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Assessing and addressing the impact of warmer autumns on the success of grain cooling

by

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ABSTRACT

Grain cooling by low volume ambient aeration is a well-established technique for preventing biodeterioration of stored grain after harvest. It is primarily used to control insect pests. However, it is only successful if specific targets are met by specified times; this can only be achieved by using appropriate equipment and good management. Over the past few years some growers have experienced problems in achieving targets at the correct time.

This project aimed to gather preliminary evidence from growers on their experiences with cooling and to show, through use of simple and cheap differential thermostatic controllers, that it is possible to meet targets at a lower price compared to manual control.

In a nationwide survey of on-farm stores during 2007 only one grower achieved all three targets by the required time and a few others met one of the targets. Whilst some growers could have improved their cooling practice, the study provides tentative evidence that the changing climate may be having an impact on the speed of cooling. This is being further explored in a LINK project running from 2006 to 2011.

Despite this, UK growers are still able to prevent insect infestation through grain cooling. The project demonstrated the benefits of differential fan control in terms of efficacy, enabling adaptation to climate change. Reduced fan operation saved 34-40% in energy and operating costs, and demonstrated the potential to reduce the carbon footprint of grain storage.

Key messages from the project were incorporated into a successful series of grower workshops in late winter and early 2008 and at the UK Cereals Event. Other technology transfer initiatives are planned in autumn 2008.

1. GENERAL INTRODUCTION

1.1 Low volume aeration

Low volume ambient aeration is a well-established technique for preventing biodeterioration of stored grain after harvest. Cold ambient air is blown into a grain bulk at a minimum rate of 10 $m^3/h/t$, to reduce the grain temperature to below that of the breeding threshold of insects and to slow down the development of mites and fungi. Grain typically enters stores at temperatures upwards of 20°C, and so the efficiency of the operation depends on ventilating when ambient temperatures are below those of the grain bulk. The speed of cooling is critical to ensure that cooling targets are met fast enough to prevent insect species completing their life cycle from egg to adult. Typically, storekeepers switch their fans on manually when they judge that conditions are right and cold air is available. Cooling normally starts in early autumn, ending in mid winter. With the continued withdrawal of contact insecticides for grain storage, the loss of methyl bromide, and the likelihood that new actives will not come along to replace these, cooling has become the backbone and mainstay of UK store management and is key to ensuring continued quality and food safety.

1.2 Integrated pest management – grain storage

Cooling is an integral part of a cost-effective, integrated pest management (IPM) strategy for the storage of cereal crops, developed by UK researchers over the last 20 years. This robust strategy informs and provides the basis of the HGCA grain storage guide (Armitage and Wildey, 2003). Originally published as the result of a 3-year HGCA-sponsored study (Wilkin *et al*, 1990) this evolving strategy can be summarised as –

- Clean the empty store and monitor with traps before harvest to help minimise potential sources of infestation.
- Treat the empty store if pests are present with an approved product to control residual pests.

- Dry cereals to 14.5% moisture content (MC) or less at harvest, to eliminate mites and moulds, and prevent mycotoxin production.
- Cool the grain at an airflow of 10 m^3/tonne/hr to below 15°C within 2 weeks, to prevent the saw-toothed grain beetle breeding, to below 10°C within a further 2 months, to prevent the grain weevil breeding and to below 5°C by winter to prevent mites breeding and to kill insects.
- Use automatic fan control with a differential thermostat set at 4-6°C to guarantee achievement of cooling targets and preferably a time clock to select night tariff electricity to cut costs.
- Monitoring insect numbers using traps, to check the success of the strategy.
- Optionally, top dress with an approved product, to kill upward-moving insects and mites that may survive at the surface. This will also prevent any mite infestations that might otherwise occur as the surface absorbs moisture in the winter.

1.3 Cooling targets – the implications of climate change

Although UK cooling targets are commonly quoted in the simplified form as above, the time taken to achieve each 5°C reduction in temperature (or cooling front) does alter depending upon the time of harvest, the location and start of ventilation (Table 1).

Table 1. Cooling targets for UK stores using low volume aeration at 10 m^3/tonne/hr.

Cooling starts on		1 Jul	1 Aug	1 Sep	1 Oct
Latest	15°C	16 Jul	17 Aug	12 Sep	8 Oct
date to	10°C	29 Sep	9 Oct	14 Oct	9 Nov
cool to	5°C	8 Dec	8 Dec	9 Dec	1 Jan

(After – Armitage *et al*., 1991)

Far from being arbitrary, these target temperatures are based on past HGCA funded modelling work and validated by a large-scale experiment, which drew together 3 key variables so that the recommendations are fit for typical cooling set-ups, are relevant to UK climate and when applied, are capable of preventing pest outbreak under typical conditions (Armitage *et al*., 1991): -

- ***Aeration rates***; a range of airflows required to cool 1 tonne of grain, measured in m3/tonne/hr were compared for best efficacy.
- ***Meteorological considerations***; temperature data sets for two widely separated regions in England based on a 20 year average and in addition a hot autumn and a mild winter at each location were used to model outcomes.
- ***Biological considerations***; cooling needs to be fast enough to prevent the quickest developing insect completing its life-cycle and to a temperature low enough to prevent the most cold hardy. Modelled outcomes were supported by robust experimental data.

However, over recent years growers have reported that they feel that cooling of grain at harvest is presenting a greater problem because of higher temperatures and earlier harvests. This has been recorded from grower feedback at events such as “Cereals”, enquiries to CSL and also at HGCA workshops on grain storage. This concern is pertinent, given that climate change represents a major challenge with the combination of rising summer temperatures resulting in warmer harvested grain, earlier harvests and milder winters (Hulme *et al*., 2002), and was the focus of a recent review that considered the impact of climate change on grain storage (Cook *et al*., 2004).

The extent of the issue is illustrated by the UK Meteorological (Met.) office’s central England temperature data set, which is one of the key references used by researchers with records going back to 1659 (Manley, 1974; Parker *et al*., 1992). There has been a steady rise in temperature during the last century by as much as 1°C in central England, but most alarming has been the acceleration of warming over the past two decades, that has occurred since the original studies that set out our cooling strategy. This is typically illustrated by comparing the 30 year average of 1961 – 1990 to recent years as shown in figure 1.

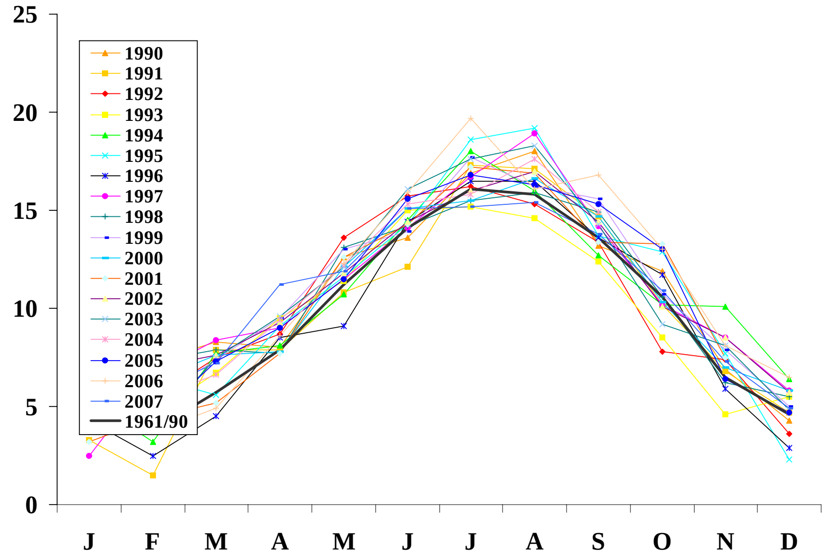


Figure 1. Comparison of mean monthly temperatures from 1961 to the present day. (Source: Manley, 1974; Parker *et al*., 1992 – updated by the Hadley Centre for Climate Prediction and Research, Met. Office, Berkshire, UK.)

However, relying on mean temperatures alone may distort the picture. Although there has been an unequivocal rise in mean temperatures, the question that needs to be asked is – “are ***minimum*** temperatures still low enough to enable grain cooling?”

To support this, figure 2 clearly shows that although mean temperatures have been elevated in recent years during the period at and after harvest, ambient minimum temperatures are still well below the cooling targets for those periods. It is therefore hypothetically possible to achieve these targets given this representation of the cold air capacity available to low-volume ventilation cooling systems.

So whilst there is evidence to support growers concerns, it is not completely clear whether this is a problem resulting from changed climatic conditions, changes in storage practices e.g. higher yields leading to “overloading” of stores beyond their design capacity, or just a perception. Clearly, it is important to establish whether or not the problem is real, if it is, how best to deal with it and if it is not, how best to educate growers to ensure rapid cooling of grain.

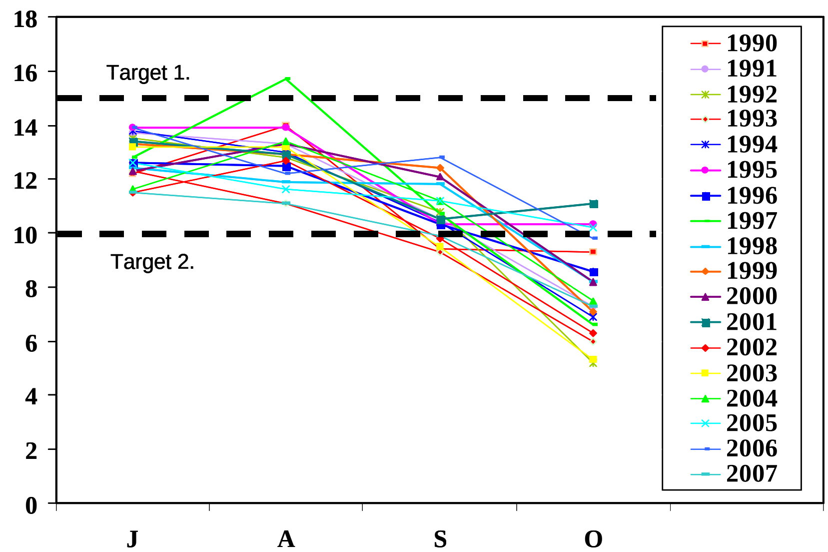


Figure 2. Minimum temperatures for the period immediately after harvest compared to the storage target temperatures of 15°C and 10°C.
(Source: Manley, 1974; Parker *et al*., 1992 – updated by the Hadley Centre for Climate Prediction and Research, Met. Office, Berkshire, UK.)

For example, 'automatic' cooling strategies where fans are switched on by a micro-controller at a given differential between bulk and air temperatures have been developed to help ensure that targets are met, and that the windows of coldest air are selected (Wilkin *et al*.1990). However, despite much effort to promote these techniques, the industry still remains to be convinced of the benefits of investing in this technology. This is ironic, considering that capital outlay can be rapidly recouped through reduced running costs with reduced fan running times. Wider adoption of this approach will therefore not only help adaptation to climate change, but will also help the UK farming industry contribute to mitigation, via reduced energy use.

The rationale of this project was therefore two-fold. An unprecedented wide-ranging monitoring study on UK farm stores was conducted to demonstrate whether cooling targets are being met, and whether climate change is impacting upon the UKs ability to manage stored grain. Concurrent trials monitored paired grain bulks on sites across the country to demonstrate that automatic control using grain-ambient differentials is one way that growers can adapt to climate change. A further novelty of the project was that it was designed to feed its results directly into the series of HGCA storage workshops that were run in the late winter/spring of 2008 that are also briefly reported on here, and offered a powerful route for technology transfer of its outcomes.

2. EFFICIENT CONTROL OF AERATION – ADAPTATION TO CLIMATE CHANGE USING DIFFERENTIAL THERMOSTATS

2.1 Introduction

Differential controllers are simple electronic control units that compare grain temperature to ambient air temperature. The controllers are configured so that the ventilating fans are only switched on when the air temperature is lower than the grain temperature. This well developed technique was designed to ensure that cooling systems have the potential to run during all available hours of cold air until targets are met, are automatically shut off once grain is cooled to ambient temperatures where further fan running would waste electricity and incur unnecessary cost, and to avoid re-heating the grain when temperatures warm.

Historic research has demonstrated that the ideal grain/ambient air temperature differential for efficient and cost-effective control of cooling is between 2 and 6°C; i.e. fans are switched on when the ambient air temperature is 2 – 6°C lower than the grain temperature. Advice to growers is to start at a differential of 4°C in the first season of use. If temperature targets are achieved easily then in subsequent years the differential can be increased up to 6°C to further save on energy and fan running costs. Alternatively if targets are not easily met then a differential down toward 2°C is recommended.

A typical differential control set-up consists of a temperature probe(s) inserted into the grain bulk being cooled and a temperature sensor(s) at ambient conditions, both linked to the controller that in turn is wired into the fan starter (Plate 1). The original controllers were based on thermostats, although modern units are either of a microprocessor based stand-alone design or are software driven on a personal computer (PC). The latter are normally sold as part of an integrated temperature monitoring and control package. The systems are low capital cost starting at as little as under £200 for a basic setup. Regardless of controller type, the units are commonly referred to as differential thermostats in homage to the technology employed in the earlier devices.

