Store Managers’ Guide
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Introduction

This is the second edition of the Potato Council’s Store Managers’ Guide. It has been produced to offer a comprehensive overview of best practice in potato store management.

Management is key

Potato storage is a critical component of the potato production process, with some crops spending longer in storage than they do in the ground. It follows therefore that potatoes in stores should be afforded a similar level of management input as might be applied to a growing crop. The situation in stores is dynamic; the crop is respiring and reacting to its environment. Store operators must have the capability – in both expertise and environmental control equipment – to respond to this change to optimise conditions in the store and maintain quality throughout the storage period.

A critical time for potato storage

Much of the potato storage in Great Britain has suffered from a lengthy period without major capital investment. Many businesses now face critical decisions about the continued suitability of some older stores.

The first step on this decision-making path is the store assessment process (Section 1). This helps to identify any deficiencies or areas for improvement, evaluation of performance, prioritisation for operation and suitability for specific uses. Having the right equipment for the job is fundamental to success. Storage is not just about keeping potatoes; it is about maintaining their quality throughout the storage period so that it is possible to deliver consistently, in accordance with the market specification, at an economic and sustainable cost to earn a worthwhile return.

Changes to a trusted guide

In updating this guide, the same tried-and-tested format has been retained and emphasis has been placed on providing advice which is applicable to most storage installations. However, the opportunity has also been taken to highlight new developments and techniques which will be of interest to those looking to move their storage forward over the coming seasons.

Topics which feature prominently in the Potato Council’s research priorities include
• Disease management
• Chemical residue minimisation
• Cost control
• Energy efficiency and sustainability

Focused, issue-specific strategies have been introduced and are an increasingly important aspect of potato store management. These include
• The Safe Haven scheme for the prevention of notifiable diseases
• The Potato Industry CIPC Stewardship Action Plan to address all aspects of the use of the sprout suppressant. Please refer to www.potato.org.uk/cipc for the latest information.

Finding the information you need

The guide is written in a modular format, with cross-referencing, so you can move between the sections which are relevant to your storage. Best practice guidance is based around information from a range of sources, summarised in the bibliography (Appendix 1).

Much of the information is derived from levy-funded research and development, but is also supported by some from government, industry or the private sector. If you need further assistance in the interpretation of the guide, please contact the Storage Advice Line on 0800 02 82 111 or e-mail sbcsr@potato.ahdb.org.uk.
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Store self-assessment

For each store feature in the table, consider the factors listed and ring the description on each line which best summarises your own store. Use the assessment to identify those areas where improvements can be made (any scoring 1 as a minimum) and consult the appropriate section for further information. Some problems may be easy to solve and will quickly produce significant benefits; others may need longer-term planning to rectify.

<table>
<thead>
<tr>
<th>STORE FEATURE</th>
<th>POOR PRACTICE</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>BEST PRACTICE</th>
<th>4</th>
<th>REFER TO SECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYGIENE</td>
<td>HIGH RISK OF CONTAMINATION</td>
<td>No cleaning</td>
<td>Cleaned annually</td>
<td>Vacuum + wash</td>
<td>VERY LOW DISEASE RISK</td>
<td>Store cleaned daily + disinfectant applied</td>
<td>Store hygiene</td>
</tr>
<tr>
<td>Cleaning frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main method used where?</td>
<td>Sweeping</td>
<td>Floor and walls</td>
<td>+ wash boxes &amp; main surfaces</td>
<td>+ fog applied to entire store</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VERMIN CONTROL</td>
<td>No specific measures</td>
<td>Control measures in place within store</td>
<td>Accredited professional pest control for farm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>LEAKY, PRONE TO CONDENSATION</td>
<td>Lot of light enters</td>
<td>Some light enters</td>
<td>Odd pinpricks of light</td>
<td>SEALED, CONTROLLABLE</td>
<td>Completely dark</td>
<td>Storage buildings &amp; condensation on the crop</td>
</tr>
<tr>
<td>Store fabric</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Door(s)</td>
<td>2 or more, gaps all round</td>
<td>Door(s) sealed with brushes or rubber</td>
<td>One external door only, sealed all round</td>
<td>No external doors: load via grading area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure</td>
<td>No shelter</td>
<td>Sheltered from prevailing wind</td>
<td>Sheltered all round</td>
<td>Single door exits to grading area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INSULATION</td>
<td>NO INSULATION</td>
<td>Single skin roof</td>
<td>Double skin + glassfibre roof</td>
<td>&lt;75mm EEP/sprayfoam</td>
<td>HIGH LEVEL INSULATION</td>
<td>75mm + foam/EEP insulation</td>
<td>Storage buildings</td>
</tr>
<tr>
<td>Roof</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall</td>
<td>Brick, block, stone walls</td>
<td>Lightweight cavity walls</td>
<td>Composite panel + &gt;50mm foam/EEP</td>
<td>As column 3 but &gt;75mm</td>
<td></td>
<td></td>
<td>Storage buildings</td>
</tr>
</tbody>
</table>
- Ring the descriptions which most closely describe your store
- Consider the factors and risks this self-assessment identifies
- Decide on any action needed
- Refer to the appropriate section of the guide or seek further specialist advice

