Northern Periphery and Arctic Programme

Northern Cereals – New Markets for a Changing Environment

Drying and Storage of Harvested Grain

Case Studies

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Title: Drying and Storage of Harvested Grain – Case Studies

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1. Introduction

The drying of harvested grain is critical for good grain storage and high grain quality. Different drying methods and equipment can be used for drying grain. The selection of equipment and energy sources will have great impact on the production cost of cereals and the profit of the farms.

Case studies on barley drying have been carried out at five locations in Iceland, one location in Norway and one in Orkney. Studies in Iceland were carried out at the following locations: Thorvasldseyri, Belgsholt, Grund, Jaðar and Hjalteyri. The drying facilities utilise different energy sources. For example, at Thorvaldseyri farm diesel is used for heating the air for the dryer while at Belgsholt geothermal water is the energy source.

Data from several drying facilities were collected 2015. Measurements were carried out during the harvesting seasons 2015 and 2016. The summer of 2015 was not very favourable for cereal growing in Iceland and the autumn was very wet causing farmers to harvest their cereals late and in some cases it was not ready for drying. This limited the available options for selecting farms where the drying procedure could be observed. Therefore, measurements were completed during the 2016 harvesting season. Table 1 lists some of the farms in Iceland equipped with grain drying facilities.

Table 1. Grain drying facilities at farms and drying plants in Iceland 2016. The list is not complete.

Farm or location	Region	Farmer or contact person	Energy source and comments
Birtingaholt 4	South	Sigurður Ágústsson	Diesel and geothermal water
Gunnarsholt	South	Björgvin Þór Harðarson	Diesel
Móheiðarhvoll	South	Birkir Arnar Tómasson	Diesel and straw. Straw provides 30-60% of energy.
Sandhólar	South	Örn Karlsson	Diesel
Þorvaldseyri	South	Ólafur Eggertsson	Diesel. Reuse of hot air.
Grund	North	Halldór Örn Árnason	Geothermal water and diesel
Hjalteyri plant	North	Stefán Magnússon	Geothermal water
Vallanes	East	Eymundur Magnússon	Diesel
Belgsholt	West	Haraldur Magnússon	Geothermal water
Jaðar	West	Eiríkur Blöndal	Geothermal water

In North-Norway there is one drying plant used to dry cereals and in Orkney at least three plants. No grain driers were available in the Faroe Islands. There are a few small dryers owned by farmers in

Newfoundland. Drying facilities in Newfoundland are very limited since grain has not been harvested up until the last few years. There are two farmers that have small dryers on their up-right silos. One of those dryers has never been used since the benefits of high moisture grain for animal feed are preferred and the other farmer hasn't had grain in the last two years. Grain drying will become more important as cereal production increases in Newfoundland.

2. Methods

Case studies in Iceland

Case studies for grain drying in Iceland were based on visits to selected farms and descriptions of the drying process and equipment prepared by Matis staff with help from the farmers. An important part of the studies is temperature recording by use of sensors at key locations. The temperature data indicate if adjustments were needed for maximum product quality. Also the measurements serve as a basis for advising farmers in Iceland and partner countries.

Case studies in Norway, Orkney and Newfoundland

Case studies in Norway and Orkney were based on collection of information from drying facilities. Temperature recording was not included but information on temperature was requested from operators. The information requested for each case were as follows:

Cereal drying plants

- Description of the dryer: Type, model, heating component / burner, methods (thin-layer drying / deep-bed drying / batch drying / continuous-flow drying), etc.
- Description of the drying process.
- Fuel / type of energy used and unit price. E.g. diesel, liquid propane gas, natural gas, geothermal water.
- How many tons cereals are dried each year?
- How many days is the drying plant in operation per year?
- How many tons are dried per batch and how many hours does the drying cycle take? What is the energy use (if known).
- Maximum actual grain temperature during drying and the temperature of the air in the dryer.

Cereal drying conditions in 2015

Conditions in 2015 were difficult for many cereal farmers and there might have been problems with drying.

- The average or range of moisture content of cereals at harvest.
- The moisture content of dried cereals.

- Description of any problems in 2015
- Typical outdoor temperature and % relative humidity (RH) during the drying period.

Storage of dried cereals

- Description of facilities
- Storage time
- Control of storage temperature and %RH.
- Use of grain: Feed, food, malt, seed?
- Are mycotoxins inspected regularly?

3. Case Studies

Case study IS1 - 2015 – Thorvaldseyri farm

Þorvaldseyri is located on the south coast of Iceland, right under the volcano Eyjafjalljökull. The location is shown in Figure 1 below. The annual precipitation is high compared to other parts of the country. The grain drying facilities at Þorvaldseyri have been built recently (Figure 2) and replaced older facilities. The facilities include two batch dryers, a diesel burner for heating air, a fan for delivering hot air to the dryers, and four storage silos. Incoming wet grain is transferred mechanically to the dryers and dried grain is transferred to storage silos. During drying the contents of the dryers is mixed mechanically. The capacity of each dryer is about 20 tons and the drying period can be about 24 hours. In the dryers, loose husk and unwanted plant materials are separated and collected in a container. The end of drying is determined by measurement of grain moisture. After drying, the fan is kept running to cool the dried grain. In case of failure of the burner, the fan can be used to extend the storage life of wet grain. No exhaust air from the burner comes in contact with the grain. Exhaust air from the dryers could be used again to reduce cost but a heat exchanger would be preferred for that purpose.

Figure 1. Location of Þorvaldseyri farm.

The measurements were carried out in September 2015 and the temperature loggers were put into place 25th of September. Temperature loggers were placed at a few critical locations in the system as listed below:

- Two loggers for ambient temperature
  - One in front of the blower
  - One in the doorway of the heater room
- Window for air intake for preheated air
- In the pipe after heating

- Exhaust pipe

Figure 2. The new drying facility at Þorvaldseyri

The logger in the exhaust pipe was damaged so no data was obtained from this logger. This logger was also the only logger that was supposed to measure relative humidity as well as temperature. Figure 4 shows a graph of the measurements. It can be seen on the graph that at 2:30 am on the 26th the doors on the heating room were opened and the temperature in front of the blower falls instantly and the ambient temperature in the room falls below the temperature of the preheated air, until then it had been higher due to residual heat from the heater and the blower. This however had little or no impact on the temperature of the air in the inlet pipe and the change in oil consumption was not measured so it is hard to conclude if the preheated air has an impact on the energy consumption. The current setup for using residual heat might also cause extra load on the blower as there is more resistance in the airway.

Figure 3. Blower and burner for the dryer. The opening in the upper left corner is for air intake where the residual heat from the dryer is used to preheat the air before drying.