Other than choice of device, growers should also be aware of the ideal placement of sensors. The ambient sensor should be placed close to the fan inlet but away from any heat generated by the fan. For pedestal systems this would normally require placement within the headspace of the store, and away from the fan outlet when operated in sucking mode due to the warm air expelled from the bulk in the earliest stages of cooling. Ideally the grain probe should be placed in the region of the grain bulk that is slowest to cool. This will be half a metre from the surface when blowing, or toward the bottom of the bulk when sucking, although the latter is often not practical. It is important that the grain sensor does not sit on or too close to the surface, otherwise this sensor will track ambient temperatures rather than bulk temperature and the system will not run.

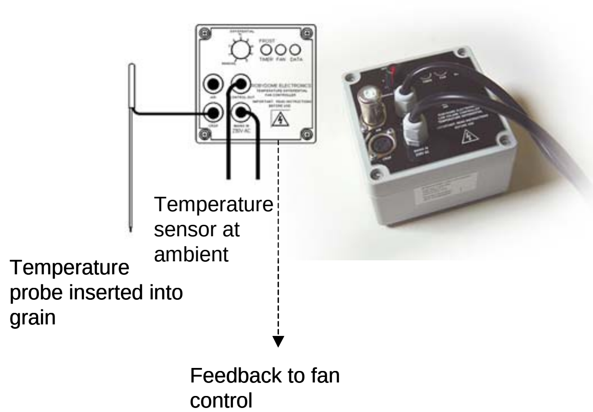


Plate 1. An example of a differential controller, commercially available in the UK.

The aim of the differential thermostat trials was to compare manual control of fans, as determined by the normal operation and judgement of the storekeeper against automatically controlled fans, using differential thermostats. The objective of this work was to produce contemporary data, updating trials work of 15 – 20 years ago (Figure 3) to reflect the recent changes in autumn / winter ambient temperature conditions that have been attributed to climate change.

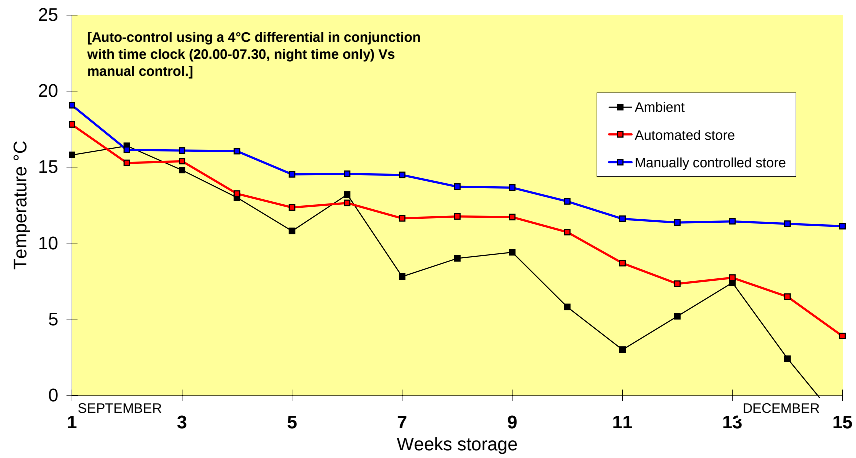


Figure 3. Trials data from CSL experiment comparing the cooling of two 3,000 tonne stores in East Lincolnshire during the Autumn of 1991.

In doing so the trial was hoped to generate data that could be used in technology transfer initiatives to demonstrate that this simple technology could help UK growers adapt their cooling operations to climate change, and guarantee cost-effective achievement of cooling targets, despite warmer autumns and winters.

2.2 Materials and methods

The trials work was carried out at 3 sites, in different regions and in a variety of storage types. These were –

Site 1. Darlington (Independent grower; farm storage feed wheat) – on floor storage of 700t capacity cooling with pedestals
Site 2. Cambridgeshire (Large-scale co-operative storage feed wheat) – silos of 3,000t cooling with conventional horizontal ducts
Site 3. Norfolk (Commercial storage malting barley) – on floor stores of 3,000t capacity cooling with conventional horizontal ducts

Unfortunately due to the understandable commercial demands on the store, there was unanticipated movement of grain in and out of the stores at site 3 that compromised the experiment. Therefore only sites 1 and 2 will be reported for this part of the project.

Site1. Darlington: The Darlington site comprised a single on-floor farm store measuring 12 x 90m of 700 t capacity. The store was cooled using 0.3m diameter "pedestal" vertical aeration ducts, with 0.95m perforated bases. Four of these were placed equidistantly down the centre of the shed at spacings of 4.5 – 6m apart. The pedestal/fan spacing was determined by crop depth according to guidelines from precious research in order to provide a low-volume ventilation rate of $10m^3/h/t$ (Bartlett *et al*., 2002). As was normal practice at this site, the pedestals were run in sucking mode.

For the experiment, wheat harvested at ca. 20-23% moisture content (mc), was passed through the farm's hot air drier and was loaded into store at ex-drier temperatures of ca. 35°C, and 14.5% mc. The store was loaded to a depth of 4m during the week commencing 13/08/07. The store was continuously ventilated ahead of the installation of the automated control system in order to reduce the immediate risk of spoilage due to the elevated temperatures, and to even out the temperatures out across the bulk whilst it was being filled. With an average bulk temperature of 19°C, the bulk was divided into virtual halves for the start of the experiment, giving 2 identical experimental zones.

A single 1.5 Kw fan was shared between 2 pedestals as per the manufacturer's recommendations. This gave 2 pedestals with a single fan for each zone, with one zone cooled by manual switching of fans and the other by automatic control system (Figure 4). A software based control and monitoring system (Robydome, StoreCheck) running on a personal computer (PC) was installed, along with 12 temperature probes that were inserted to 1m depth. Six probes were placed equidistantly between each set of pedestals to monitor progress of the cooling. Each store half was identical in temperature at the experiment's start. Hours metres were installed to monitor the fan hours run for each experimental zone.

Plate 2. Pedestal ducts and view across Darlington store (700t wheat).

The experiment commenced on the 7/9/07. The automated zone was configured to switch fans on when there was a 2°C differential. The storekeeper, who had many years practical experience, was instructed to run the fan in the other store-half according to his normal practice. The trial terminated at Christmas.

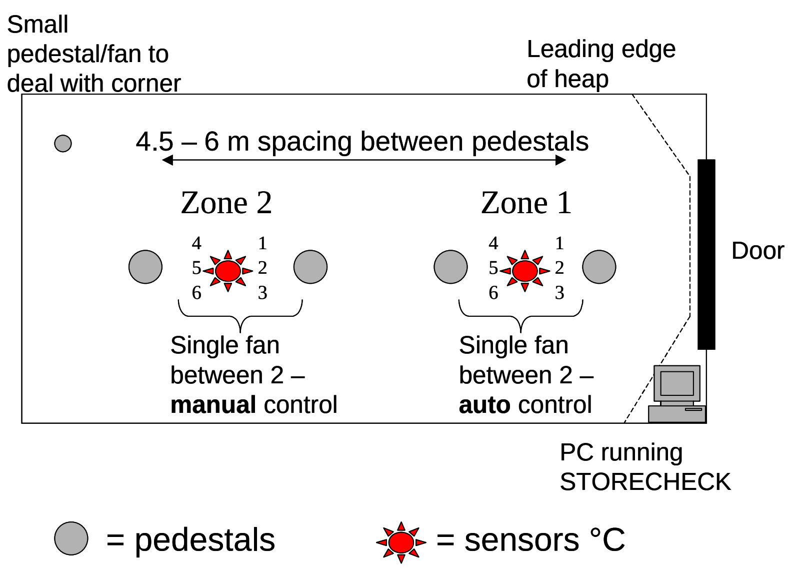


Figure 4. Schematic of Darlington store (750 t bulk)

Site2. Cambridgeshire: The second site was a very large cooperative store, and again with a highly experienced store manager. At this site, all of the storage was in large silos and two identical 3,000 t capacity silos were selected for the trial. Each silo had an existing temperature monitoring system linked to StoreCheck software running on PC from the site's central control room. Each silo had six suspended temperature cables, with sensors at three depths on each corresponding to top, middle and bottom. The system was upgraded to enable automated fan running using a temperature differential, and hours meters were installed to record fan hours run. Each silo was serviced by a conventional aeration system of horizontal ducts, with fans blowing upwards; site records confirmed the system was engineered to ventilate at ca. $10m^3/h/t$.

Both silos were filled with 3, 000 t wheat at 14.5% mc toward the end of August. Both silos were uniform in temperature at just under 20°C. The experiment commenced on 7/9/07, with one of the silos cooled using automated fan control at a differential of 4°C and the other manually controlled by the storekeeper, as per his normal practice. The experiment terminated in early January.

Plate 3. Trial silos containing 3, 000 t of wheat at Cambridge store.

Record-keeping and data analysis: For both trials sites, the StoreCheck system logged daily temperatures. Fan hours were transcribed from the hour metres and recorded manually by the storekeepers. The temperature and fan running data were exported to excel spreadsheet for analysis and presentation into graphical form. The cooling profiles were compared to the targets in table 1, after Armitage *et al*. (1991), depending upon when aeration started.

2.3 Results

Site1. Darlington: The cooling profiles for the Darlington site are shown in figure 5. The automated zone of the bulk started dropping in temperature towards the first 15°C target within a week of the start of the experiment and ahead of the manually cooled zone. Unfortunately this coincided with a data logging failure and the exact date of the achievement of this cooling target was missed, although once the data logging was resumed it was apparent that this had probably occurred at least within a week or two of the target date. However it is notable that after the first target had been achieved, the auto-controlled zone was 2°C lower than the manually controlled zone. As cooling progressed, the automatic zone hit its 10°C target on 25/10/07, which was 5 days late but the manual zone took until 12/11/08, which was almost a month later than target. However, both zones were below 5°C by mid December, with little between them in timing and both were a day ahead of target. During the experiment the automatic zone was consistently lower than the manual zone, although with only a few deg. C difference, the grower had actually performed quite well and very close to the automatic system. However when the fan operating hours are compared, a much more dramatic difference is observed.

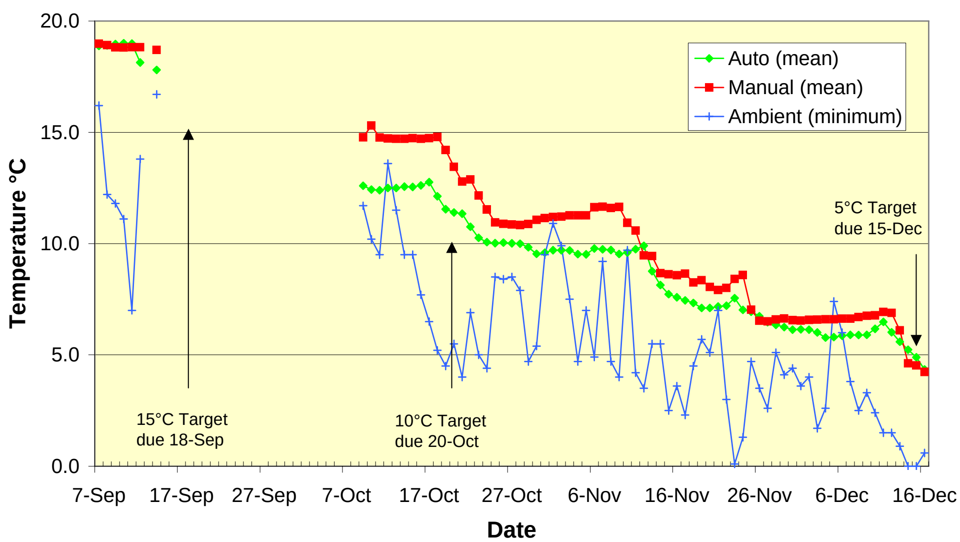


Figure 5. Darlington site - 700 t bulk of wheat cooled by pedestals, sucking (fans in half of store manually controlled and the other half of store automatic using 2°C differential).

The hours of aeration were 1032 for the manually controlled part of the bulk compared to 608 for the automated fan running (Figure 6). The hours to cool using the automated system was modestly high compared to ideal estimates of 417 hours to pass 3 cooling fronts through the grain at aeration rates of $10m^3/h/t$ (Wilkin *et al*, 1990), whereas the manual cooling took more than twice as long. The automated system running on a 2°C differential therefore offered a substantial saving in energy and therefore running costs.

The power required to aerate either store half was 1.5 Kw at an electricity tariff of 7.4p/Kwh. Allowing for the fans having a nominal efficiency of 66%, the cost would be -

Fan power (Kw) x price (p/Kwh) x hours run / tonne x 100/66

- Giving manual costs of 50 p/t, compared to lower costs of 29 p/t for the automated system.