<table>
<thead>
<tr>
<th>STORE FEATURE</th>
<th>POOR PRACTICE</th>
<th>2</th>
<th>3</th>
<th>BEST PRACTICE</th>
<th>REFER TO SECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>VENTILATION</td>
<td><strong>HIGH RISK OF CONTAMINATION</strong>&lt;br&gt;No fan: open door only</td>
<td>Fans &lt;0.02m³/s/t</td>
<td></td>
<td><strong>POSITIVE &amp; FAST DRYING</strong>&lt;br&gt;Fans ≥0.02m³/s/t</td>
<td>Ventilation</td>
</tr>
<tr>
<td>Bulk store system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Box store system</td>
<td>No fan: open door only</td>
<td>Fans &lt;0.02m³/s/t</td>
<td>Space ventilation &amp; fans ≥0.02m³/s/t</td>
<td>Positive ventilation &amp; fans ≥0.04m³/s/t</td>
<td></td>
</tr>
<tr>
<td>Box store: air distribution</td>
<td>Around boxes: no single “air roll” established</td>
<td>Space ventilation forms roll of air, part via box apertures</td>
<td>As column 2 + roof fans or positive ventilation with traditional boxes</td>
<td>Positive ventilation using purpose designed boxes</td>
<td></td>
</tr>
<tr>
<td>Recirculation</td>
<td>None</td>
<td>Some air movement but no air roll</td>
<td>Intermittent&lt;br&gt;&lt;0.02m³/s/t&lt;br&gt;Low rate, part store</td>
<td>Intermittent&lt;br&gt;≥0.02m³/s/t&lt;br&gt;Low rate continuous</td>
<td></td>
</tr>
<tr>
<td>FAN SYSTEMS</td>
<td><strong>UNCONTROLLED: RISK TO CROP</strong>&lt;br&gt;Centrifugal fan</td>
<td>Axial (propeller style)</td>
<td>Automated axial fans</td>
<td><strong>FULL CONTROL OF COOLING</strong>&lt;br&gt;Axial fans for positive ventilation&lt;br&gt;Soft start, high-efficiency, low noise fans</td>
<td></td>
</tr>
<tr>
<td>Fan type</td>
<td>Centrifugal fan</td>
<td>Axial (propeller style)</td>
<td>Automated axial fans</td>
<td>Axial fans for positive ventilation&lt;br&gt;Soft start, high-efficiency, low noise fans</td>
<td>Ventilation</td>
</tr>
<tr>
<td>Fan efficiency</td>
<td>Old, aged fan with big starting load</td>
<td>Modern fan(s) with power-factor correction</td>
<td>High-efficiency fans for low running cost</td>
<td>Automated variable speed control of fans</td>
<td></td>
</tr>
<tr>
<td>Ventilation control</td>
<td>On/off switching</td>
<td>Automatic switching of single/multiple fans</td>
<td>Manual speed control of automatic single/multiple fans</td>
<td>Auto + air mixing &amp; dew-point control</td>
<td></td>
</tr>
<tr>
<td>Mixing</td>
<td>Manual</td>
<td>Auto: no air mixing</td>
<td>Auto + air mixing</td>
<td>Inlet temperature control</td>
<td></td>
</tr>
<tr>
<td>Inlet air protection</td>
<td>No frost thermostat</td>
<td>Thermostat to cut fan off in event of frost</td>
<td>Inlet temperature control</td>
<td>Inlet temperature + condensation control</td>
<td></td>
</tr>
</tbody>
</table>
## Store self-assessment