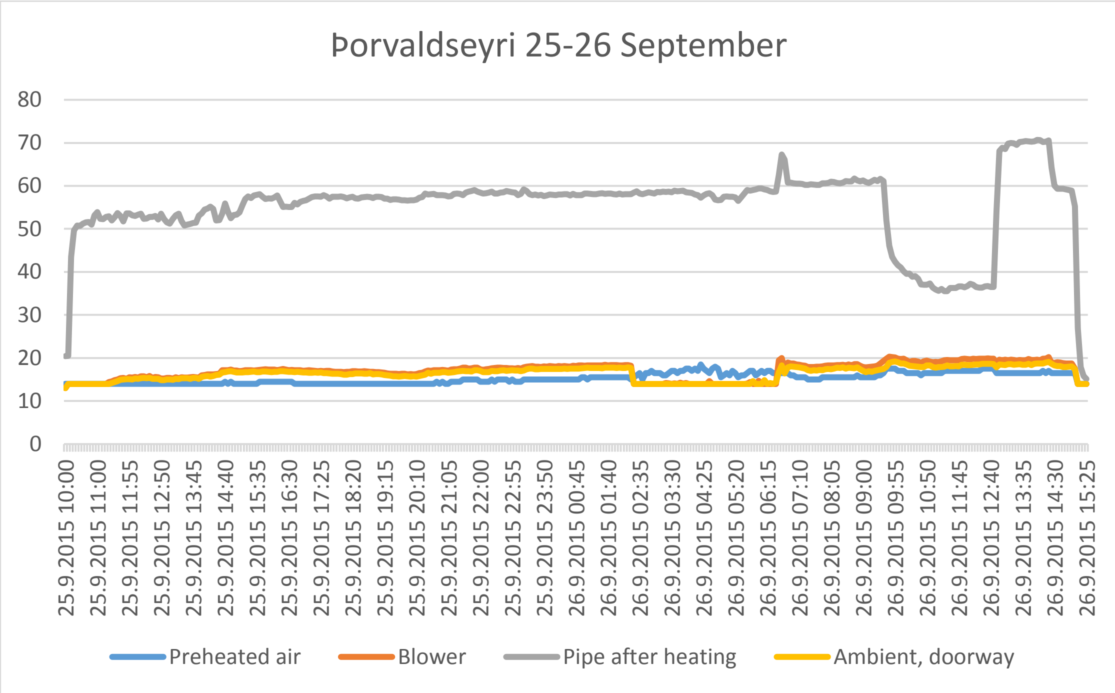


Figure 4. Temperature measurements (°C) during drying at Þorvaldseyri 2015.

Case study IS1 - 2016 – Thorvaldseyri farm

Measurements were repeated at the Thorvaldseyri farm in September 2016. Temperature loggers were used to record temperature as before. Additionally humidity loggers were used to record humidity inside the dryers during drying. Decreasing humidity during the drying process can be seen in Tables 2 and 3. Table 4 reports increasing temperature within dryer 1 during the drying process.

Table 2. Humidity (air moisture) under mixing of grain in drier 1.

Time Date and hour	Humidity (%)
4/9 17:00	18,1
4/9 21:00	16,2
4/9 24:00	14,3
5/9 8:30	14,1

Table 3. Humidity under mixing of grain in drier 2.

Time Date and hour	Humidity (%)
4/9 17:00	24,1
4/9 21:00	20,4
4/9 24:00	18,2
5/9 02:00	14,4
5/9 04:00	13,6
5/9 08:00	13,0

Table 4. Temperature in dryer 1.

Time Date and hour	Temperature (°C)
4/9 – 09:45	26
4/9 – 17:00	28
4/9 – 21:00	34
4/9 – 24:00	43

Graphs from temperature loggers are shown in Figures 5 to 11. Air temperature inside the dryers reached about 60-70 °C during a limited period. It can be seen that the air temperature differs within the dryers. Also the two dryers differed regarding temperature. It can be seen that the temperature of the air in the dryers and the exhaust air increased after about 2000 minutes. This indicates that grain drying should be complete.

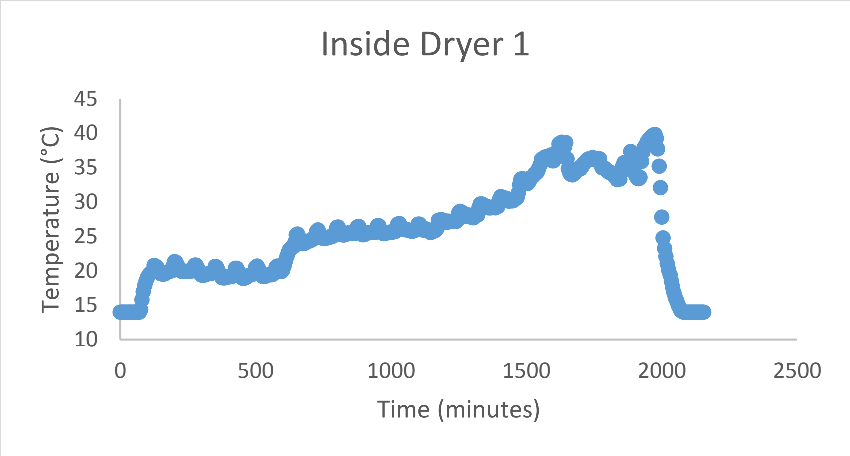


Figure 5. Air temperature inside dryer 1 during drying.

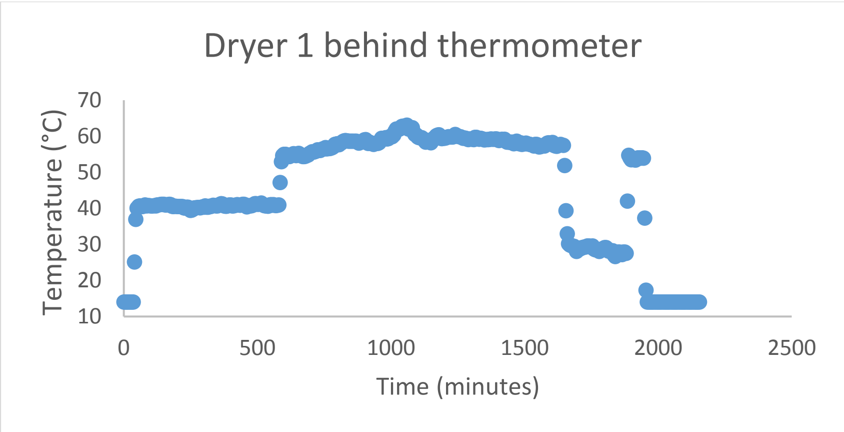


Figure 6. Air temperature inside dryer 1 behind thermometer during drying.

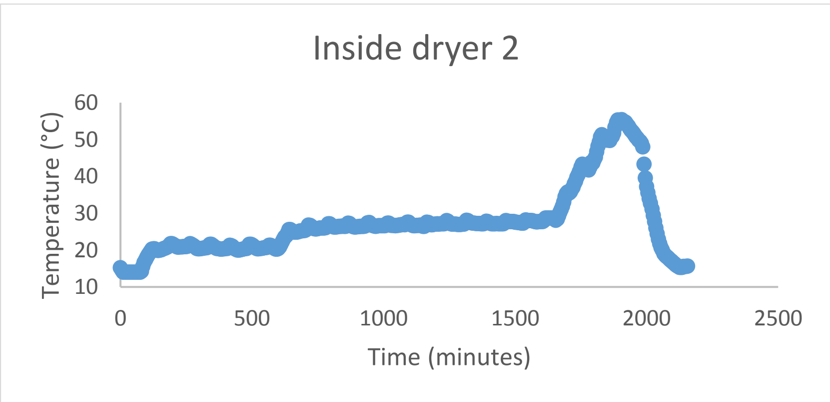


Figure 7. Air temperature inside dryer 2 during drying.