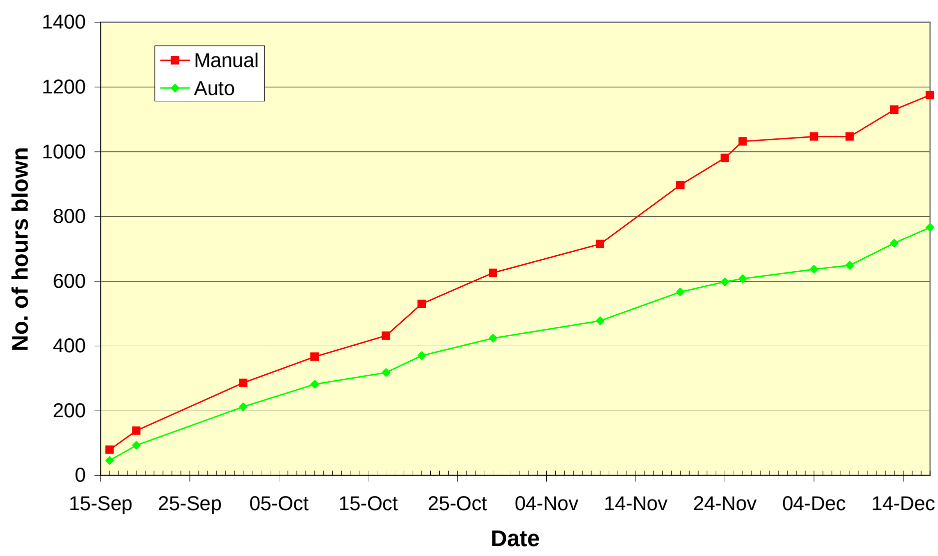
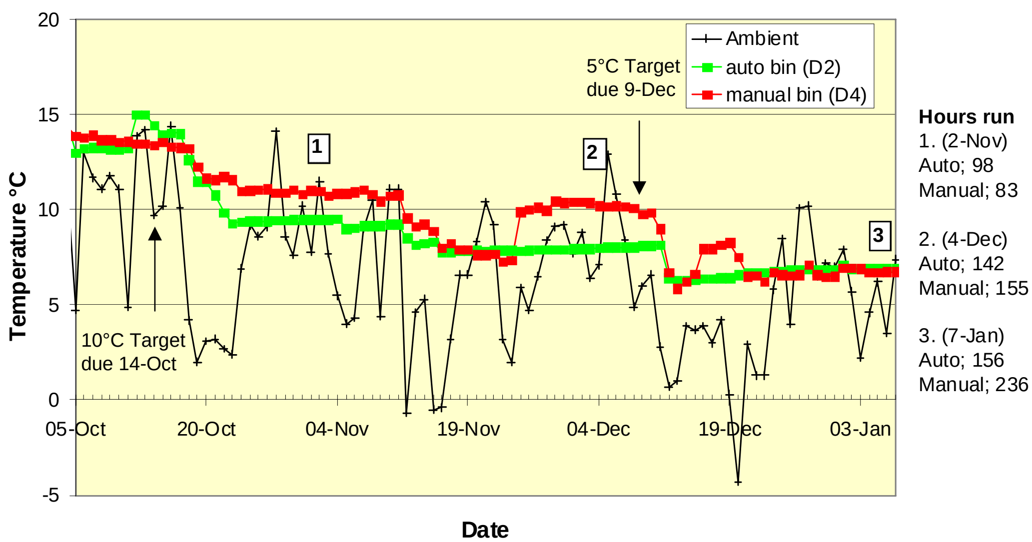


Figure 6. Darlington site - comparison of cumulative hours blown by manual and automatically (2°C differential) controlled fans.

Site2. Cambridgeshire: At the Cambridgeshire site, the cooling progress was again very close between the manually and auto-controlled silos when comparing mean temperatures (Figure 7). The 10°C target was late by 8 days for the auto-controlled silo and a month late for the manually controlled silo. The 5°C target was not achieved for either silo with the lowest temperatures reached of 6-7°C.

Despite there being little difference between the temperatures of each silo the auto-controlled system demonstrated an obvious advantage when on two occasions in December, the storekeeper inadvertently raised the temperature of the manually controlled bin by running the fans when the ambient temperature was greater than the temperature of the grain. Running the fans automatically by differential control avoided this scenario.

Again, the greatest benefit of auto-control was the saving in fan operation time, and therefore energy inputs / costs. Although the storekeeper did an excellent job of running a lean operation to the beginning of December, the automated system had demonstrated a 34% saving by the end of the experiment in early January.



<u>Figure 7. Cambridgeshire site - comparison of two 3,000t silos of wheat cooled by horizontal duct system (blowing); one silo manually controlled vs a silo automatically controlled using 4°C differential.</u>

3. COOLING MONITORING EXERCISE – HOW WELL ARE GROWERS DOING?

The second part of the project was to monitor how well growers are currently managing the cooling of grain in their stores. The objective behind this part of the study was to get some idea of the different practices being used to store and aerate grain and to try and get some idea of the implications of this for good storage practice. In order to do this, 12 sites were selected around England and monitored with temperature sensors to record the temperature profile of the grain throughout the period from harvest to the end of the year. Temperatures were monitored using iButton (Maxim Integrated Products, Dallas Semiconductor) temperature loggers placed at 0.5m and 1.0m depths in the grain and a third logger used to monitor the ambient temperature.

3.1 Materials and methods

The ambient temperature recorder was placed close to the air inlet which would have been outside the building for under-floor ducts or close to the fan inlet on top of a pedestal thus reflecting the true temperature of air that was being blown through the grain. The iButtons were distributed, along with instructions on where to place them, to growers at harvest time for insertion in the grain. For a variety of reasons not all buttons were placed in the grain immediately or were placed imperfectly resulting in missing or anomalous results.

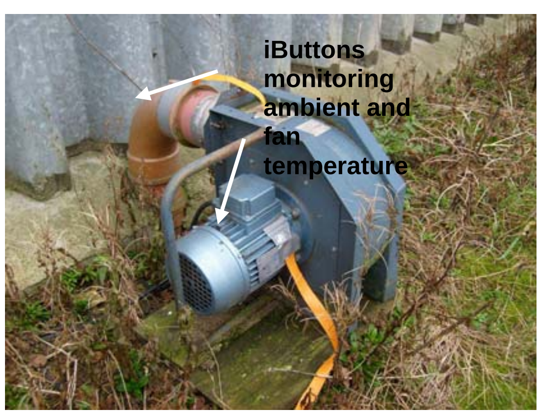


Plate 4. Position of iButtons for ambient temperature monitoring

The stores were selected to reflect a range of different climate conditions and storage and aeration practices. Occasionally monitoring finished prematurely due to grain being sold but since this was being done on-farm this was a risk that had to be taken, although useful data was still obtained from these sites. Details of these sites and their location and characteristics are given in table 2.

Table 2. Location and basic details of stores monitored during autumn & winter 2007.

Location	Type	Quantity (tonnes)	Depth (metres)	Aeration LV=Low volume HV=High volume	Differential Thermostat
Berwickshire	Flat store	980	7	Pedestals (LV)	No
Yorkshire	Flat store	700	3	Pedestals (LV)	No
Lincolnshire	Flat store	700	3	Pedestals (LV)	Yes
Northamptonshire	Flat store	550	3	Pedestals (LV)	No
Leicestershire	Flat store	1000	2.7	Pedestals (HV)	No
Norfolk	Bin	40	5.5	Under-floor (LV)	No
Cambridge	Flat store	350	3	Under-floor (HV)	Yes
Suffolk	Bin	28	4	Under-floor (LV)	No
Oxfordshire	Flat store	350	1.8	Under-floor (HV)	Yes
Hampshire	Bin	225	12	Under-floor (LV)	Yes
Kent	Flat store	600	2-6 (heap)	Under-floor (LV)	Yes
Dorset	Flat store	220	3	Pedestals (LV)	Yes

Plates 5 & 6. Contrasting store types 40t concrete bins and flat store holding 600t in a heap.

3.2. Results

The full results of the monitoring are shown in Appendix 1 with plots of the temperature of the grain and the ambient temperature for each of the locations. Examination of these shows when there is a significant differential between ambient and grain temperature and also when cooling is effective. As before, the cooling targets are taken from table 1, after Armitage *et al*. (1991), and the target dates for 15^{o}C, 10^{o}C and 5^{o}C are marked on each of the graphs so it is possible to make an assessment of the success of the cooling. Key points from the different sites are outlined in table 3.

Table 3.3. Achievement of cooling targets by the monitored farms arranged from the most southerly to the most northerly.

Location	Air flow P=Pedestal U=Under-floor	Differential	Target (^{o}C)	Target met
Dorset	~10m^3/t/h P	Yes	15 10 5	- 3 weeks late Not met
Kent	~10m^3/t/h U	No	15 10 5	2 weeks late On time 2 weeks late
Hampshire	~10m^3/t/h U	Yes	15 10 5	- 4 weeks late 1 week early
Oxon	High volume U	Yes	15 10 5	1 week late On time Not met
Northants	~10m^3/t/h P	No	15 10 5	2 weeks late 2 weeks late Not met
Cambridge	High volume U	Yes	15 10 5	- 4 weeks late Not met
Suffolk	~10m^3/t/h U	No	15 10 5	10 weeks late Not met Not met
Leicestershire	High volume P	No	15 10 5	7 weeks late 6 weeks late Not met
Norfolk	~10m^3/t/h U	No	15 10 5	- 5 weeks late 3 weeks late
Lincolnshire	~10m^3/t/h P	Yes	15 10 5	7 weeks late 4 weeks late 1 week early
Yorkshire	~10m^3/t/h P	No	15 10 5	7 weeks late 4 weeks late 3 weeks late
Berwickshire	~10m^3/t/h P	No	15 10 5	On time 1 week early 1 week early

It is notable that three of the stores were not using low-volume cooling setups but instead were utilising their high-volume drying fans for cooling once the grain had been dried. As is typical for these setups, the much higher ventilation rates of 180m^3/h/t meant that temperature targets were achieved within a few evenings rather that over several weeks. When cooling with drying fans the timing (manual control) of fan operation is therefore critical with respect to achieving cooling target dates.

Whilst the results are a very small sample it is interesting to note that only one of the locations achieved all of the cooling targets within the recommended timeframe. Of the sites that have data for the first cooling target of 15^{o}C (2 weeks after going in to store) only one site managed to achieve this and this is the most northerly site. When examining the ambient temperature for each of the locations it is clear that the most northerly site had the best opportunities for cooling the grain. Early in the season there was a difference of as much as 7^{o}C between the coolest and warmest site using the mean temperature. Whilst this hides to some degree the day-to-day opportunities to cool it does highlight the fact that some locations have an inherent advantage in terms of suitable conditions (Figure 8).

Further analysis of the data shows that 3 sites hit the cooling target for 10^{o}C approximately 2 months after harvest whilst 3 sites hit the final target of 5^{o}C by the start of December. The cooling of the grain is obviously due to a combination of factors including the decision making of the grower (e.g. whether or not to pursue the 5^{o}C target), the equipment (pedestals vs. under-floor, air flow rates), the weather and the quantity of grain. Given the number of variables it is not possible to say which one of these was the main factor in determining the end result. However, there were a number of examples where there were obvious improvements to practice that could be made and these will be further considered in the discussion.

If the performance of those growers using differential thermostats is compared with those who did not use them there is little difference in terms of their performance with perhaps the controller groups performing slightly better. However, the time at which the target was met is only one dimension and it is possible that those using the controllers achieved the cooling more efficiently with fans running for fewer hours. Unfortunately whilst this information was asked for it was often incomplete or missing. There was very little difference between the performance of pedestals and under-floor systems.