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<th>BEST PRACTICE</th>
<th>REFER TO SECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOX STACKING</td>
<td>RESTRICTED AIRFLOW, RISK OF CONDENSATION</td>
<td>OPTIMAL AIRFLOW, LOW RISK OF CONDENSATION</td>
<td>Loading the store</td>
</tr>
<tr>
<td>Space ventilated stores</td>
<td>Boxes stacked randomly</td>
<td>Gaps &gt;150mm between rows</td>
<td>Gaps &lt;150mm and supplementary fans to target ‘dead spots’</td>
</tr>
<tr>
<td>Cross-stacked boxes (i.e. at 90° to main block)</td>
<td>Boxes stacked across pallet slots of main block</td>
<td>Slatted boxes less restrictive to airflow when cross-stacked if only 2 wide</td>
<td>Boxes stacked at 90° to airflow with 50mm gaps between alternate boxes within rows</td>
</tr>
<tr>
<td>Box height</td>
<td>Inconsistent stacking height throughout store</td>
<td>All boxes at same height</td>
<td>All boxes at same height; roof space ventilated/heated</td>
</tr>
<tr>
<td>REFRIGERATION</td>
<td>DEHYDRATION RISK</td>
<td>FRIDGE SIZE OPTIMAL</td>
<td>Refrigeration</td>
</tr>
<tr>
<td>Fridge system size &amp; performance</td>
<td>Small fridge coil with air-on/air-off temp. difference &gt;3.5°C</td>
<td>Air-on/air-off temperature difference ~2.5°C</td>
<td></td>
</tr>
<tr>
<td>Space ventilation cooling rate</td>
<td>Long running times: no effective cooling</td>
<td>Cools at &gt;0.5°C/day</td>
<td>Cools at ~0.5°C/day</td>
</tr>
<tr>
<td>Positive ventilation cooling rate</td>
<td>As above</td>
<td>Cools at &gt;1°C/day (Manage condensation risk 📌11)</td>
<td>Cools at ~1°C/day</td>
</tr>
<tr>
<td>STORE FEATURE</td>
<td>POOR PRACTICE</td>
<td>BEST PRACTICE</td>
<td>REFER TO SECTION</td>
</tr>
<tr>
<td>--------------------------</td>
<td>--------------</td>
<td>---------------</td>
<td>------------------</td>
</tr>
<tr>
<td><strong>LACK OF CONTROL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature sensors</td>
<td>No sensors in store</td>
<td>In air only; crop condition unknown</td>
<td>1 sensor per 100 tonnes</td>
</tr>
<tr>
<td>Bulk stack sensor placement</td>
<td>As above</td>
<td>Top surface only - prone to influence by air above</td>
<td>As column 3 but also 300mm down to anticipate condensation</td>
</tr>
<tr>
<td>Condensation control</td>
<td>As above</td>
<td>Control of temperature differentials</td>
<td>Skin resistance sensing to measure any wetting</td>
</tr>
<tr>
<td>Stock control</td>
<td>Chemical records only; legal minimum</td>
<td>Chemical use plus stock location in store recorded</td>
<td>Box records include location - feedback on storage problems</td>
</tr>
<tr>
<td>Store recording</td>
<td>As above</td>
<td>Occasional manual recording of store temperatures</td>
<td>Automatic logging of store temperatures and fan running times</td>
</tr>
<tr>
<td><strong>FULL CAPABILITY</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loading the store &amp; Store monitoring and quality assurance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>POOR PRACTICE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QC SAMPLING</td>
<td>Single point sampling</td>
<td>Multi-point sampling on one level</td>
<td>Storage for markets</td>
</tr>
<tr>
<td>SEED GRADING</td>
<td>In store</td>
<td>Next door but no airlock</td>
<td>Condensation on the crop</td>
</tr>
<tr>
<td>CONDENSATION RISK</td>
<td></td>
<td>Next door with strip curtain</td>
<td>STORE ISOLATED</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Storage buildings

A well sealed and insulated potato store (Figure 2.1) will:

- Allow the crop to be kept at a stable temperature, largely unaffected by diurnal variation and ambient conditions
- Help maintain a relative humidity of 90-100% to minimise tuber weight loss
- Allow crops to be stored, free from condensation, in changeable weather conditions

**Controlled ventilation**

Controlled ventilation allows crop respiration heat to be removed and the crop to be dried and cooled. Fans are positioned to create a flow of air through the crop (positive ventilation, bulk or box) or to form a rolling mass of air that will flow over the stack of boxes and through their pallet slots (space ventilation).

Cooling can be achieved using ambient air and/or mechanical cooling (refrigeration). Internal recirculation of air (without cooling) can be used to eliminate temperature variation or to distribute chemicals for sprout suppression or disease control.

Air flow should be as uniform as possible throughout the store, to give even drying and stable crop temperatures. A well designed store will have been balanced to achieve uniformity of airflow at its typical operating condition. This might include features such as tapered air ducts or graduated lateral outlets to deliver similar quantities of air across the whole store.

Fabric or door leakage to wind-induced ventilation reduces the benefits of the store as it is likely to lead to loss of environmental control, crop weight loss and possible condensation on the crop. Ventilation or refrigeration run-time will increase, to cool the crop, warmed by the leaking air.

**Containment**

The capital cost of a bulk store, with load-bearing, insulated retaining walls, is higher than for a box store. But when the capital cost of boxes is added, bulk storage is cheaper overall. Box stores ease separation for different stocks, and provide more flexibility for crop movement and marketing. Deep bulk piles can lead to pressure bruising problems if the crop is stored over 4.0m high or if excessively ventilated by non-humidified air. Box storage is normally free from pressure bruising and, depending on their quality, boxes can be stacked up to 8 high.

**Insulation**

The quality of the insulation will determine to a large extent how well a potato store performs. Insulation is a key factor for a potato store, much more so than it is for general purpose buildings.