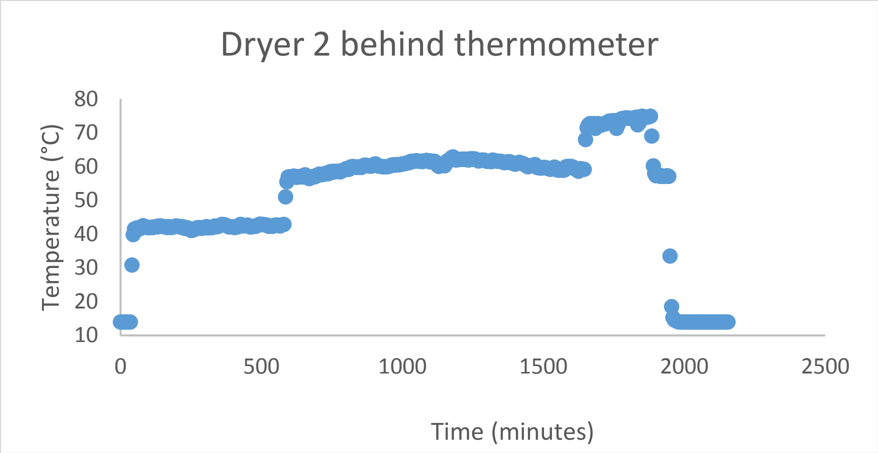


Figure 8. Air temperature inside dryer 2 behind thermometer during drying.

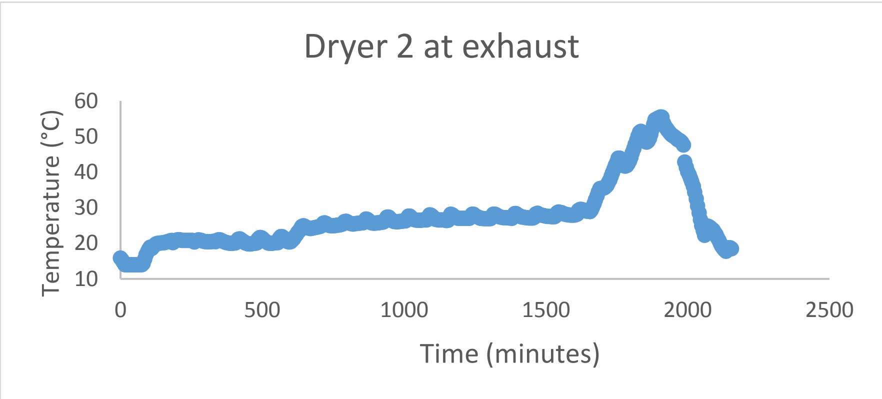


Figure 9. Temperature of exhaust air from dryer 2.

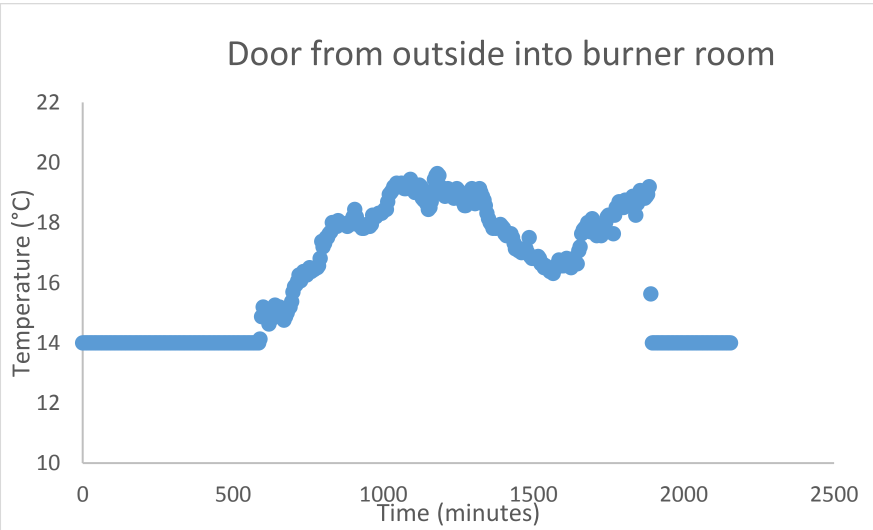


Figure 10. Outdoor air temperature.

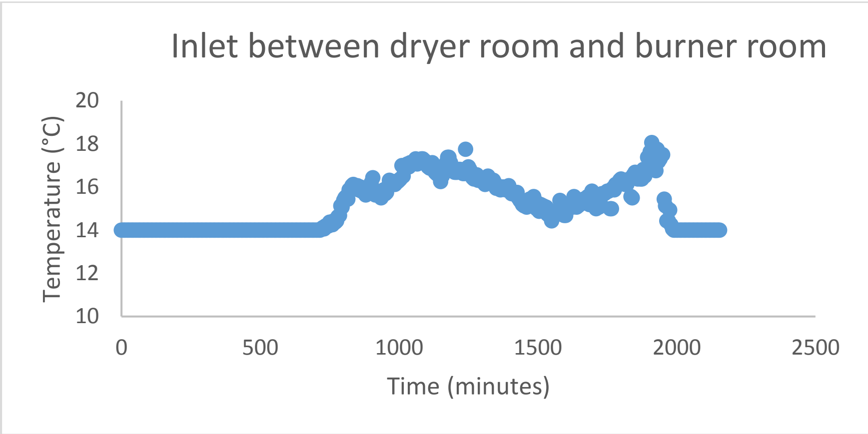


Figure 11. Air temperature at the inlet between the burner room and dryer room.

Case Study IS2 – Belgsholt farm

Belgsholt is located on the west cost of Iceland not far from municipality of Akranes. Its location, close to the pipeline supplying hot water from Deildartunguhver to Akranes, has opened the possibility of using hot water for cereal drying in an area where no hot springs are found. The farmer Haraldur Magnússon built a special pipeline from the main pipe to his farm, for which he receives a significant discount form the distributor. However, the water he receives is not as hot as in the main pipe due to poor insulation of the pipe. The system in Belgsholt consists of two serially connected water-to-air heat exchangers. The former is at the entrance of a room containing the heating system and air is sucked through it into the room; the second one is on an inlet to a pipe leading to the silo of the dryer. Residual water from the second heat exchanger is used for the first one. The air in between absorbs the residual heat in the heating room. The airway through and around the heat exchangers might cause some resistance and therefore additional load on the air blower but this was not measured on this occasion.

Figure 12. Location of Belgsholt farm.

There were two measurements carried out at Belgsholt, the first included only temperature loggers placed at the following locations in the system:.

- Ambient temperature
- Air inlet for heating room, before first heat exchanger
- Heating room between heat exchangers
- Inlet to dryer after second heat exchanger
- Exhaust air from dryer