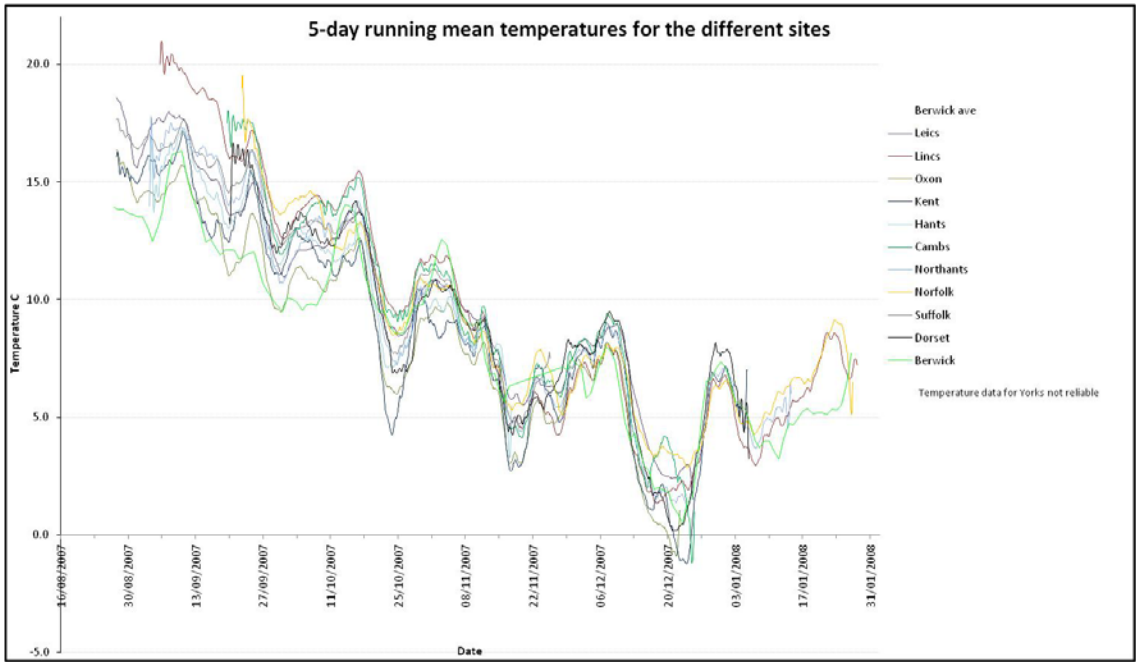


Figure 8. Five day running mean of ambient temperatures at monitoring locations

4. DISCUSSION – IMPLICATIONS FOR STOREKEEPERS

The first conclusion that can be drawn from the project is that assuming these growers are representative of farmers storing grain in the UK it would appear that the vast majority are missing the targets for cooling. This was apparent both from the survey data and the trials results comparing the performance of differential fan control. Furthermore, during the trials it was demonstrated that the use of differential thermostats enabled closer adherence to the target dates than manually controlled fans. However, many caveats must be placed upon the interpretation of this work.

4.1. Missed targets

Firstly, the missed target dates were not as severe in consequence as could appear. In some cases, although the target temperature due date had occurred, bulk temperatures had cooled close to and only a few deg. C above the target temperatures. This was especially apparent for the two trials. To appreciate the relevance of this it is worth referring back to the biological basis upon which the performance of a cooling system is judged.

Taking the initial target of 15°C. The aim of cooling in the earliest stages is to cool quickly enough to prevent the fastest breeding UK storage insect species the saw-toothed grain beetle (*Oryzaephilus surinamensis*) from completing its life cycle, which can be as fast as 17 days at 30-35°C (Howe, 1956; Back and Cotton, 1926) - hence, the rule of thumb of two weeks to achieve this first target. However even a reduction in temperature down to 20°C will significantly slow the breeding of this species down. Recent research has shown that on an ideal diet, the time taken for this species to complete its lifecycle is lengthened to 59 days at conditions of 20°C and 70% relative humidity (rh) (Fleming and Armitage, 2003). So even if the target date has been missed, any lowering of temperature will still widen the window of safety, and it should also be noted that the target is highly conservative in order to account for the worst-case scenario (i.e. very warm harvested or ex-drier grain at 30°C+). It must also be remembered that the cooling targets are rounded up for convenience and that this species cannot complete it's lifecycle below 17°C – not 15°C.

Meeting this initial target alone is a very robust measure in preventing insect infestation. This is because there is only a single storage species, the grain weevil (*Sitophilus granarius*) that can complete its lifecycle below 15°C, although once the grain is at this temperature the grain weevil takes around 6 months to develop from egg to adult. Again, this development time is well in excess of the target time set to drop the next 5 degree step down to 10°C, and the actual lower breeding threshold of 12°C for this species is also slightly higher than the target of 10°C.

Having therefore established that these targets have a degree of in-built conservatism, recent research suggests that these targets are perhaps even more robust than this. This is since some of the historic data that was used to establish these cooling targets 20 years ago, was based upon life-studies of insect development on "ideal" laboratory diets. Ideal/artificial diets are commonly used for experiments with species such as the saw-toothed grain beetle to accommodate that they cannot easily penetrate whole grain with their mouthparts, and require a percentage of broken kernels on which to feed. For this species, much of the work had been done using an ideal diet of wheat feed, rolled oats and yeast. Fleming and Armitage (2003), therefore recently compared the development of two UK strains of grain pest including the saw-toothed grain beetle, on artificial and whole wheat diets (homogenous samples prepared with a percentage of broken kernels in proportions representing practice). They concluded that current recommendations for passing a cooling front through grain for insect control can probably be extended by 2-3 weeks, based on this new data on a more representative diet.

Whilst it would therefore seem that a high degree of robustness is built in to the UK cooling strategy, it still matters that growers try to achieve the cooling targets as quickly as possible. Whilst achievement of the first two targets prevents infestation from developing in the bulk, there is always the risk that surviving adults can breed at the grain surface where fluctuating temperatures, and especially day-time highs, enable some pest development. Although grain cooled to 10°C should avoid pest problems since this is below breeding thresholds, the only guarantee to achieving pest free grain is to drop grain temperatures to the final target of 5°C, where storage insects enter a state of chill-coma where they cease feeding, causing them to dehydrate and die. Additionally once temperatures dip below 3°C, the more cold-hardy mites can no longer breed too, although growers should remember that drying to 14.5% mc should be the primary physical control measure for storage mites.

Although all of the twelve stores surveyed achieved the 10°C target, not all of the stores reached the final target, with only five cooling to 5°C. Whilst for storage of malting barley there is a compromise to be sought by not cooling below 10°C due to possible negative impacts on seed dormancy (Armitage and Woods, 1997), some of the stores appeared to choose not to pursue this final target for unknown reasons.

Although the missed targets did not compromise the pest management of the stores, the targets should have been achievable, given that they were based upon representative meteorological considerations in the studies of twenty years ago. This of course assumes that global warming has not reduced the cold air available and compromised efficacy. One of the aims of the project was therefore to test this hypothesis, although appreciating that it was beyond the scope of the project to provide quantitatively robust evidence, since a one-year study could only provide a snap shot, lacking the repeatability for correlation of trends across multiple years. However, looking back at figure 1, 2007 was one of the coolest autumn and winters of the 1990s' – 2000s' and despite this, the majority of stores in this study failed to meet their cooling targets. Although not definitive, this does at least provide some tentative evidence that climate change is making cooling more challenging but it must be recognised that some of the stores were self-limiting by not making best use of the available air in their timing of fan operation. For example (see appendix);-

- Oxfordshire, stopped cooling after early October.
- Lincolnshire did not run fans until late October as the differential was set too high (10°C).
- Leicestershire only cooled on two occasions in mid October.

The Dorset site was interesting in that it was running its pedestal fans on a differential and yet there were two periods corresponding to late October and mid December in which the bulk did not cool correspondingly with a drop in temperature under which the system should have operated. The Suffolk site also underperformed and failed to utilise the cold air that was available when temperatures dropped in late October.

4.2. Further research needs

So although far from conclusive, this study at least supports the need to further examine climate effects on grain cooling in more detail, which is one of the aims of a parallel LINK project in which the authors and HGCA are involved. This project; “Defining and managing risks to safety and quality during food and feed grain storage” (HGCA project RD-2005-3201; LK0985) aims to identify areas within the grain storage process where there is insufficient knowledge to properly assess and control risks. Research is being undertaken to meet the industry need for a scientifically validated guide to best practice based upon the HACCP principle. With grain cooling a key control measure, its future robustness in the face of climate change is being studied by adapting an existing model on grain ventilation and building in new parameters based on the most up-to-date climate change predictions. This model will simulate cooling in two UK locations with incorporation of new insect growth models.

4.3. Key messages – adaptation and reduced energy use

So despite the missed targets within this study, it can be concluded that growers should still be able to prevent infestation because of the in-built conservatism contained within those targets. However, ongoing research will examine future impacts of further global warming and will highlight any future risks.

Never the less, it is also apparent that there is much that growers can do to improve practice. It is vitally important that the timing of fan operation coincides with periods of cold weather. Whilst some growers judge this relatively well, the trials work within this project has shown the benefits of auto-control of fans using differential thermostats. Even though both storekeepers in the comparison trials reached their target temperatures close to that achieved by the differential setups, there were occasions when misjudged manual operation resulted in ventilation with warmer air, which heated the bulks. This should never occur with a properly configured and installed differential control system.

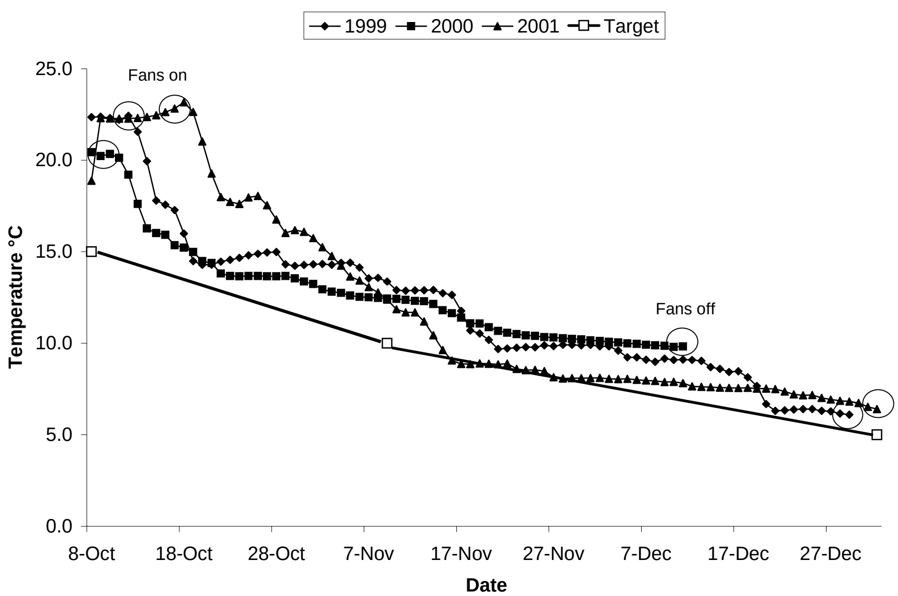
Although this project only represents a single years worth of data, cooling experiments at CSL's experimental grain store in North Yorkshire have shown that cooling can be achieved consistently close to cooling targets when using differential thermostats in recent years. This is illustrated by published data for the cooling of 20t bins at a rate of $10m^3/h/t$ during the warmer years (compared to 2007) of 1999-2001, reproduced in figure 9.

It is also apparent in conversation with growers that there is a myth around re-wetting the grain that needs to be dispelled. Some growers are reluctant to use automatic fan control for fear of ventilating during periods of high humidity or during rainfall. Whilst there is a risk of re-wetting the grain if cooling using a high-volume (180 $m^3/h/t$) drying setup, there is no risk when ventilating at low-volume rates (10 $m^3/h/t$) because;-

- The fan (when blowing) heats the intake air by 2-5°C and drops the relative humidity (rh) of the incoming air.
- As the cold air meets the warmer grain, it heats up and the rh drops further.

- Cold air only carries a fraction of the moisture of hot air, so the actual amount of water carried by the air is greatly reduced in the winter, despite it's "relative" value.

Taken together, there is insufficient water added even on the wettest day, to significantly raise the mc of the grain. In fact, the only risk of wetting the grain during low-volume ventilation occurs during early autumn and when the temperature difference between the silo/shed roof and the warm air exiting the bulk is greatest, causing condensation to drip onto the grain surface. However, best practice is to ensure that the headspace of the shed or silo is adequately ventilated either at the eaves or by installation of roof fans. It should also be noted that a dampening of the grain surface is inevitable during storage due to the absorption of moisture from the headspace (Armitage and Cook, 1999), and this should not be confused as the effect of ventilation.



<u>Figure 9. Mean cooling profiles for 20 tonne bins during 1999, 2000 and 2001 (n=6, n=6, n=4 respectively) controlled by 6 degC differential compared to UK cooling targets if aeration begins 1st October. (Source; Cook *et al*. 2004),</u>

Finally, and if for no other reason, there is great incentive for growers to consider these simple low cost controllers as there are considerable savings on fan operating costs. Within this project, it was demonstrated that a saving of 34-40% on fan running could be made, which at the electricity rate used during the farmer trial saved up to 21 pence per tonne. With the farming industry being challenged to reduce its carbon footprint, the reduction in energy use when using differential controllers means that these devices can be used to both adapt to, and to help mitigate against, climate change.

5. TECHNOLOGY TRANSFER

5.1. Storage and mycotoxin workshops - 2008

The results of the project fed directly into a series of 16 events, mainly targeted at growers, and held between January and March 2008 at locations around England. The events tied together topics on pesticide residues, mycotoxins, grain storage and grain sampling. The focus of the grain storage topic was cost effective grain cooling. The impact of climate change and the use of differential thermostats complimented well the other best practice messages for cooling that were promoted and both authors were involved in the workshops.