Maintaining temperatures above freezing point is seldom a problem given the quantity of heat produced in a large store. However, any heat that leaks into a store has to be removed by expending energy, either in the form of ventilation or refrigeration. In addition to the implications on cost, the avoidable operation of environmental control

*Figure 2.1 A well sealed and insulated potato store*
equipment will always increase water loss from the crop. It is therefore just as beneficial to use insulation to limit any heat ingress into the store as it is to minimise the effects of cold weather. A light-coloured, reflective, external surface will reduce unwanted solar radiation gains.

Nearly all insulation materials have their performance reduced significantly by very small increases in their moisture content. The use of vapour barriers to protect insulation is only effective in the high humidity conditions found in potato stores where composite metal/polyisocyanurate (PIR) sandwich panels are used. These are commonplace nowadays for newly built stores. Other systems for upgrades offer, at best, little more than a vapour check. This tends to limit the choice of insulation to either spray or board polyurethane or, alternatively, expanded, extruded polystyrene board.

Specialist advice should be sought for all aspects of storage building design.

ACTION POINTS

STORAGE BUILDINGS

Store assessment
• Undertake a detailed assessment of your store as described in section 1.

Balanced ventilation
• The ventilation system in a store should be in balance. This means that, for optimal performance, design features are required – eg tapered ducts – to offset the effects of pressure drop in the ventilation system.

Doors and louvres
• Doors and louvres are the weak points of the insulation ‘envelope’. Make sure they close properly and stay closed. Regular, positive actuation from a controller is beneficial for keeping ambient louvers, which are subject to wind pressure, closed.

Insulation
• Ensure store insulation is in good condition and effective.
• Watch for signs of condensation within the structure that will degrade the insulation value, eg delaminated insulation boards where moisture has got in behind the panels.
• Ensure any new build, with composite construction, uses PIR panels which are resistant to spread of flame in the core in the event of fire.
Respiration
Potato tubers are living organisms and, in store, continue to respire and respond to their environment. They do so by using sugars, from starch, in respiration. This process consumes oxygen and releases carbon dioxide and some heat energy which impact on storage systems.

Respiration is highest at harvest and falls rapidly to a basal level in the first weeks of storage (Figure 3.1). Respiration is greater in early Lifted immature crops than in late-Lifted, mature crops.

Basal respiration rate depends predominantly on storage temperature (Figure 3.2). Minimum respiration rate is achieved at around 5°C, with the rate increasing above or below this temperature.

Handling, mechanical damage, exposure to ethylene and sprouting will lead to an increase in respiration rate.

![Figure 3.1 Respiration after lifting – early harvest](image)

![Figure 3.2 Respiration in relation to storage temperature](image)

Evaporation
Although some moisture is lost in the process of respiration, most is lost by simple evaporation from the tuber surface. Effective wound-healing and sprout control is important in limiting moisture loss from tubers.

All other things being equal, moisture loss is a function of store humidity and airflow rate. Potato stores will usually settle to approximately 98% relative humidity and, in the absence of a humidification system, this will be derived by evaporation of moisture from tubers. Inappropriately specified refrigeration units can exacerbate moisture loss.

![Figure 3.3 Moisture exchange between tuber skin and surrounding air in balance at 98% relative humidity](image)

Dormancy
Freshly harvested tubers usually do not sprout even when conditions are optimal for sprout growth. The period over which sprout growth is inhibited by tuber physiology, rather than environmental reasons, is termed the dormant period or simply ‘dormancy’.

Large differences in dormancy occur between varieties. Warm storage temperatures have a dormancy-breaking effect. Selection of varieties by dormancy characteristics can be useful for minimising sprout-suppressant inputs.

Dormancy break is taken as the point where 50% of tubers have sprouts of 3mm or more in length. Warm dry summers tend to reduce dormancy (in extreme cases leading to sprout growth in the field before harvest), while cool growing conditions will generally prolong it. Waterlogging has a dormancy-breaking effect.

Wound healing (curing)
Where tubers have been subjected to wounding (e.g. by handling during harvest), the tuber will attempt to heal the wound – a process involving suberisation and cell division. The speed of this process, which is important for preventing moisture loss and disease ingress, is affected by a number of factors. These include storage temperature and humidity, with warmer temperatures and higher humidity reducing the time required for wound healing.

Although effective wound-healing is important, conditions that are optimal for curing may also be suitable for disease development. Where crops are harvested early, under good conditions or where storage duration is limited, sufficient curing may occur during the period over which crop temperature is reduced to the holding value.
This is accomplished simply by increasing storage temperature. However, reconditioning leads to variability in fry colour and is therefore not recommended as a routine storage practice.

Preconditioning may also be used to maintain processing quality. Here there are no distinct curing/pull-down/holding periods and fry colour or sugar content is used to determine crop storage temperature. Temperature reduction, to a target holding value, only occurs providing good processing quality is maintained.