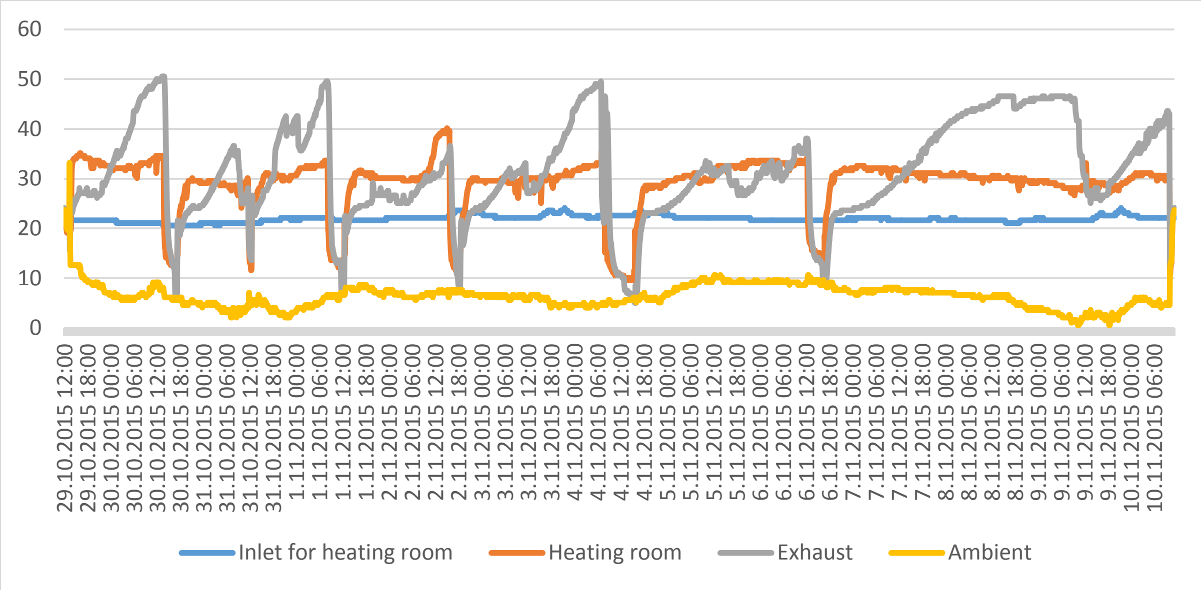


Figure 13. Results from temperature (°C) measurements at Belgsholt 2015.

Figure 13 shows the results from the first measurements at Belgsholt. The logger for the temperature on the air inlet for the dryer was broken when collected and its data were lost. The graph shows cycles in the process when the dryer was unloaded and loaded again. It is interesting to see the grey line rise through each cycle as expected as air cools down while picking up moisture and throughout the process the amount absorbed is reduced. Since there are no results for temperature of warm air entering the dryer it is hard to estimate if the drying went on for too long but it seems likely that this happened in the cycle starting 6th of November as the temperature of the exhaust air is constant for a long time.

Figure 14 shows that air during the drying was cold and the relative humidity was high, above 80 % for most of the time. Then after being preheated the air is much hotter and the humidity is lower as shown in Figure 15. As before, the cycles in the graph can be explained by loading and unloading of the dryer. Then the heating is turned off and the heating room shows temperature and humidity values that are closer to the ambient air than before. Figure 16 shows well what is going on in the drying cycle: at the start of each cycle, the exhaust air is relatively cold and the humidity high as the air absorbs moisture from the cereals, then, as the drying proceeds, the air becomes warmer and dryer.

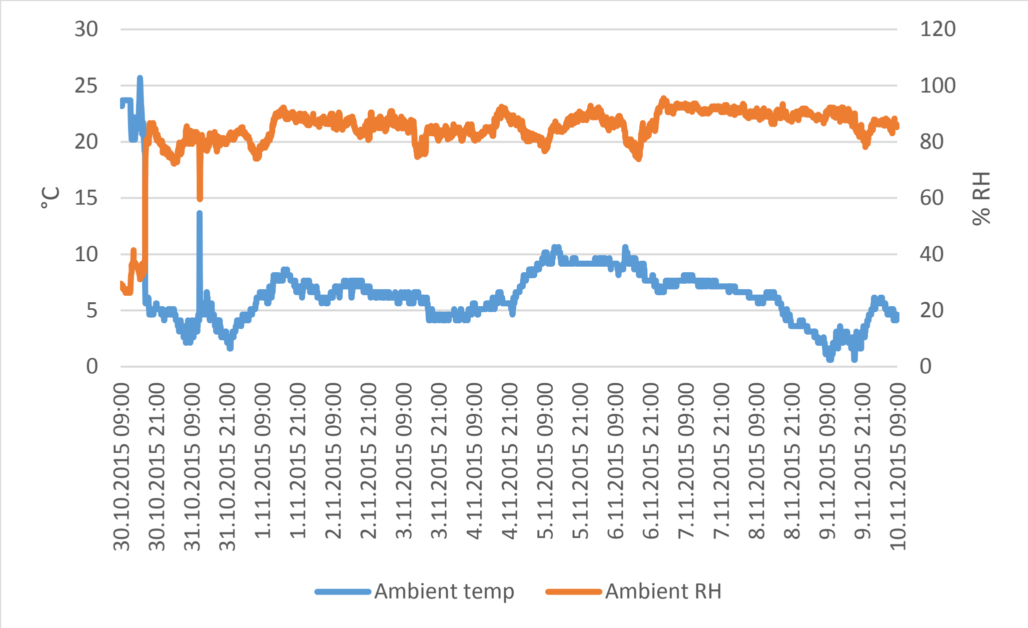


Figure 14. Temperature and relative humidity of the ambient air.

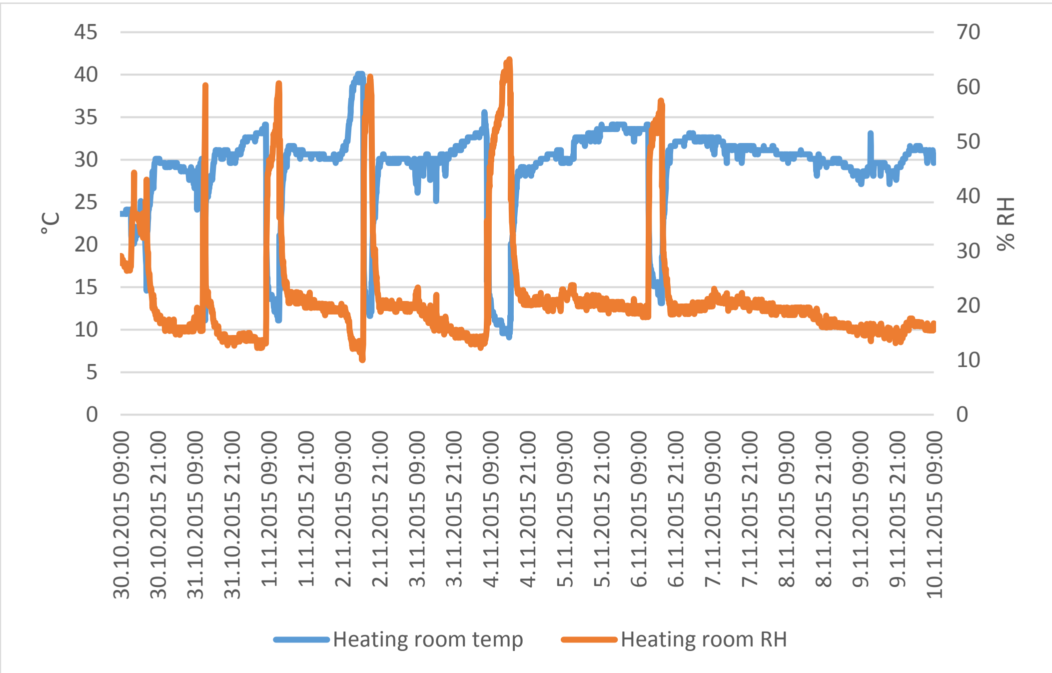


Figure 15. Temperature and relative humidity of the air in the heating room after going through the first heat exchanger.