In terms of structure, the cooling topic was introduced through presentation on the fundamentals and benefits of cooling by aeration, different strategies and types of setup, leading to the impact of climate change and the results of this work. We aimed wherever possible at each event to select data from the cooling survey that was local to the venue, whilst showing all of the results from the differential control trials. In some instances, the survey data usefully enforced the best practice messages. For example in one case, the farm store had failed to reach its first target because fans were controlled by too large a temperature differential (10°C) that resulted in the system not running, in contrast to the recommended 2 – 6°C differential.

It was heartening that the majority of growers in the audience used some form of cooling, although only a minority appeared to employ any form of automated fan control. However judging by the growers’ responses during the events, many went away convinced that they should invest in differential controllers.

In summary, the events received very high satisfaction ratings: 100% thought the event was relevant to business needs and the Cooling presentation received a mean score of 8.48 (out of 10) from those who attended.

Event Dates and Locations

29th January – Exeter, Devon
30th January – Taunton, Somerset
5th February – Witham, Essex
6th February – Cambourne, Cambridgeshire
7th February – Ipswich, Suffolk
12th February – Tonbridge, Kent
13th February – Andover, Hampshire
14th February – Wallingford, Oxon
19th February – Collingtree, Northants
20th February – Coventry, Warwickshire
21st February – Linton, Cambridgeshire
26th February – York, Yorkshire
27th February – Beverley, East Yorkshire
28th February – Lincoln, Lincolnshire
4th March – Darlington, Co. Durham
5th March – Shrewsbury, Shropshire
No of venues: 16
Total no of delegates: 502

5.2. Other KT initiatives

In addition to the workshops, the outcomes of the project were the focus of the HGCA storage exhibit at the Cereals Event 2008. A poster on the project was also presented at the HGCA R&D conference in February 2008, supporting its climate change theme. Further KT initiatives are planned for October 2008, at the Farming Futures/HGCA on-farm climate change event and a seminar presentation at the Grain Event in November 2008. The project has been featured in numerous media articles.

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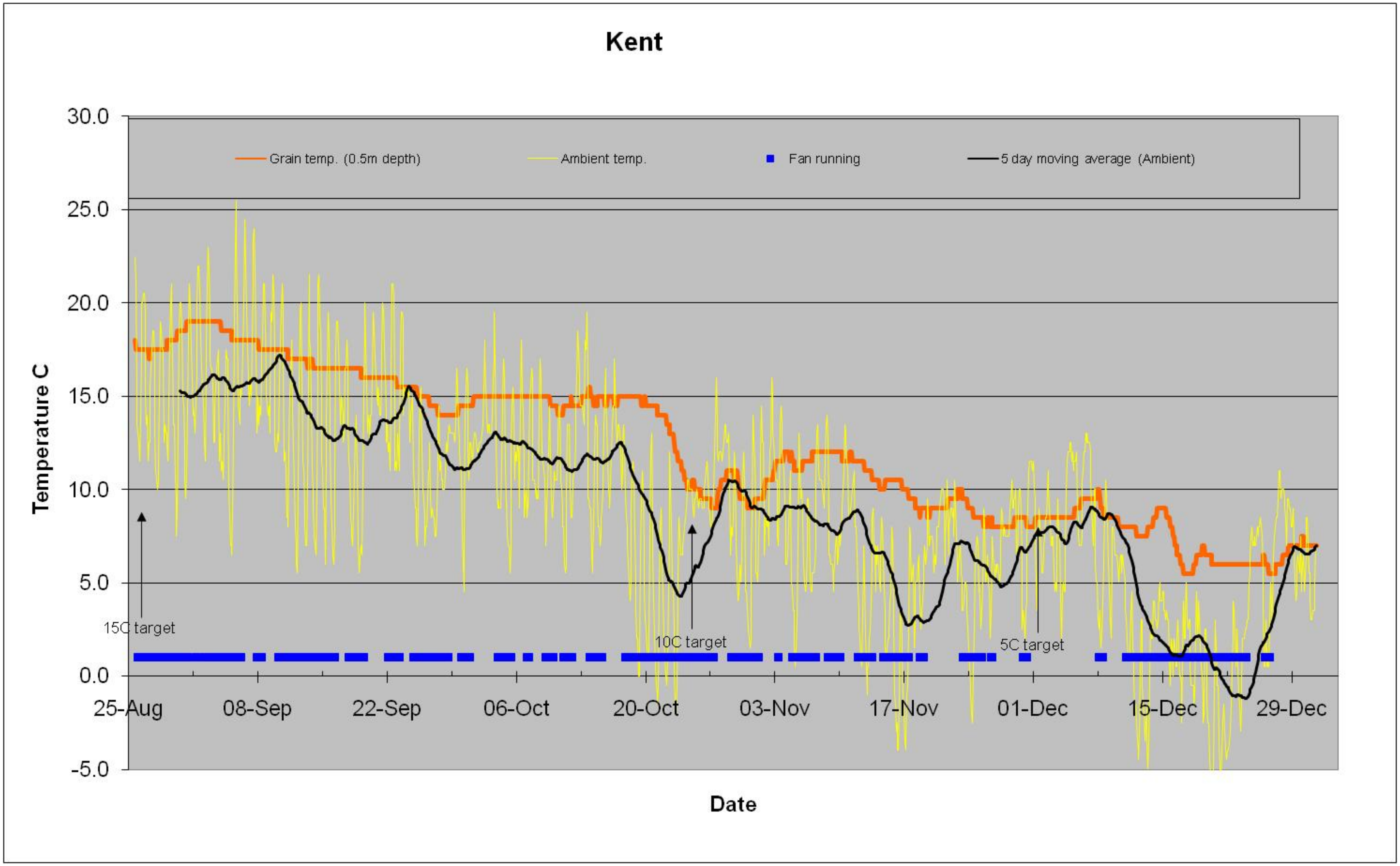
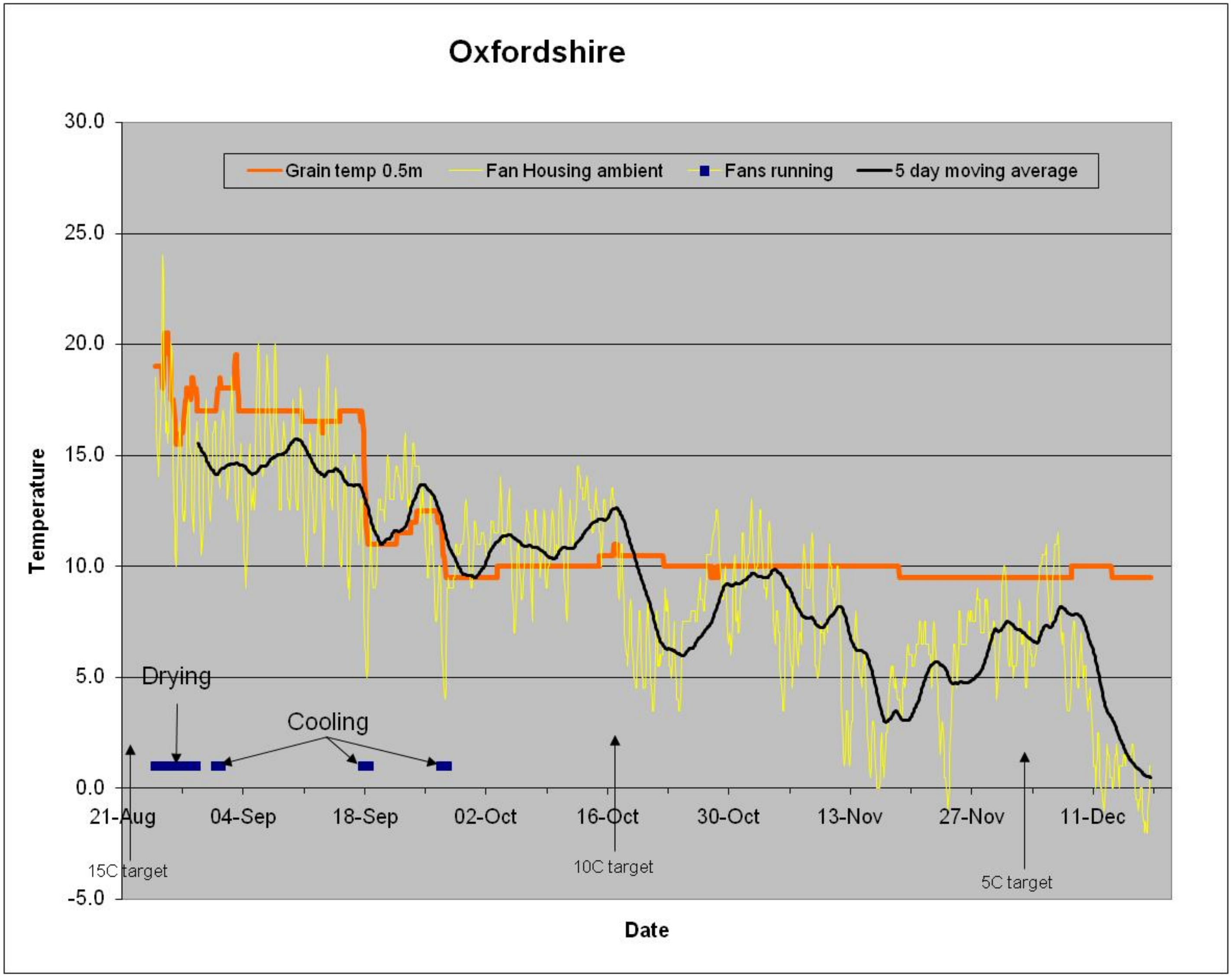
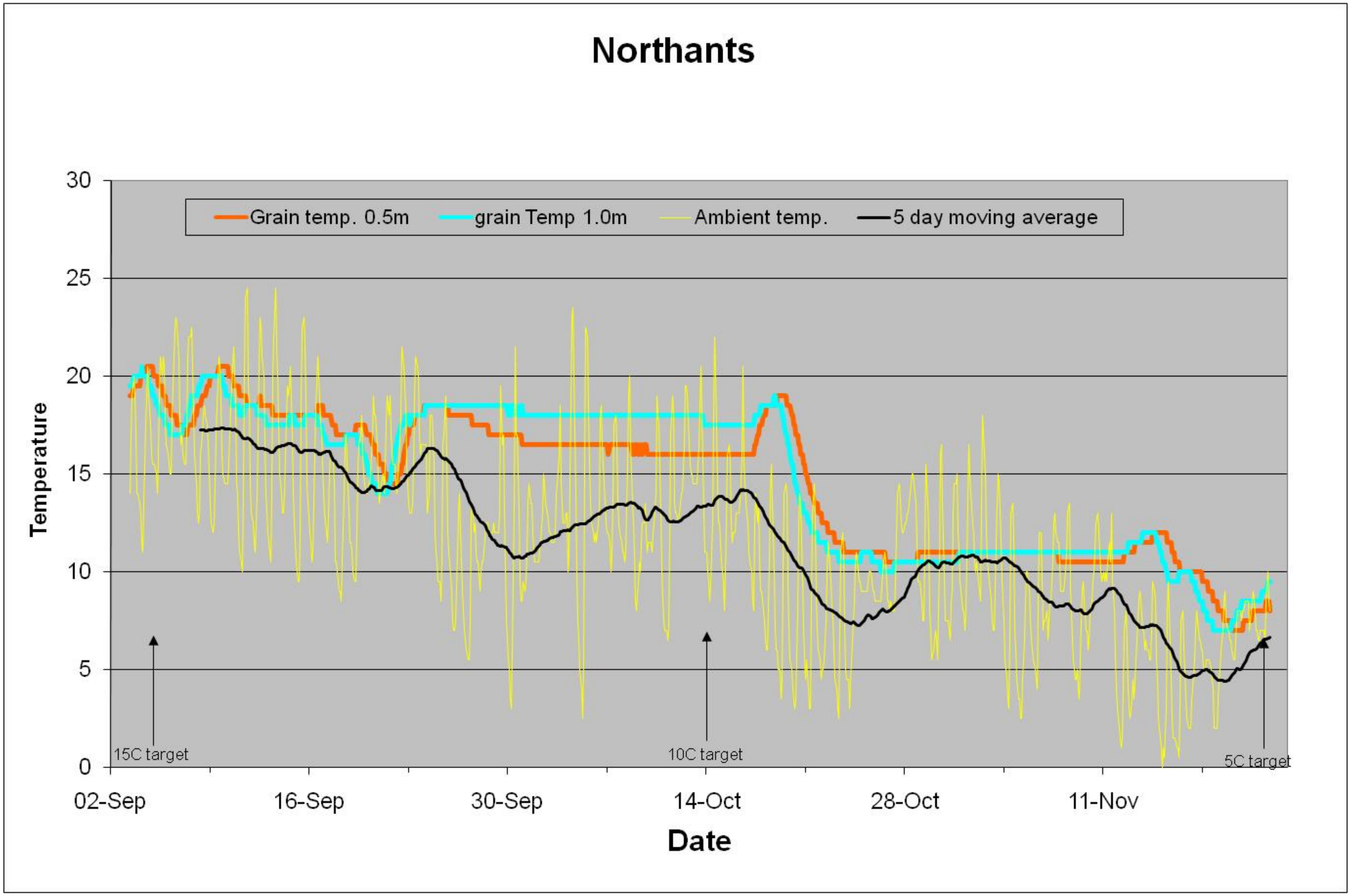
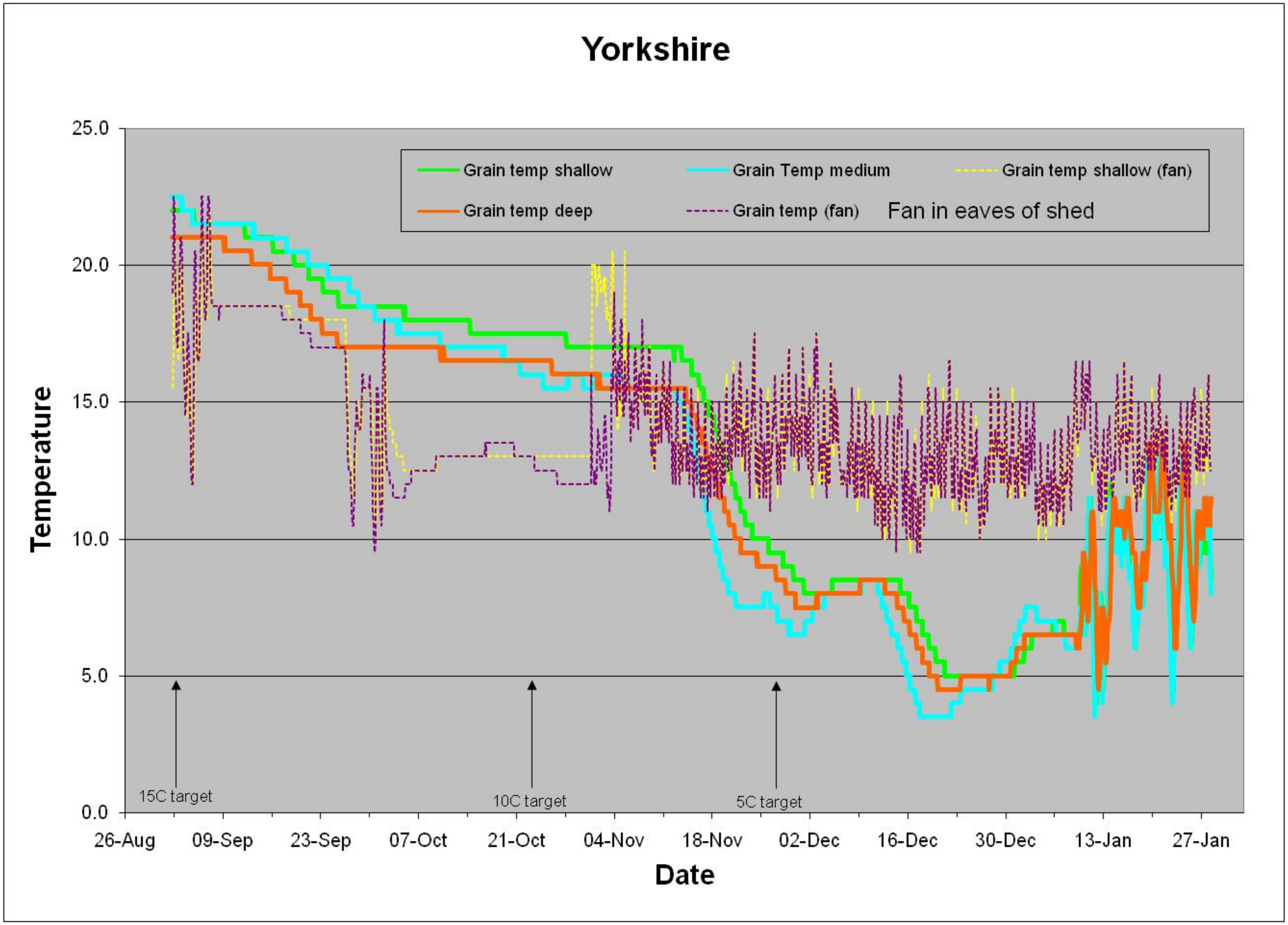
Appendix 1