**Greening and glycoalkaloids**

Tubers exposed to light will turn green, which results from the synthesis of chlorophyll. Chlorophyll is itself harmless but green tubers are generally rejected because they have elevated levels of glycoalkaloids, a group of natural toxicants present in potatoes.

To prevent greening in storage, exposure to light should therefore be minimised, although the need to see the crop clearly and health and safety requirements will override this during loading and subsequent short periods when stores are accessed to be inspected or sampled.

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**Sugars and conditioning**

Potatoes contain three main sugars: glucose and fructose (monosaccharides), and sucrose (a disaccharide). All three sugars are sweet and are important flavour components in ware potatoes. In potatoes for processing, the store manager is primarily interested in the monosaccharides. During processing these react with other components to produce the browning which is assessed by markets as fry colour. A store manager supplying crop for processing may also be interested in sucrose content. Although sucrose does not take part in browning reactions, trends in sucrose levels may be used to help ensure low reducing sugars, and light fry colour, during storage.

Variety, growth stage and storage temperature are important in determining tuber sugar content. Potatoes exhibit low temperature-sweetening, where sugars accumulate within the tuber, as temperature is reduced. During storage for processing, temperature should therefore be maintained at the lowest level that safely maintains acceptable fry colour.

For processing crops, changes in sugar content (and hence fry colour) can be achieved using reconditioning.

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**ACTION POINTS**

**CROP PHYSIOLOGY**

**Respiration**

The greater the respiration rate of the potatoes, the more likely it is that warm air will condense on cooler surface potatoes.

- Positively ventilate potatoes to remove respiration heat, to prevent surface condensation.
- Use high ventilation rates to prevent condensation in heavily respiring early-lifted or immature crops.

**Evaporation**

Moisture loss from potatoes due to evaporation will occur if the relative humidity (RH) of the air surrounding the potatoes is less than 98%.

- Keep store well-sealed to minimise weight loss.
- Prevent uncontrolled external air ingress, as this usually has a lower RH than the storage environment.

**Sugars**

Sugars increase, and fry colours will darken, if potatoes are stored at cold temperatures.

- Store crops for processing at c7-10°C.
- Monitor cold-stored pre-pack potatoes for effects of sugar increase on taste.
- If unsure, check storage requirements with your customer.
Control of storage diseases

Disease control is a fundamental component of storage management. Most diseases do not originate in store; they come from two primary sources: the seed or the soil. However, many of the disease problems affecting the premium markets can develop to some degree in store and, if not controlled, the consequences can be catastrophic, either in terms of physical breakdown of the crop or in loss of market value. Whether disease will develop in store or not (Figure 4.1) depends on:

- The amount of inoculum, usually spores or bacteria, present on the tubers
- Whether moisture, nutrients and temperature are suitable for the disease to grow
- The natural resistance of the tuber to the disease organism

<table>
<thead>
<tr>
<th>moderate infection</th>
<th>Silver scurf</th>
<th>Black dot</th>
<th>Skin spot</th>
<th>Dry rot</th>
<th>Gangrene</th>
<th>Soft rot</th>
</tr>
</thead>
<tbody>
<tr>
<td>severe infection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### PRE-STORAGE CONTROL MEASURES

| Healthy seed | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Wide rotations | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Short growing seasons | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Early harvest | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Resistant variety | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Minimise damage | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Dry harvest conditions | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

### MEASURES FOR CONTROL IN STORAGE

| Curing | ✓ | ✓ | ✓ | ✓ |
| Immediate pull-down | ✓ | ✓ | ✓ | ✓ |
| Rapid pull-down | ✓ | ✓ | ✓ | ✓ |
| Low temperature (holding) | ✓ | ✓ | ✓ | ✓ |
| Minimise grading damage | ✓ | ✓ | ✓ | ✓ |
| Store hygiene | ✓ | ✓ | ✓ | ✓ |
| Box & grader hygiene | ✓ | ✓ | ✓ | ✓ |
Store management allows us to influence this relationship, particularly in relation to the micro-climate around the tuber to control diseases during storage.

**Notifiable diseases**

Some diseases are not indigenous in Britain and their establishment would affect the long-term viability of the potato industry. If symptoms of either brown rot or ring rot are suspected then immediate contact with local DEFRA offices or Plant Health and Seed inspectorate is necessary. Visit www.defra.gov.uk/planth/ph.htm, email planthealth, info@defra.gsi.gov.uk or telephone 01904 455174 to report suspected cases in England and Wales. In Scotland, visit www.sasa.gov.uk/plant_health.

Preventative measures exist. Go to www.potato.org.uk/safehaven to learn more about national schemes that protect seed and ware crop health.

### NOTES

- Use of certified seed preferred where possible.
- Disease can survive in the absence of a potato crop but will usually decline over time. A five/six year break is usually effective.
- Typically, the longer potatoes stay in the ground, the more disease is likely to develop. Dry rot is an exception and may be more of a problem for crops lifted in summer.
- Once desiccated or senesced, crops may become predisposed to diseases like black dot. Rapid harvest is encouraged, providing adequate skin set has been achieved.
- For invasive diseases like skin spot and gangrene, varietal resistance decreases the likelihood of disease development. Use variety database. www.potato.org.uk/varieties
- Open wounds, if left untreated, allow rapid access for rotting diseases.
- Many diseases develop more rapidly when free moisture is available.