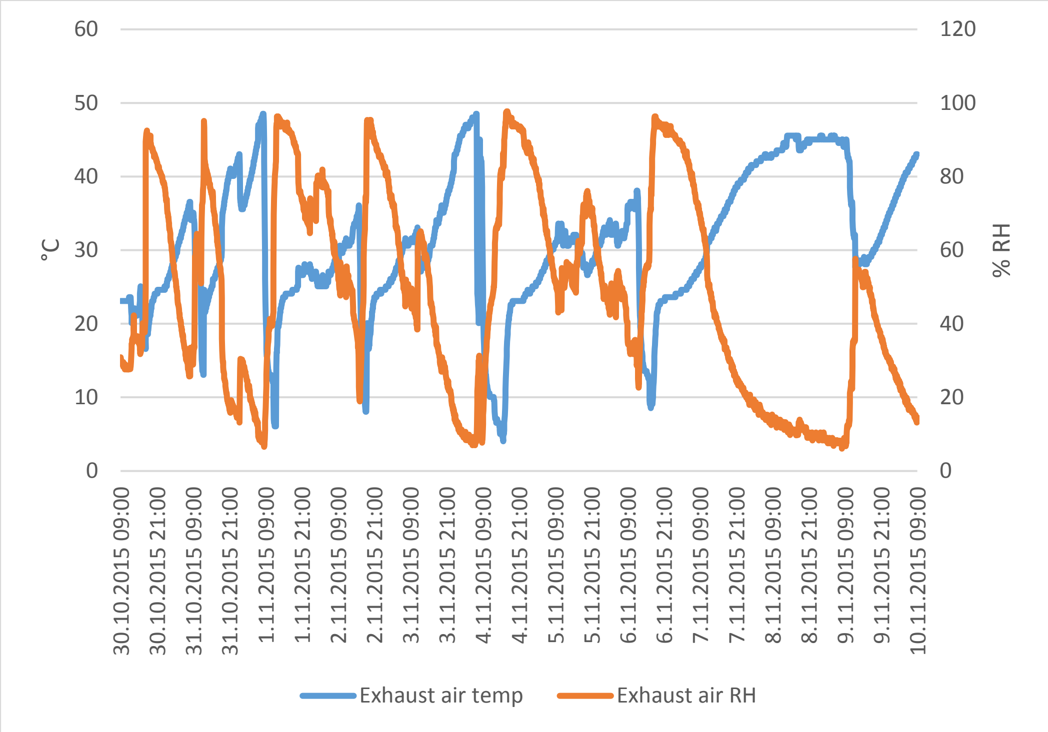


Figure 16. Temperature and relative humidity of the exhaust air after drying.

Case Study IS3 – Grund farm

At the farm Grund in Eyjafjörður Northern Iceland, cereals (barley) and rape seed are dried by use of geothermal water. An old building was improved for the drying operations. Hot water is received from the community supply and pumped through a heat exchanger to provide hot air. The heat exchanger was built specially for the operation. The hot air is pumped through small holes in metal sheets in the floor where wet grain is loaded. A system was designed to control and monitor the drying process. The company Raftákn developed the control system for the process. The design was based on the requirements that the dried grain and rape seed would be ready for milling and that the final moisture of products would be 15% or less. The system controls the whole drying process, records information immediately and helps to guarantee the quality of products. The recorded information ensures traceability within the process and is important for the preparation of a quality manual. The grain is milled after drying and is then ready for the preparation of feed concentrates. The dried grain is only used for feed but in the future it might be sold for food production.

Figure 17. Facilities for incoming wet grain.

Figure 18. A heat exchanger for the incoming geothermal water.

Figure 19. Monitoring unit for grain drying.

The drying process at Grund farm was studied in 2015 and measurements carried out during the 2016 harvesting season. The temperature of the air for drying did not rise above 30 °C. This drying of grain has been sufficient. The low temperature should support maximum quality of grain.

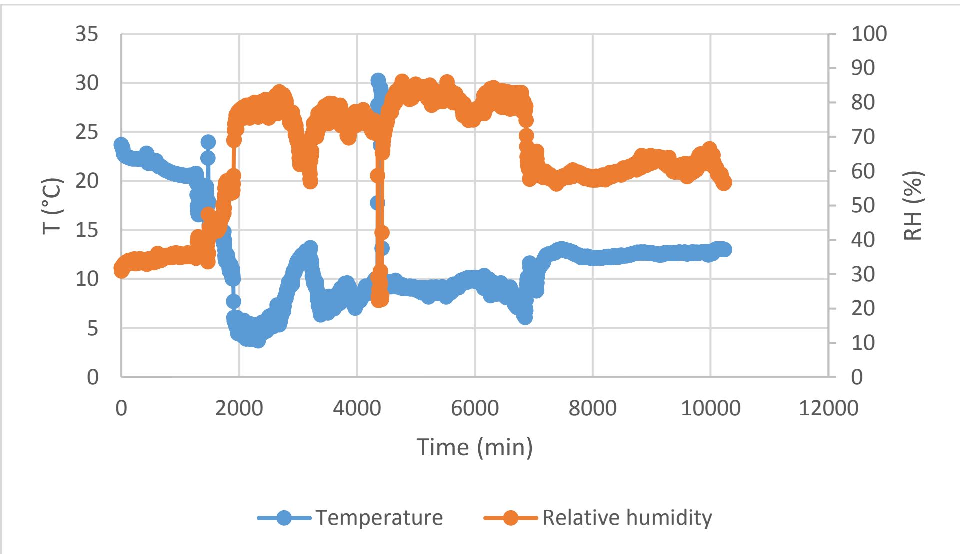


Figure 20. Temperature and relative humidity of intake air to the drying facilities.

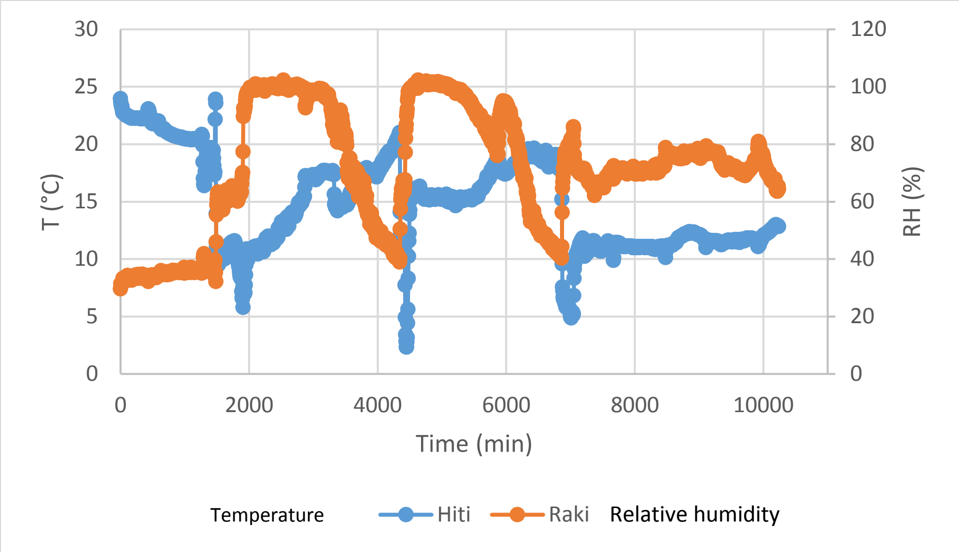


Figure 21. Temperature and relative humidity of exhaust air from the drying facilities.

