bottom part of the trench was 4.6 m wide, leaving a ledge of 1.2 m on each side and 2.2 m deep. Total depth of the trench was 5.4 m.

Excavation began on June 2 and a depth of 2 m was reached. On June 3, the 3.1 m excavation was completed. June 4 the 2.2 m second step was completed.

Observations: As we approached the target depth, it became very difficult to throw the snow over the edge to the surface and a substantial amount of snow fell back into the trench. This was due to the limited reach of the snow blowers and due to the automatic build-up of extra snow along the sides from the blowing itself.

Filling the balloon:

The balloon was inserted on June 4 (this required only two people) and later inflated. Inflation of the 280 m3 air volume took 3 hours.

We mounted a clear plastic water hose to the pressure gauge fitting and fixed the other end of the water hose to a plywood sheet in a U-shape. We added an amount of blue glycol solution to the U and drew a scale onto the plywood with a speed marker. As the balloon was guaranteed to hold pressures at 1.1 bar, we drew max pressure lines at a glycol height difference of 80 cm (taking the slightly higher density of glycol solution into consideration).

On June 5 we inflated the tank to 75 cm height difference (close to 1.1 bar). At this pressure the balloon was rock hard. We observed that the balloon had "jumped" out of the bottom part of the trench. It was resting on the ledges with the bottom floating some 30 cm over the floor. It was easy to push the balloon along in the trench so that the end pointed into the inclined trench entrance.

Observations: The balloon was supposed to stay put in the bottom trench; but because the maximum diameter of the balloon was 2.425 m over the floor, a depth of 2.2 m was not enough. In the future, the second stage of the trench has to be 30 cm deeper, i.e. 2.5 m deep to make sure the balloon stays put.

We decreased the pressure to 10 cm liquid level (ca. 1.01 bar) and the balloon dropped to the floor.

During the backfilling of the trench and the following sintering process, we maintained a pressure of 25 cm fluid level (1.025 bar pressure). During the three days of sintering, we could maintain the pressure by running the pump for 2 minutes each 6 hours.

Backfilling:

Burial of the balloon and backfilling the trench took two days and was done June 5and 6. Temperatures these two days were -3 to -6 C. At the end, the roof of the trench was 1 m above the free snow surface.

As the amount of blown snow along the edge of the trench was 1 m thick, we did not blow back the snow closest to the edge of the trench. We left a wall 1 m wide along all sides, both for safety and to increase the volume of the roof.

During the back filling, we ran out of snow to blow back and we had to request snow to be pushed to the site by our Pistenbully. Roughly 1/3 of the snow needed had to be pushed to the site.

Observations: When blowing back, the snow blowers should aim at the opposite side of the trench, blowing snow in a X-pattern.

Several leaks along the sides of the balloon were observed where the blown snow continued to trickle down into the trench. These leaks could not be blocked by just blowing more snow, so a lot of snow fell down below the balloon and created fan shaped stacks of snow in the cave**.**

Solution: Before backfilling, the sides along the balloon should be sealed manually with a shovel and snow and blocks of snow. Also, increasing pressure in the balloon is a parameter to work with.

The balloon should be turned so that the hose fittings are on top side rather than on the bottom side of the balloon. This reduces the digging free of hoses.

A lot of snow fell down into the inclined trench because we put in vertical plywood sheets too late. In the future we should use plywood sheets with a PVC cover, allowing easy removal of the plywood after sintering.

Sintering:

June 6, 7 and 8 we monitored the hardening of the blown snow, while we maintained pressure. On June 8 in the afternoon, the snow on the roof was rock hard. Jumping on the roof did not leave foot prints and it was impossible to push in a bamboo pole anywhere on the roof. We decided to deflate the balloon. Sepp Kipfstuhl from AWI has taken samples from the roof and along the walls to measure density and physical properties. These samples have not been analysed yet, but indications are that the densities are aroud 550-600 kg/m3.

Deflating:

In the inclined trench we began to carefully dig snow away with shovels. As the snow had already hardened somewhat, it became a delicate procedure, because the pressure hose and air hose had to be uncovered without punching a hole in them. As we neared the trench, we could feel the snow getting harder, and the end of the balloon was exposed as the snow around it cracked and fell away. It was possible to put an arm into the space between the balloon and the cast snow wall and slide it all the way around. The balloon was not stuck to the snow wall anywhere.

In the picture to the left the partly folded and deflated balloon is on the floor.

Once the end of the balloon was exposed, we began to deflate the balloon by reversing the pump. Deflating took 3 hours and happened in the evening of June 8.

We then enlarged the hole to form an entrance, and it felt like crushing the shell of an egg breaking the inner layers of snow. The exposed trench had the desired shape: A flat floor, vertical walls 2.2 m high and an arched roof. However we were surprised to see the amount of snow that had been leaking down along the sides during back filling. The snow fans reach out from the walls and give the trench an almost cylindrical appearance. These leaks have to be avoided in the future.