Wound healing is essential to prevent development of invasive diseases, such as gangrene and dry rot, but high temperature use may encourage development of silver scurf, black dot and soft rotting.

Where wound healing is not essential (low damage) immediate pull-down can reduce the risk of black dot, silver scurf and soft rotting.

Where wound healing is not essential a fast rate of pull-down can reduce the risk of black dot, silver scurf and soft rotting.

Many diseases develop at warmer temperatures, this can be restricted at lower temperatures. Exceptions are skin spot and gangrene where the tuber’s defence mechanisms are poor at low temperatures.

Warming (to 8°C) prior to grading will help minimise damage and reduce opportunity for invasive diseases to develop.

Regular store hygiene will help remove spores and fungal fragments of most pathogens.

Wound or rotting diseases can be considered stubborn as they can persist on grading lines or boxes. Identifying and cleaning contaminated areas will reduce risk.
A clean store, free from discarded tubers, dust and debris, has a number of advantages. It will minimise crop infection, improve air flow, contribute to worker health and comfort, and is likely to impress clients and customers.

Some soil is inevitably brought into store with the harvested crop. Once dry this becomes a potential source of dust when the crop is moved. If the crop is free of disease when harvested, and it remains so over the storage period, then the dust will be mainly mineral in nature. However, if the crop is diseased, or becomes so during storage, the dust may contain large quantities of spores which will be a source of inoculum in the present or future years.

**Dust dispersal**

Convection currents, caused by respiration heat from the crop, will circulate dust and spores throughout the store.

Cross contamination of spores between potato stocks is inevitable. Fan ventilation within the store may increase the speed of this movement, compared with natural convection. But the airflow is a benefit as it helps keep the crop free from condensation, preventing any spores which do settle from germinating.

Major dust movement and dispersal occurs when forklift trucks stir up dust on the floor during handling. The resultant dust cloud will settle on top of the crop, where the condensation needed for germination is most likely. If grading is carried out within the store, this will also create a considerable dust cloud with similar consequences.

**Dust removal**

Sweeping with a brush moves the heavier dust particles along the floor, while creating a cloud of lighter particles, which includes the majority of spores. Vacuuming loosens and removes all fractions of dust, and, if fitted with a fine filter, will remove most harmful spores from the store. Vacuuming is therefore much preferred to sweeping.

**Disinfection**

Removing dust and squashed tubers will remove the majority of inoculum present. Some dust and spores will remain on the floor, walls and rafters as well as the floor and sides of potato boxes, the majority of which can be removed by power washing. If total removal of viable spores is required, e.g. for high health crops, a disinfectant can be used. This is particularly relevant in stores where damage related diseases such as dry rot have occurred.
Leaving boxes outside will allow light to kill viable spores. Boxes should not be stacked more than four boxes high for safety, and, if stacked in pairs, a small gap between rows will allow natural (ultra violet) light to reach one side of every box. However, outside stacking can reduce box life by up to 40%.

Cleaning and energy efficiency
Maintaining fans, ventilation and refrigeration equipment in a clean condition will help prolong their working life and improve their working efficiency. Ensure that temperature and humidity probes are kept clean and inspect louvres, evaporators and condensers. If necessary clean by vacuuming or power washing. If washing, take care around electrical and moving systems and ensure that any resulting ice is removed by defrosting.

ACTION POINTS

STORE HYGIENE

Post-storage cleaning
• Store-cleaning should be undertaken annually. In box stores this is best carried out immediately after the last crop has been removed, so cleaned boxes can be returned to store.
• In a year following crop infection by silver scurf or skin spot, extra rigorous cleaning should be carried out.
• Vacuum dirt and debris from floors, ledges, beams and other horizontal surfaces.
• Where insulation is damaged, or is rough and collects dust, repair and vacuum.
• Only power hose if insulation is moisture-proof.

Cleaning boxes
• Ensure that box-tippers on grading lines are designed to discharge the total box contents to get rid of major contamination.
• Use power hose to clean boxes.
• Where cleaning boxes is routine, consider setting up a conveyor-based automatic washing system.
• Power-wash boxes for high health crops.
• Where possible, return cleaned boxes to store or keep under cover, as this can extend box life by 70%.

When to use disinfectants
For high health seed crops disinfectants may be beneficial, especially after a contaminated crop in the previous year.
• Use disinfectant mist, fog or spray after vacuuming store.
• Spray disinfect boxes which held diseased crop, out-grades or ‘brock’.
• Following grading of diseased potatoes, power-wash grading line, then spray with disinfectant where grading high health crops.
• Always use approved products and seek specialist advice.