Case Study IS4 – Jaðar farm

Jaðar farm is located in West Iceland, Borgarfjörður district. Barley drying started in 2016 and the drying facilities were built from available resources earlier the same year. The farmer, Eiríkur Blöndal, is also an engineer and was able to design the plant himself. His aim was to use geothermal water as the only energy source. A big dryer has been situated in an old farm building (Figure 22). Eiríkur Blöndal has noticed that air humidity falls sometimes in the middle of the day, increasing the drying capacity.

Measurements were carried out August 16th until August 23rd 2016. Sensors recording temperature and RH were located at the air intake to the dryer and at the exhaust. Temperature sensors were located above the heat exchanger and inside the dryer close to the bottom and top.

Results are shown in Figures 23 to 30. It can be seen that the temperature of the intake air was below 35 °C and relative humidity below 70%. Outdoor temperature was constant at 14 °C during the drying operation. Measurement of exhaust air showed temperature below 35 °C and relative humidity up to 100% carrying the grain moisture. Highest air temperature inside the dryer was about 45 °C, indicating that grain was not overheated.

Figure 22. Installation of a dryer at Jaðar farm.

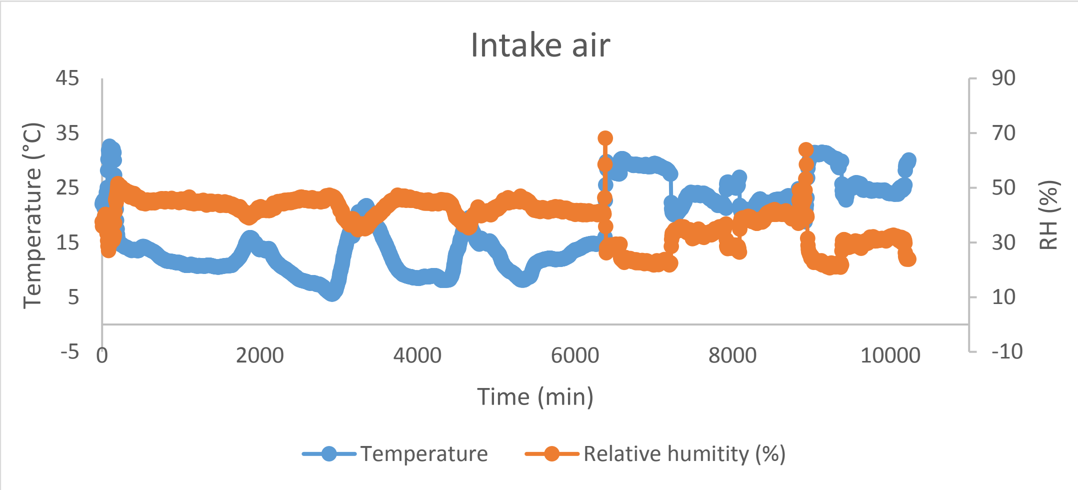


Figure 23. Temperature and RH of intake air.

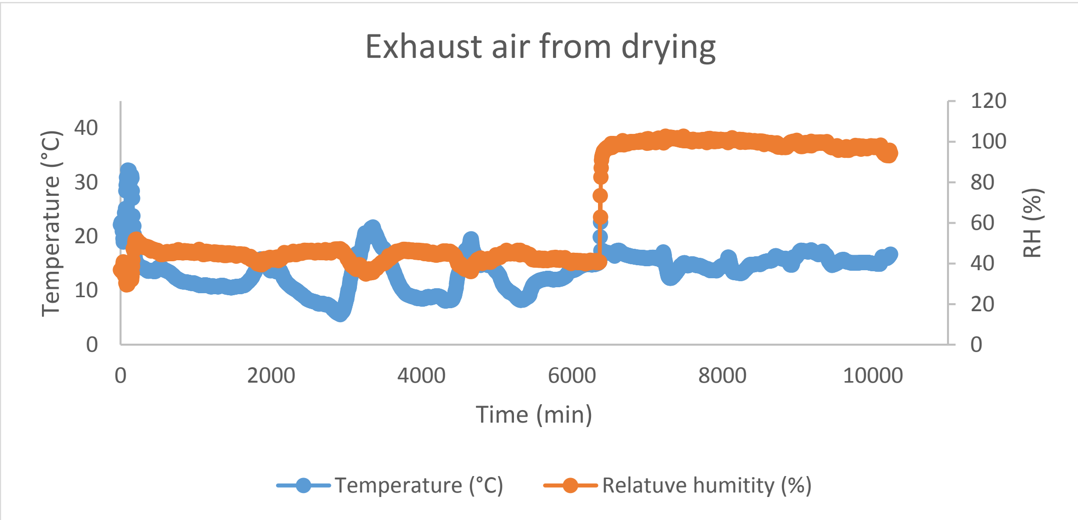


Figure 24. Temperature and RH of exhaust air.

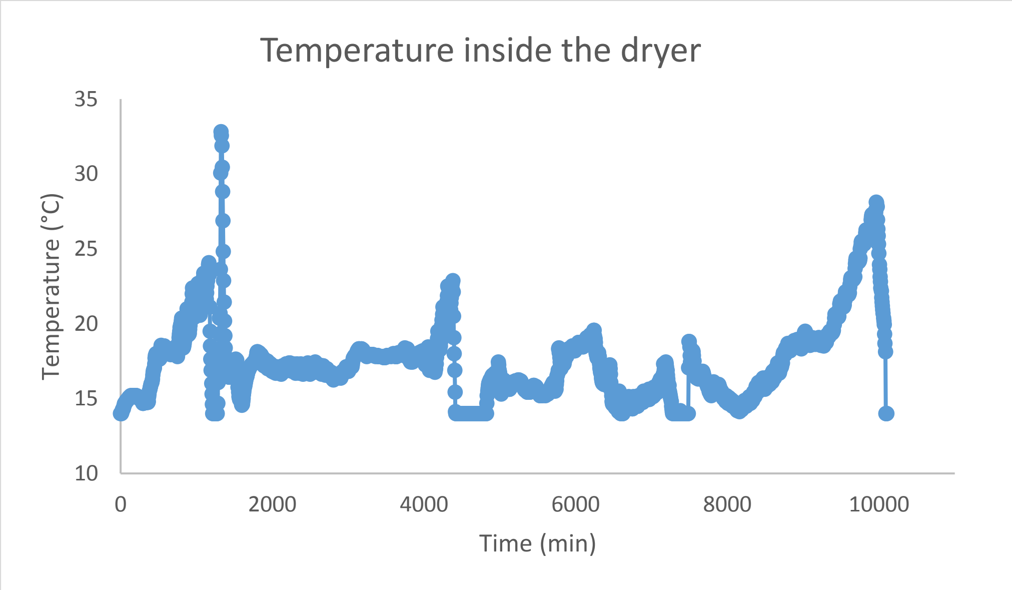


Figure 25. Temperature inside the dryer (bottom).