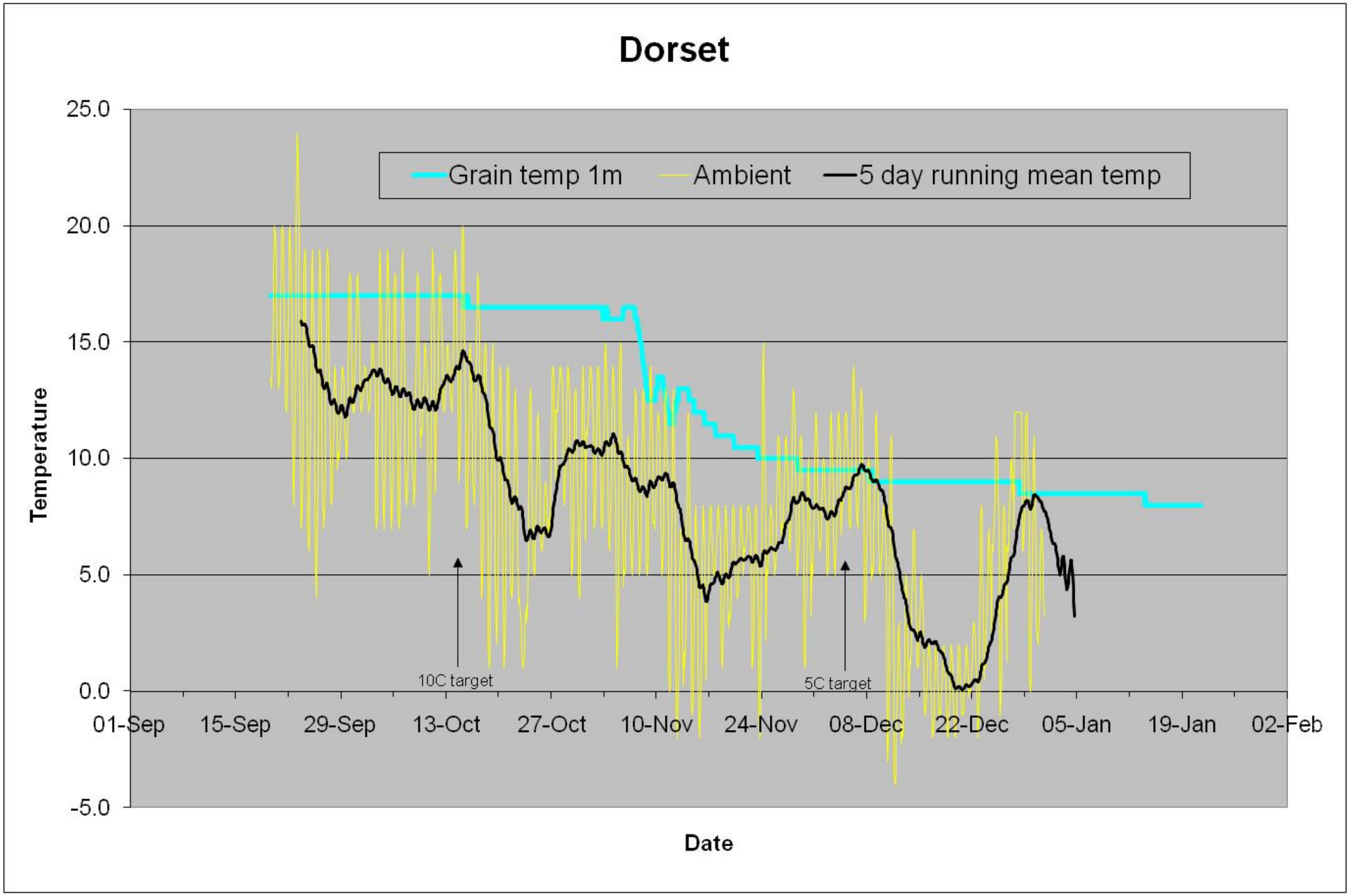


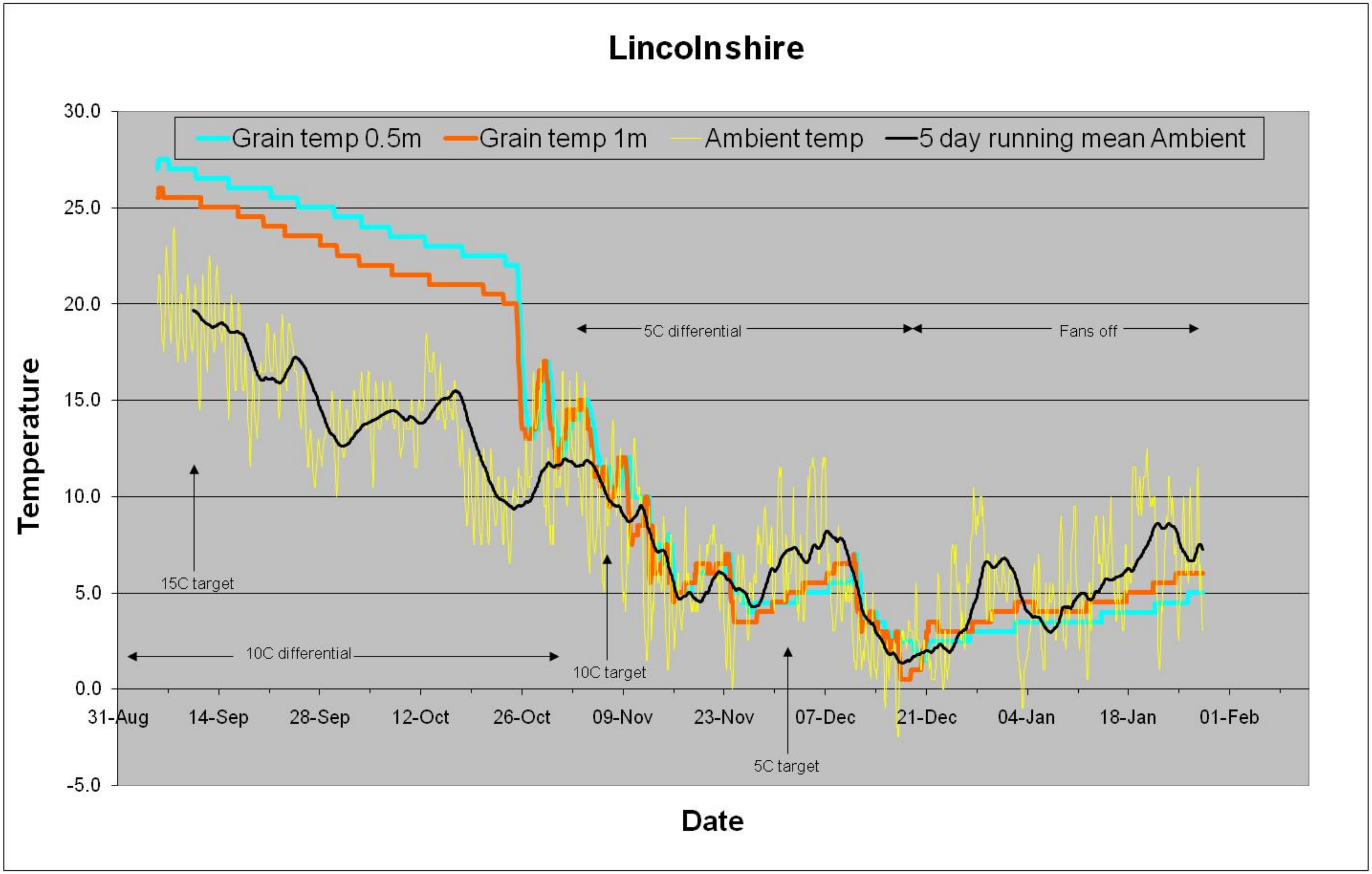
Kent
Grain temp. (0.5m depth)
Ambient temp.
Fan running
5 day moving average (Ambient)
Temperature C
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
15C target
10C target
5C target
25-Aug
08-Sep
22-Sep
06-Oct
20-Oct
03-Nov
17-Nov
01-Dec
15-Dec
29-Dec
Date


Oxfordshire
Grain temp 0.5m
Fan Housing ambient
Fans running
5 day moving average
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
Temperature
Drying
Cooling
21-Aug
04-Sep
18-Sep
02-Oct
16-Oct
30-Oct
13-Nov
27-Nov
11-Dec
15C target
10C target
5C target
Date