Note: some disinfectants may damage store insulation and electrical fittings – consult the product label before use.

Daily cleaning
• Vacuum the floor, particularly forklift routes and under graders, at least once a day.

Grading in store
Grading in store is likely to increase the amount of contaminated dust in the store and the likelihood of ambient air entering through open doors. Dust provides disease inoculum, while ambient air may cause condensation, particularly on the top surface of boxes or pile.
• Ideally grade in separate building, with a plastic strip door between the store and grading area.
• If grading in store is unavoidable, enclose pickers in warmed cabin, and fit a dust control system to the line.
• Fit dew point temperature monitor to warn of condensation risks.
Servicing and sensors

Servicing
Stores should be cleaned and equipment checked as soon after emptying as possible. Any faults discovered can then be sorted in good time prior to harvest. Empty boxes can be put back into store before harvest.

Routine servicing by installers of refrigeration, cooling and monitoring equipment will ensure reliable and efficient store operation during the winter and prolong plant life. Refrigeration equipment in particular is too complex to be serviced by non-specialist personnel. In addition, impending regulations will soon require refrigerant leakage to be monitored, to minimise ozone depletion in the upper atmosphere.

![Figure 6.1 Damaged insulation will need to be repaired](image)

**Store cleaning and inspection**
An annual inspection of store fabric and hardware can be carried out at the same time as store cleaning. Look for signs of damage and take action to seal any gaps and repair defective equipment (Figure 6.1).

**Internal store sensors**
Condensation on potatoes may occur if there are temperature differentials within the crop. Good store management should therefore ensure crop temperatures are as uniform as possible, so sensors should be sufficiently accurate to measure differences as small as 0.5°C. Regular verification against a calibrated, precision thermometer at ambient temperature and melting ice at 0°C should be carried out to ensure that any differentials measured are real, and not due to sensor inaccuracy. Always replace sensors which show any sign of damage to either the cable or probe.

In both box and bulk stores, sensors should preferably be located in the top and bottom of the stack with most located in the top of the crop and some at the base, e.g. Figure 6.3 and Figure 6.4 (box store). For optimal

![Figure 6.2 Calibration of sensors using melting ice](image)

sensing, two pairs of sensors measuring the surface layer differential should be located below overhead cooling air jets in space ventilation systems, while bulk stores should have two pairs of sensors in the top surface layers, with one or two sensors 300 mm off the floor (Figure 6.3). If condensation occurs in the sides of the store, a sensor half way up the side of the pile can be installed. Alkathene tube (e.g. water pipe) makes a good sleeve in which to fit sensors at low level in a bulk store.

**External sensors**
Accurate external sensors, placed to avoid interference from the sun, reflected heat etc., are important to ensure ambient air-cooling operates when suitable cool air is available. A 1°C error in an external temperature probe could significantly reduce the amount of cooling obtained. Suppliers should calibrate external RH sensors every 1-2 years.

![Figure 6.3 Locating temperature sensors for measuring temperature differentials](image)
Figure 6.4 Sensor placement in a box store

**ACTION POINTS**

**SERVICING & SENSORS**

**Servicing**
- Ensure stores are serviced annually.
- Pay particular attention to factors which will influence the store’s efficiency such as refrigeration equipment and louvre-sealing.

**Sensors**
- Faulty or misplaced sensors will affect crop quality as the store will not run correctly. This may result in over-ventilation, which will increase weight loss, or incorrect storage temperatures which will affect fry colour or blemish disease control.
- Replace any damaged sensors or cables and calibrate annually to ensure accuracy.
- Place sensors to provide comprehensive feedback on store performance.
Loading the store should be an activity which is planned well in advance of harvest. It is important to match crops, in terms of their quality, likely storage periods and market expectations to the storage available, so that management is effective and returns are maximised.

**Harvesting**

Crops should be harvested as free as possible from damage, soil, stones and haulm. Within an hour or two of entering store, the crop should be ventilated to remove surface moisture from tubers and from any remaining soil. If positive ventilation is available, as in bulk stores or letterbox stores, ventilation will prevent condensation forming on tubers in crops lifted in dry conditions. The airflow removes the warm air produced by the rapidly respiring crop and will reduce the likelihood of the warm up-current condensing on the cooler potatoes above.

**Speed of loading**

Try to load stores within a week and absolute maximum of 14 days. This ensures potatoes can be brought under optimal control and reduces the need to compromise on store management and, ultimately, crop quality. If loading within this timeframe is not normally achievable, you may benefit from dividing your store into two smaller sections. Temporary curtains can be used as a cost-effective option for this.

**Crop sampling**

Field sampling will identify rots, blemish disease, or slug damage, while warm storage (>20°C) of samples before harvest can identify potential rotting prior to loading. Crops with rots, or loads which have been rained on, should be kept out of the bulk pile to prevent spread of rotting throughout the pile. Crops with 1-2% rots should be set aside, ideally in boxes, and positively ventilated continuously for 4-6 weeks until the rots are mummified. Crops with over 2% rot should be sold immediately for consumption or stock feed.