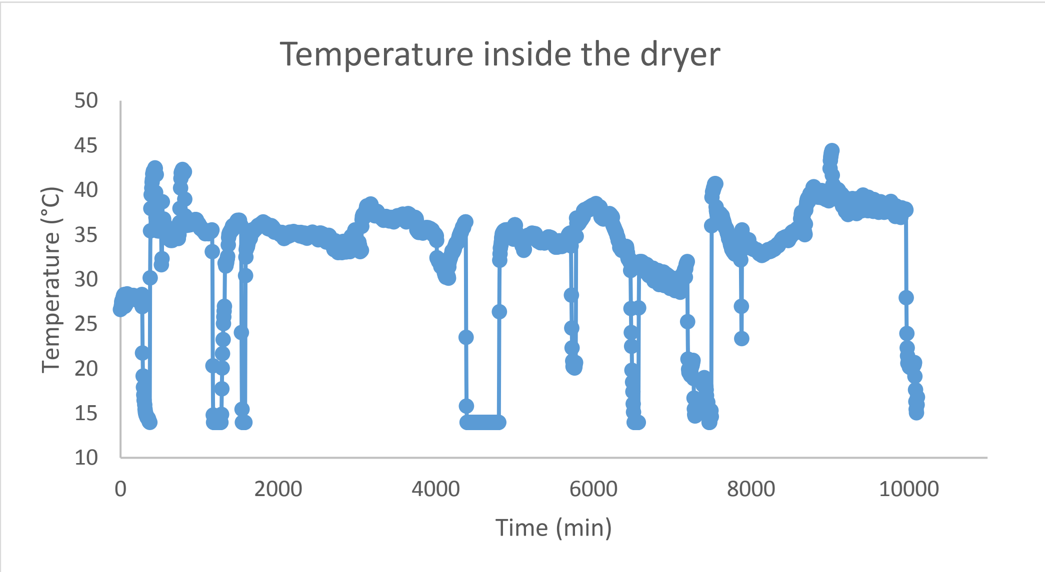


Figure 26. Results from temperature measurements inside the dryer (top).

Figure 27. Location of a temperature sensor inside the dryer close to the top.

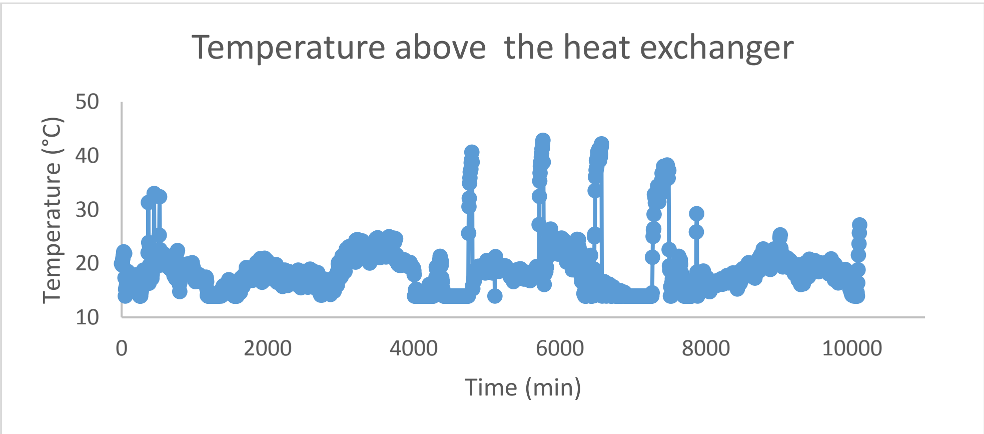


Figure 28. Measurements of air temperatures above the heat exchanger.

Figure 29. A heat exchanger for the dryer. A temperature sensor is located above the heat exchanger.

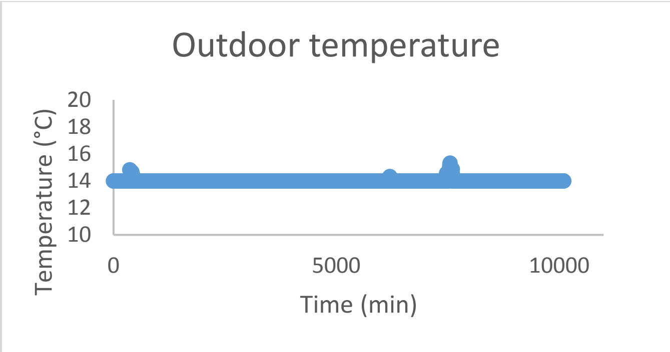


Figure 30. Temperature of air outside the building, quite stable at 14 °C.

Case Study IS5 – Hjalteyri drying plant

Hjalteyri drying plant is located on the west coast of Eyjafjörður Northern Iceland. The plant is owned by a company which provides services to farmers including transport of the dried grain. Some of the farmers sell the dried grain to a local feed company but most of the grain is used as feed for milking cows.

The equipment was installed in an old fish meal factory and receives geothermal water at 80 °C from a local provider. Holes in the metal sheets of the dryer floor allow hot air to be blown through the grain for drying. Figure 31 shows the intake for grain to the dryer. Grain is transported mechanically to the top of the dryer where it circulates. After drying, grain is transferred to a storage tank (Figure 32). Finally, grain is transported mechanically to a transport truck outside the building.

Measurements at the Hjalteyri plant were carried out in September 2016 (September 26th until September 27th). Heated air for drying from the heat exchanger reached a maximum temperature of 70 °C. At the end, after a period to allow the grain to cool down, the air had reached the outdoor temperature of 14 °C.

Figure 31. Intake of grain to the dryer.

Figure 32. Storage tank for the grain.

Case study – Vallanes farm

Measurements were not carried out at the Vallanes farm but important information was collected. Vallanes is a farm in Fljotsdalsherad East-Iceland with over 20 years of barley growing for food production. This district often enjoys favourable conditions for cereal growing when the growing is difficult in other parts of the country.

In 2014 conditions for barley growing were very good and the harvest was about 100 tons dried barley and 4 tons dried wheat. The barley was particularly mature this year. However, in 2015, the barley growing was a total failure due to bad weather conditions. No barley was harvested this year since it was not mature and tractors could not be used due to wet soils.

The harvesting period is normally about 1 month. It is important to start to harvest early even though barley dry matter is only 60%. Otherwise too much barley might be lost due to storms and birds (geese). At the end of the one month harvesting period barley dry matter might be 80%. There is a great difference between drying costs at the start and the end of the harvesting period.

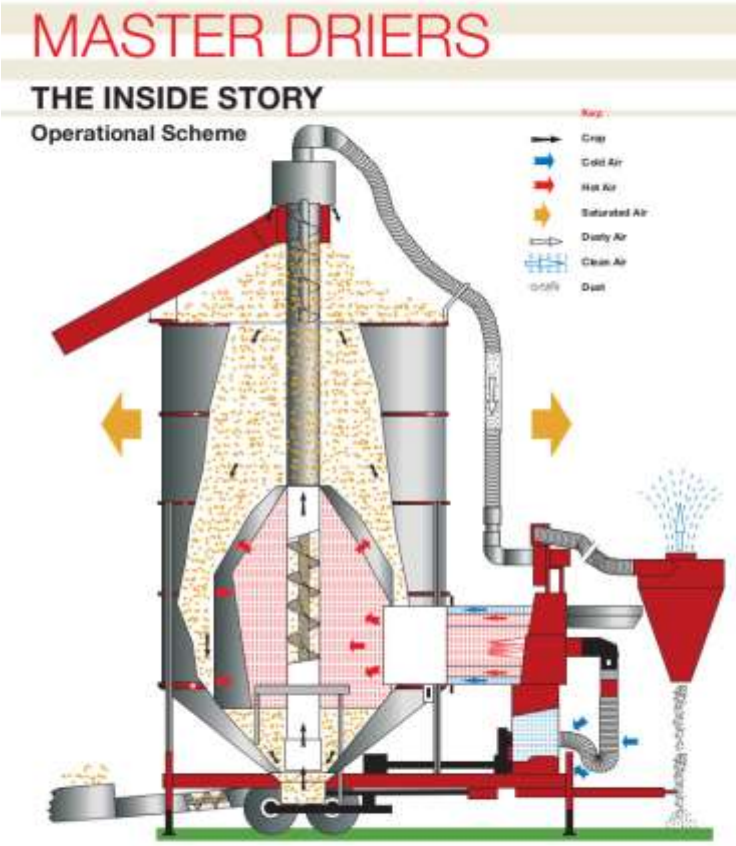
Case Study UK1 – Agronomy Institute, Orkney

During the harvest, the transportable drier is set up in a large building near the seed store. The height of the building is very useful as it enables us to dry the grain even if its pouring with rain outside. One end is open and there is a large sliding side door which can be opened to produce a through-draft, allowing diesel fumes and moisture to escape.