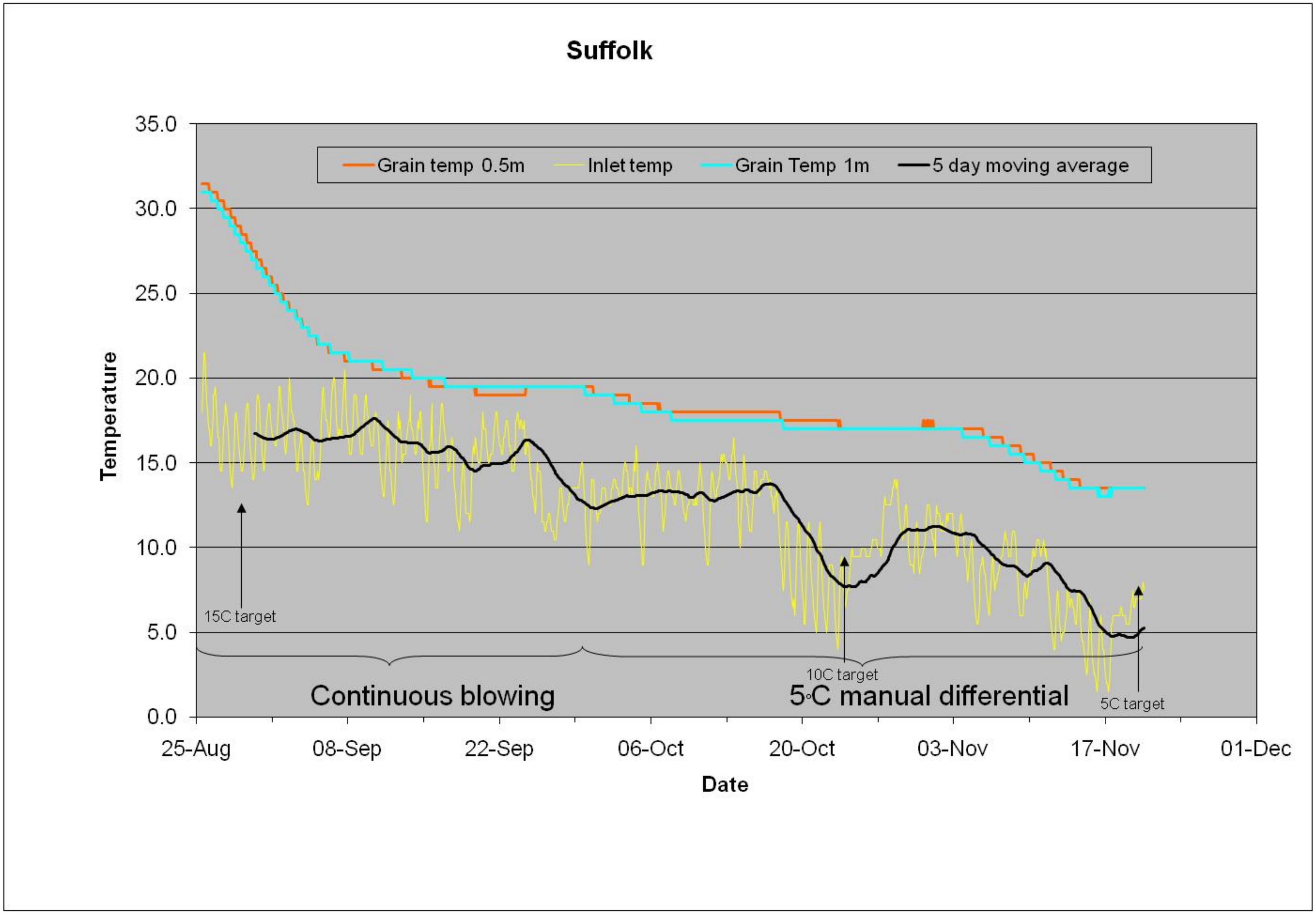

Northants
Grain temp. 0.5m
grain Temp 1.0m
Ambient temp.
5 day moving average
30
25
20
15
10
5
0
Temperature
15C target
10C target
5C target
02-Sep
16-Sep
30-Sep
14-Oct
28-Oct
11-Nov
Date

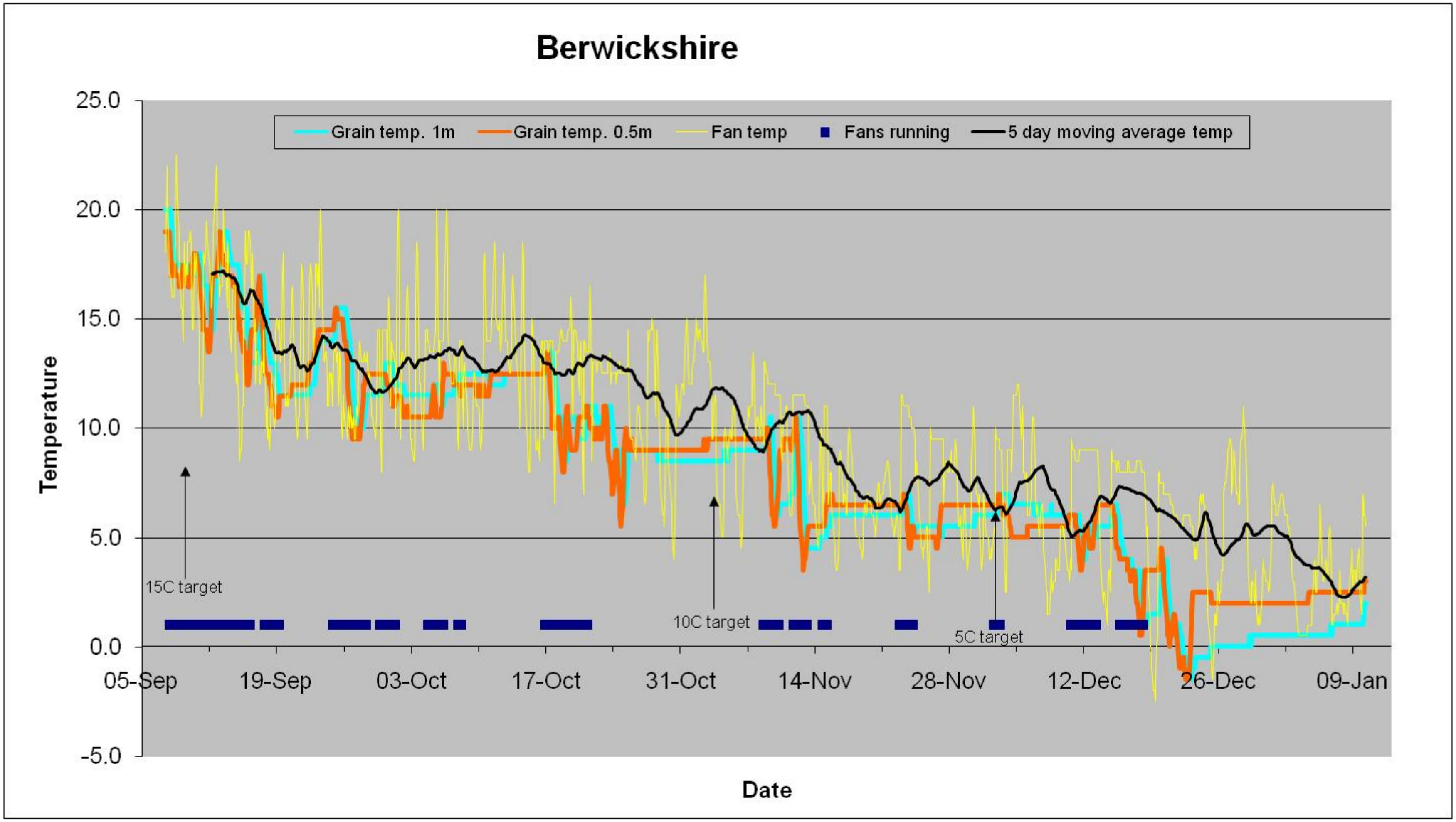

Yorkshire
Grain temp shallow
Grain Temp medium
Grain temp shallow (fan)
Grain temp deep
Grain temp (fan)
Fan in eaves of shed
25.0
20.0
15.0
10.0
5.0
0.0
Temperature
15C target
10C target
5C target
26-Aug
09-Sep
23-Sep
07-Oct
21-Oct
04-Nov
18-Nov
02-Dec
16-Dec
30-Dec
13-Jan
27-Jan
Date

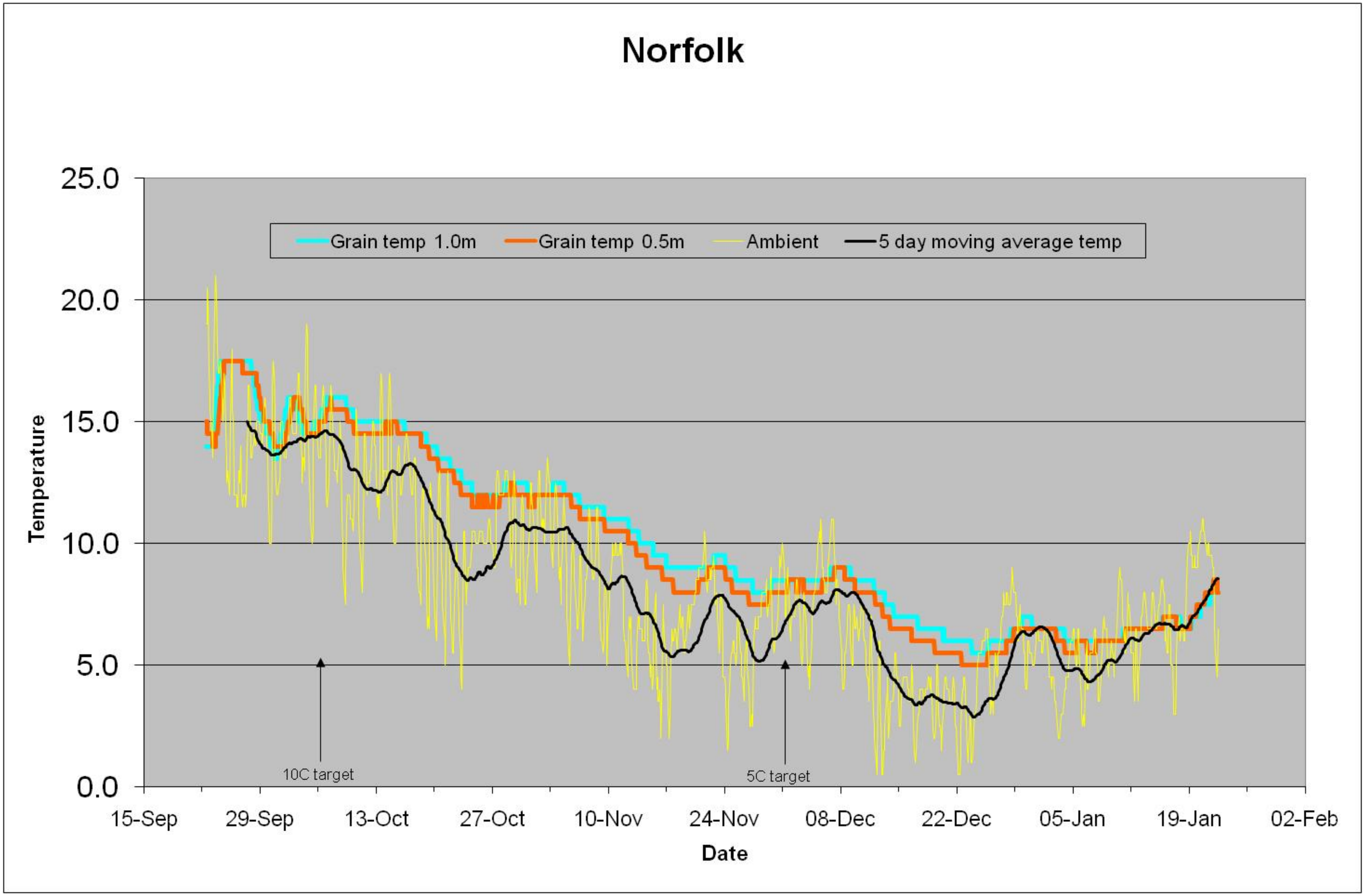

Dorset
Grain temp 1m
Ambient
5 day running mean temp
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
Temperature
10C target
5C target
01-Sep
15-Sep
29-Sep
13-Oct
27-Oct
10-Nov
24-Nov
08-Dec
22-Dec
05-Jan
19-Jan
02-Feb
Date