In the pictures above several of these snow leak features are visible as well as the entrance and the far end of the trench where the balloon has left a clear imprint in the sintered snow.

Recording the trench for the future:

The inclined trench was covered with a roof and terminated with a vertical piece of plywood so that access to the trench is possible in the future. Inside the trench, two sets of three measurement points were setup. One set in the Northern end of the cylinder and one in the Southern end.

Initial measurements. June 10, 2012.

South end: Width, 4.48 m, height from floor point to apex of ceiling 4.79 m.

North end: Width, 4.51 m, height from floor point to apex of ceiling 4.60 m.

End of season measurements. August 7, 2012.

South end: Width, 4.47 m, height from floor point to apex of ceiling 4.41 m.

North end: Width, 4.50 m, height from floor point to apex of ceiling 4.25 m.

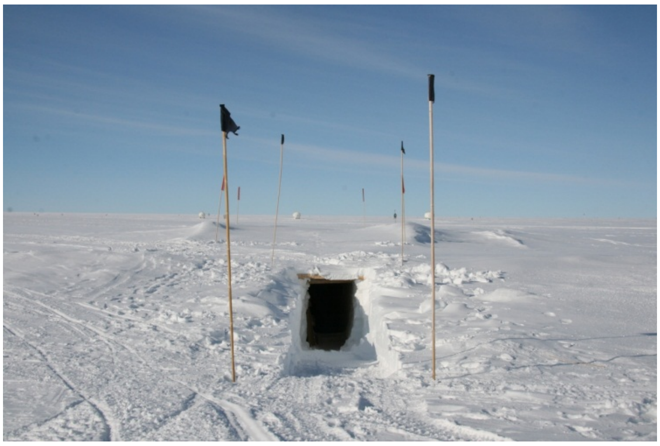
So in 60 days the apex of the ceiling has dropped 38 cm in the South end and 35 cm in the north end.

The width has remained constant.

At the northern profile it was noted that the curvature of the ceiling from apex to the left (west) was slightly more "flat". Also, clear blue areas (30 cm x 50 cm) of refrozen melt water had formed on the underside of the ceiling many places. No icicles were observed.

The change in shape of the curved ceiling and the blue ice patches are most likely connected and relate to the extraordinary melting events at NEEM: Four days in July with above zero temperatures and two days in August with similar conditions.

It is planned to visit the trench in the coming years and to repeat deformation measurements. Most of the remaining frozen food at NEEM is now stored in the trench; but there is full access to the measurement points.



The last image shows the final marking of the trench: Four red flags, one in each corner marks the trench. Four black flags mark the entrance. Two flags are placed at the start of the wooden roof (This is where the vertical plywood sheet is placed). And two flags mark the beginning of the ramp. These flags are for snow blower navigation purposes.

The future:

If this experiment is successful, we plan to construct a new ice coring camp using balloons. The same balloon can be used for both drill and science trenches. Vertical shafts for staircase and elevator can be setup using smaller balloons. Connecting tunnels and inclined trenches can be cast using the balloon technique as well. Short versions of the smaller tunnel balloons can be used to seal openings to trenches during blizzards. They can be inflated and deflated in 5 minutes.

Balloon trench re-visited 27th May 1014.

The U.S. GrIT traverse passed NEEM on their way to Thule AB. They gained access to the trench through the entrance at the ramp.

Left: The trench in May 2014. Measurement points to the side and in the floor can be seen. Right: The trench late July 2012.

The trench was found in good condition although there is a slight bulge (slumping) in the arch towards the northern end. The slumping was already visible in 2012 as mentioned above. Otherwise the shape has been constant.

The crew performed measurements and the following distances were found:

Southern end: Width 4.52 m, height 3.79 m. Northern end: Width 4.55 m, height 3.66 m

Difference in dimensions August 2012 to May 2014:

Southern end:	Width: 4.47 m – 4.52 m = -5 cm (the trench is wider now)
	Height: 4.41 m – 3.79 m = 62 cm (the trench is lower now)
Northern end:	Width: 4.50 m – 4.55 m = -5 cm (the trench is wider now)
	Height: 4.25 m – 3.66 m = 59 cm (the trench is lower now)