Cereal drying plant

<u>Description of dryer</u>:

- Make- Master
- Type- Super 120 RS Batch drier
- Heating component- Pedrotti dual stage fuel burner, twin jet oscillating flame suitable for operation with dual fuel (diesel or kerosene)



<u>Description of the drying process</u>

Wet grain enters the dryer via a ground fill auger. Once in the dryer, a central vertical auger continually moves the grain from the bottom of the dryer to the top. At the top, the grain cascades down over the top of the plenum containing the hot air produced by the burner. The burner unit oscillates between one and two flames to maintain the desired air temperature. The grain temperature is directly related to the moisture content so once it reaches 36^{o}C, the moisture is down to approx. 13% and the burner unit turns itself off and the grain starts to cool.

- Fuel / type of energy used and unit price: Red Diesel £0.45/L (€0.63/L)

- Tons of cereals dried each year: *120-140 tons*

- Days the drying plant is in operation per year: 21-28 days

- Tons of grain in each batch: To fill the grain drier takes approx. 10.3 t of barley at 23% moisture.

- Duration of the drying cycle and energy use: It roughly takes about 1 hour to reduce the grain by 1% moisture. The manufacturer estimates fuel consumption at 5 litres per ton, for 5%

moisture extraction. Our own estimate is a little more than this (approx. 120 litres per full drier)

NB: The drier requires an additional power source for operation. Depending on the set-up, this can either be from the PTO of a tractor or a 3 phase electrical supply. We use a tractor to operate our dryer. For a full dryer load, the tractor uses approximately 60 litres of diesel. Between the diesel used in the burner and the tractor, approximately 180 litres of diesel are used to dry one 10.3 ton batch of grain.

- Maximum actual grain temperature during drying and heated air temperature: An air temperature setting of 65^{0}C -75^{0}C is used for malting barley. The safety air temperature is 10^{0}C higher than air temperature. If this temperature is reached, the burner turns itself off. A grain temperature setting of 35^{0}C-38^{0}C is used.

- The average or range of moisture content of cereals at harvest: Grain moistures in 2015 ranged from 18%-25%. Harvest conditions were wet, however, and we know of other farmers who had to dry grain at c. 30% moisture.

- The moisture content of dried cereals: Highland Park require their dried barley to be below 13% on delivery. For our seed and other barley we usually dry it down to 13%-14% moisture.

Description of any problems in 2015

Very cold and wet spring resulted in sowing being delayed. Rainfall was higher than average from May-July and the harvest was about 1 month later than the previous year. Harvest itself wasn't too bad but the short day length meant harvesting conditions were short in the afternoons once the dew had disappeared.

The harvest was easier for farmers with early varieties or for those who managed to plant early because these were ready for harvesting during a good spell of weather in Sept/Oct. Harvesting of late planted crops and later maturing varieties was difficult because these matured very late this year, by which time the weather had deteriorated. Some of these crops had to be used for silage.

Typical outdoor temperature and %RH during the drying period: September 2015:

- Average temp 12.2^{o}C
- Average Max 14.5^{o}C
- Average Min 9.3^{o}C
- Average Humidity 84.8%

Storage of dried cereals

Description of facilities: Once dried, all grain is kept in 1 ton FIBC (flexible intermediate bulk container) bags and stacked in our grain store. The grain store is a 22.5 x 12 m portal framed building with mass concrete and half-clad fibre cement walls. The roof is clad with fibre cement sheets.

- Storage time: ranges from 4 to 12 months
- Control of storage temperature and %RH: no control.
- Use of grain: malt for distilling and brewing as well as seed stock for the following year
- Are mycotoxins inspected under a programme? Yes, Highland Park routinely test for Mycotoxins in the grain they use.

Case Study NO1 – Berg, Northern Norway

There is one drying plant within the region, the northernmost drying plant in the world. It is based at Berg, Sømna in Nordland. It is a cold air stream dryer, Monsoon TBGD/TBGE Norsk viftefabrikk. Before entering the dryer, the barley is cleaned and weighed (200 kg at a time) for deciding the payment to the farmer. Cold air drying requires that the grain brought in for drying is relatively dry in the beginning. After weighing the grain is put into the silo where 10 tons are dried at each time. There is only one cycle of drying. During drying, the grain is moved from the top and down in order to cool and dry it evenly. The drying temperature is similar to the outside temperature. The dryer is driven by electricity and is in use only during the harvest period in the autumn, mid-August to mid-September. After drying, the grains are moved to the factory for producing concentrated feed. The drying plant is owned and driven by Felleskjøpet Agri. Information was received from Jørn Henning Øyen.

At Berg, there is another dryer which is not currently in use, Boiler Maxi which needs 400 KW energy.

Cereal drying 2015

There were no special problems with drying this year. The last time there were challenges in drying was 3 years ago. The average moisture content of cereals at harvest is usually around 17-25%. The typical outdoor temperature when the drying plant is in use is about 12-15°C.

Storage of dried cereals

The cereal is stored as concentrated feed and used through the winter. During storage, temperature coolers are placed within each storage cell to prevent overheating of the feed. There are no regular mycotoxin inspection programs. The grains are solely used for animal feed.

Storage of undried cereals

Further north in the region where farmers do not have access to a drying facility, the grains are generally molassed into silage for animal feed.

4. Results and discussion

The drying facilities needed for grain drying depend very much on the situation in each region. Results from case studies at seven locations are presented in this report. Different solutions are reported for grain drying in the northern regions. Among the solutions found were simple facilities, home-made equipment and an advanced drying plant in a new building for grain drying.

A small transportable dryer is described in the Agronomy Institute case study. The Norwegian Case study involves cold air drying in a drying plant. This solution is unlikely to be adequate for high moisture grain. It was found that some Icelandic farmers have installed drying equipment in old buildings and worked themselves on the development (Jaðar farm, Belgsholt farm). Most farmers have bought tall drying chambers which are fed with hot air for drying the grain. One farmer has developed a different solution and pumps hot air through metal sheets on the floor (Grund farm). At the same farm, the drying is monitored electronically. At Thorvaldseyri farm, a modern drying plant has recently been built.

The comparison of different energy sources for the drying of grain is of interest for both economic and environmental reasons. Iceland has special conditions, as there is plentiful geothermal water at many locations. The drying time depends heavily on the temperature of the geothermal water. Additional heating elements would speed up the drying process. The use of geothermal energy is recommended since this solution helps to increase sustainability. Also overheating of grain is less likely for geothermal heating than with a diesel dryer. Geothermal energy offers very clean, high quality dried grain.

In some regions, farmers have to choose between diesel, natural gas and electricity. Electricity might be too expensive in many cases and diesel is the most commonly used fuel. Where diesel is used, the exhaust air from the burner should be kept away from the grain.