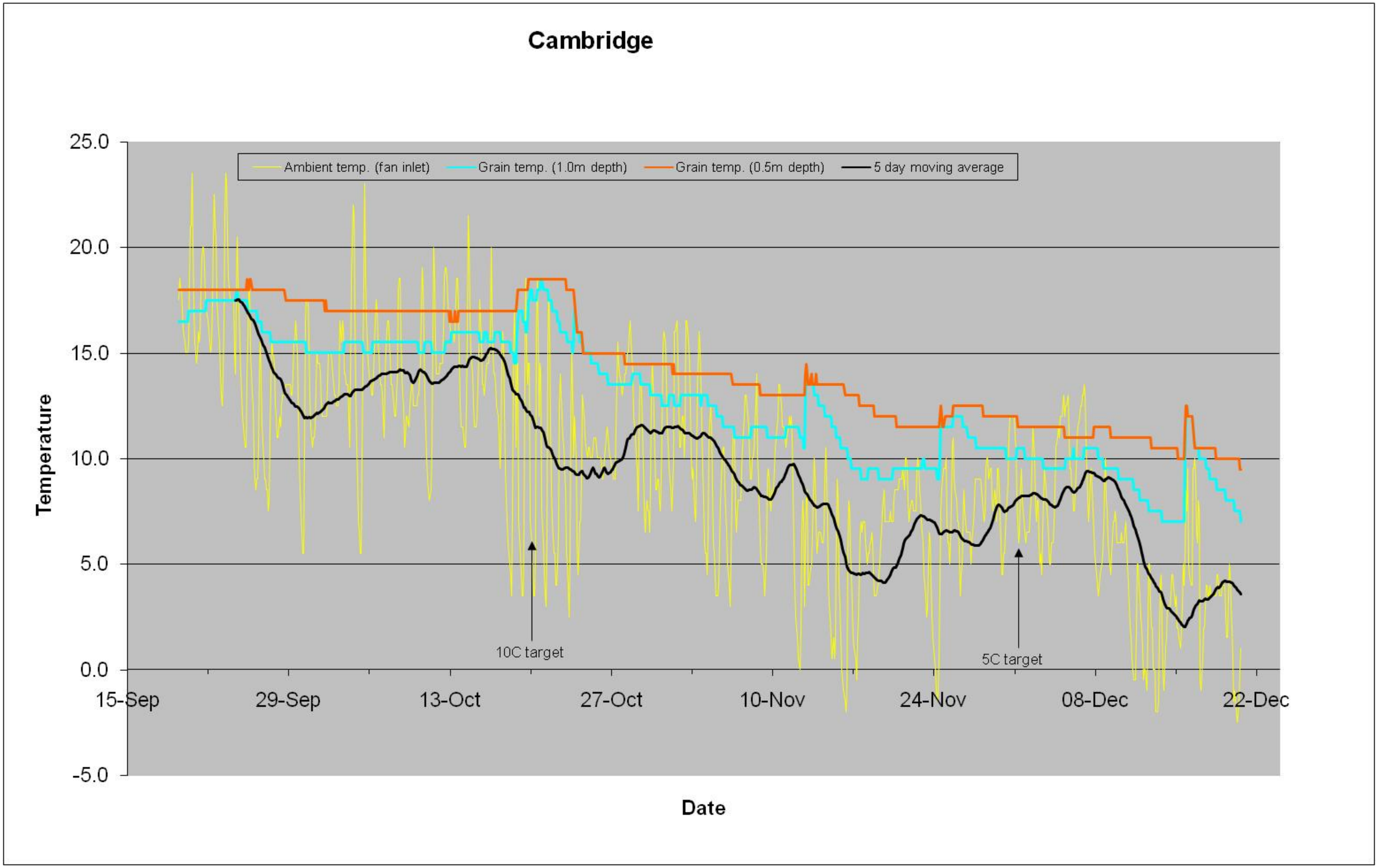
Lincolnshire
Grain temp 0.5m
Grain temp 1m
Ambient temp
5 day running mean Ambient
Temperature
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
31-Aug
14-Sep
28-Sep
12-Oct
26-Oct
09-Nov
23-Nov
07-Dec
21-Dec
04-Jan
18-Jan
01-Feb
Date
5C differential
Fans off
15C target
10C differential
10C target
5C target

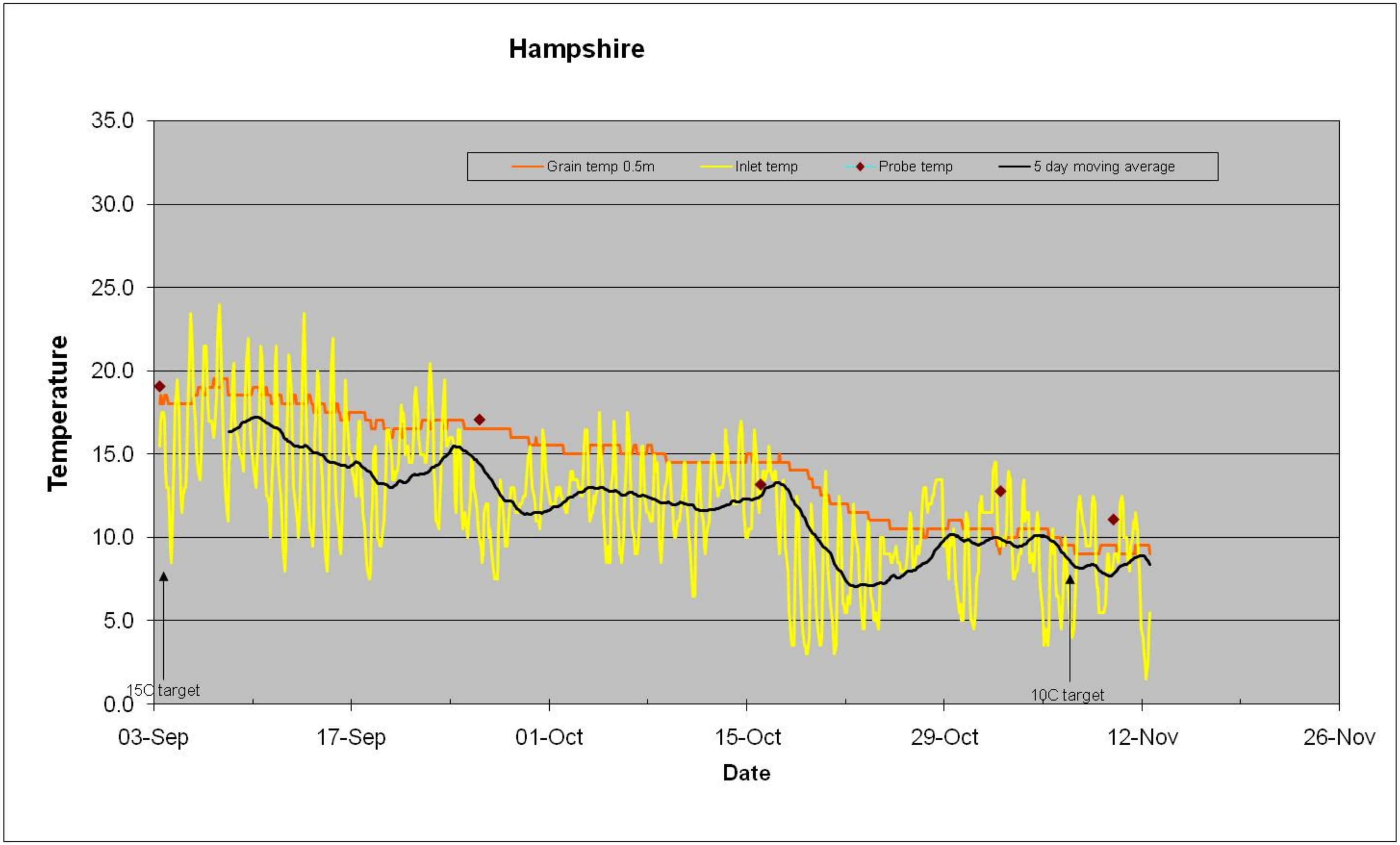

Suffolk
Grain temp 0.5m
Inlet temp
Grain Temp 1m
5 day moving average
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Temperature
15C target
10C target
5C target
Continuous blowing
5◦C manual differential
25-Aug
08-Sep
22-Sep
06-Oct
20-Oct
03-Nov
17-Nov
01-Dec
Date


Berwickshire
Grain temp. 1m
Grain temp. 0.5m
Fan temp
Fans running
5 day moving average temp
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
Temperature
15C target
10C target
5C target
05-Sep
19-Sep
03-Oct
17-Oct
31-Oct
14-Nov
28-Nov
12-Dec
26-Dec
09-Jan
Date

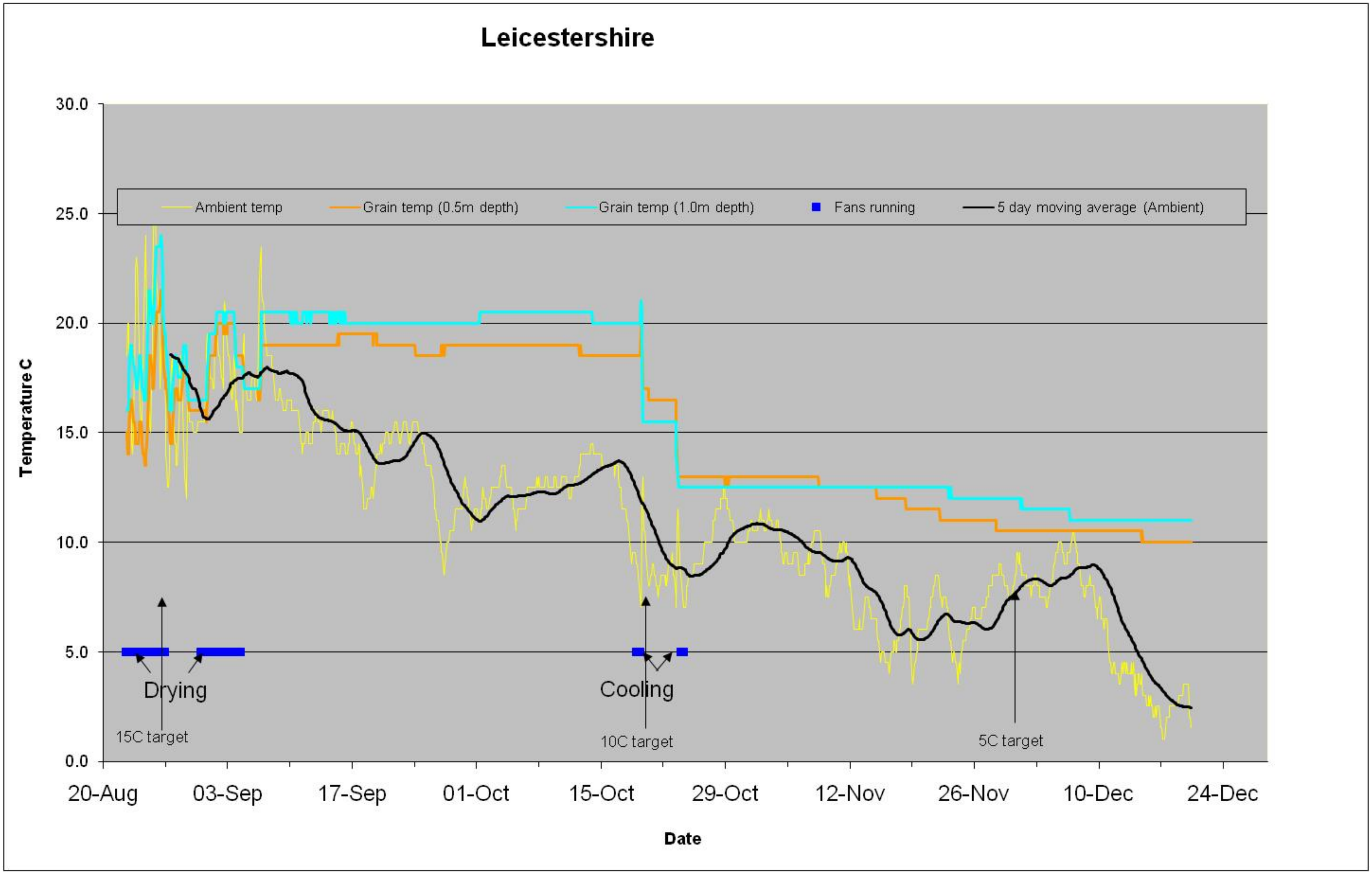


Norfolk
Grain temp 1.0m
Grain temp 0.5m
Ambient
5 day moving average temp
Temperature
25.0
20.0
15.0
10.0
5.0
0.0
10C target
5C target
15-Sep
29-Sep
13-Oct
27-Oct
10-Nov
24-Nov
08-Dec
22-Dec
05-Jan
19-Jan
02-Feb
Date


Cambridge
Ambient temp. (fan inlet)
Grain temp. (1.0m depth)
Grain temp. (0.5m depth)
5 day moving average
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
Temperature
10C target
5C target
15-Sep
29-Sep
13-Oct
27-Oct
10-Nov
24-Nov
08-Dec
22-Dec
Date



Hampshire
Grain temp 0.5m
Inlet temp
Probe temp
5 day moving average
Temperature
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
15C target
10C target
03-Sep
17-Sep
01-Oct
15-Oct
29-Oct
12-Nov
26-Nov
Date


Leicestershire
Ambient temp
Grain temp (0.5m depth)
Grain temp (1.0m depth)
Fans running
5 day moving average (Ambient)
Temperature C
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Drying
Cooling
15C target
10C target
5C target
20-Aug
03-Sep
17-Sep
01-Oct
15-Oct
29-Oct
12-Nov
26-Nov
10-Dec
24-Dec
Date