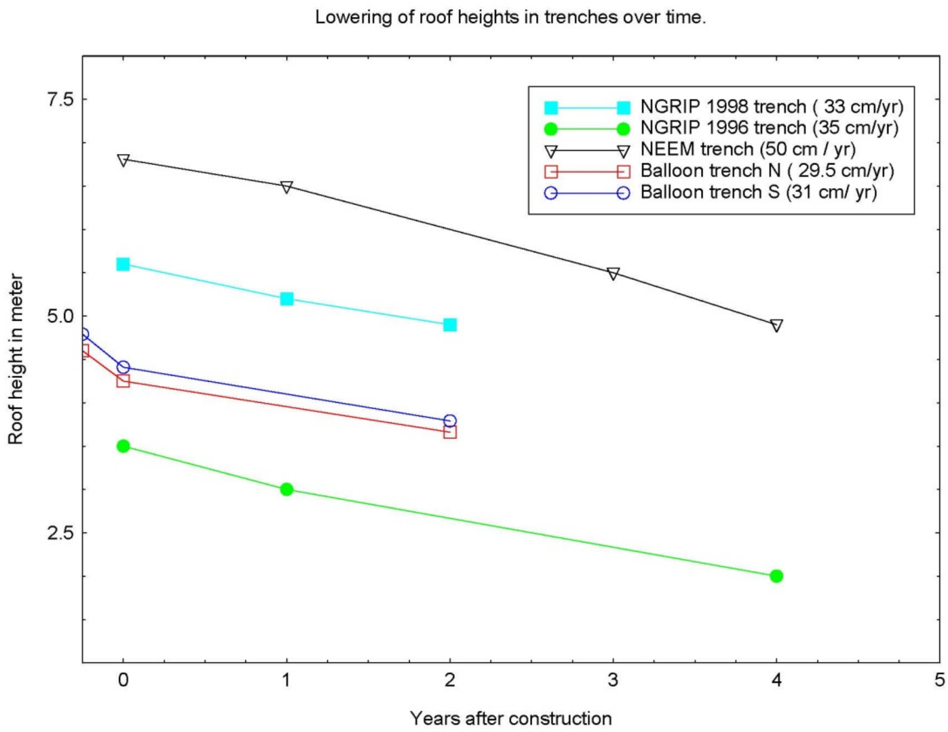
In order to compare lowering of roof height of the balloon trench to conventional trenches with a wooden roof, I studied the compression of three drill trenches, NGRIP1 (1996 – 2003), NGRIP2 (1998-2003) and NEEM (2008-2012).

Left: NEEM drill trench June 2009. Right: NEEM drill trench June 2011. Notice the location of the top sheave in the slot in the roof. Between 2009 and 2011 the tower was shortened by 1.5 m (i.e. the section just above the foot of the tower was removed).

Table of roof lowering:

Time (years).	Balloon S	Balloon N	NEEM	NGRIP1	NGRIP2
-0.25	4.79	4.6	//m	//m	//m
0	4.41	4.25	6.81	3.5	5.6
1	//m	//m	6.5	3	5.2
2	3.79	3.66	//m	//m	4.9
3	//m	//m	5.5	//m	//m
4	//m	//m	4.9	2	//m

The negative times indicate initial slumping in the first few weeks after construction. I have only data from this for the balloon trench.



This plot shows that the rate of lowering of the ceiling height is comparable to and even slightly less than that of a conventional wooden roof system. The key number appears to be 30 – 35 cm/year. The NEEM trench roof has been lowering much faster. This is partly due to the proximity of the main dome causing more than x2 snow accumulation over the trench and partly due to the proximity and width of the connecting tunnel to the science trench and the weakening of the wall due to the recessed drillers cabin.

NEEM drill trench in 2012. Note the broken beams.

NEEM drill trench with casing pipe extended, just before the trench was back filled in August 2012. All wood in drill trench and science trench had to be abandoned on site.

Conclusions:

The NEEM balloon trench experiment has been a success. By conducting this full scale experiment, it has been demonstrated that the balloon technique can be used in the future. The technique can be used for drill and science trenches, overwintering garages for vehicles, food storage tunnels, elevator and staircase shafts etc. Also, for tunnels for electrical power and liquid central heating, the technique could be used with a hose shaped balloon of 1 m diameter. The Yanmar snowblowers,we have at NEEM, have a cutting width of 1.2 m so one pass with the snowblower would make space for a 1 m diameter hose. Cables and hoses could easily be retrieved from such a tunnel.

We had a problem with the throwing height of our Yanmar snowblowers that prevented us from going deeper than 5.5 m. We have planned to buy a 4.6 m wide snowblower mount for a new Pistenbully 300 Polar. With a power of 140 kW and two funnels with extensions it should be possible to excavate trenches in a short time. Furthermore, we will not have restrictions on the excavation of both ends. We can excavate by using both ends as ramps as the balloons themselves will form near vertical ends when snow is blown back in. Finally, in the future we will not be restricted to 5.5 m width of the trenches, as this restriction comes from the maximum length of the beams (7 m) due to transport by ship and air.

In the drilling trench, a hoist of some type is often needed, and balloon trenches do not offer hard points in the ceiling. A way to solve this problem is to construct a scaffold canopy over the drill. Here the hoist could be attached. At the end of a season, this canopy should be lowered, and in the following season the canopy can be used as a platform for people using chainsaws to trim the roof back to the original height (35 cm to be removed), before the canopy is raised again.

With balloon trenches there is always a possibility of trimming the roof from the inside. This is impossible with wooden roofs, steel arches or in buried 20 foot containers.