**Initial storage**

During store-loading, the temperature of the crop already in store should ideally track the daytime average temperature of the crop in the ground, usually between 20°C down to 10°C over the harvesting period. The store should be ventilated whenever the outside air is within ±40°C of the crop temperature to ensure all surface moisture is removed and condensation is not caused. If dew-point temperature-sensing is available, it can be used instead of temperature to prevent condensation when ventilating with air warmer than the crop. Crops should be quickly blown dry to prevent disease development, as the relatively warm temperatures during this period encourage disease development if crops are moist.

**Damage prevention**

As at harvest, mechanical damage when loading should be kept to an absolute minimum. Rots and blemish diseases invade through wounds and broken skin while bruising causes rejection from premium markets. Testing for damage should be routine so that increased damage can be quickly identified. Standard methods of damage assessment are available; hot-boxing samples overnight will help to show any bruising. A swinging-head elevator will enable systematic loading in bulk stores, whilst most automated box fillers are designed to minimise drops into boxes.

**Stacking boxes**

Box-stacking arrangement is crucial to achieving uniform air distribution and crop temperatures. The rolling air mass...
Circulate air quickly

- Start ventilating the crop as soon as practicable, ensuring any uncovered ducts or short circuits are sealed off as much as possible to force air through the potatoes.
- To reduce condensation risk, make sure that the temperature in the store tracks that of the crop coming in.
- Keep differentials to below 4°C at loading and tighter as temperatures are reduced.

**Install probes as soon as possible**

- Place temperature probes into the crop as soon as possible so that there is accurate information available on the crop condition on which to control or base decisions.

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Box positioning

The majority of boxes should be aligned with the main airflow. Also make sure there’s enough gap (600mm is ideal) for air to fall into at the end of the block. This ensures that air gets into the pallet slots under the boxes and is then distributed effectively.

Box stacking

Wherever possible stacks should be of uniform height. If lower stacks must be used (on the shoulder of the store, for example) watch out for condensation and use localised ventilation to control it.

Cross-stacking

You will sometimes need to put boxes at right angles to the airflow when cross-stacking to complete the store fill. If cross-stacked boxes are solid-sided, make sure gaps of more than 50mm are left between alternate stacks to allow air to pass through.

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With ‘overhead throw’ ventilation, poor air distribution often occurs in the back corners of the store. Overhead distribution fans, which assist the roll of air within store, will help to even crop temperature and minimise potential condensation. Other measures might include separation of delivery and return air (Figure 7.1) and/or prevention of short-circuiting back to the main fan around the store perimeter.
Ventilation is a critical process in storage as the movement of air through the potatoes is the primary means of regulating the crop condition by drying, cooling, heating, humidifying or adding chemical treatments. Specific strategies are needed for key processes such as drying and initial pull-down to holding temperature and for the use of refrigeration, which are discussed in the following sections. Many potato stores, however, still employ ambient air cooling, which uses external (ambient) air, when suitable, to cool the crop (Figure 8.1). Because ambient air does not need to be mechanically cooled, running costs are about a quarter those of refrigerated cooling.

Air mixing
If a mixing system is fitted (Figure 8.2), the minimum allowed duct air temperature can be regulated in relation to the crop temperature. In spells of cold weather, the inlet louvre will be partially shut and the recirculation louvre will partially open, causing the incoming air to blend with the warmer exhaust air from the crop. This produces ventilation air which will not reduce the temperature too much (eg in a processing crop) nor create too large a differential (typically <4°C) in the pile.

Ventilation rates
In bulk stores, virtually all the air that leaves the fan will pass through the crop. Traditionally 0.02m³/s/t has been the recommended ventilation rate for bulk stores in Great Britain but, with some quality parameters increasingly dependent on efficient drying, there is a move to higher rates of up to 0.04 m³/s/t, where the airflow removes heat more rapidly, with less weight loss.

The introduction of inverters (also known as variable frequency drives or variable speed drives) that enable fan speeds to be adjusted, has offerred scope to lower rates once drying and/or pull-down is complete. This can provide significant savings in running costs, for example, reducing a fan to 80% of its full speed reduces the energy consumption by around 50% 15. It is also a useful way to circulate CIPC sprout suppressant 18.

However, reducing air speeds too much can be detrimental since there is an attendant loss of pressure. Fan running times and dehydration will also be increased and response times reduced. If air is being delivered as part of a refrigeration system 13, icing up will occur if sufficient heat is not removed on the evaporator. Use of humidification, capacity control on fridges, etc, will address some of these issues, but specialist advice must always be sought.

Ventilation rates for box stores are typically designed to be 0.02m³/s/t. In space-ventilated stores, this airflow provides sufficient air movement around the boxes to dry and cool boxes. Since the air is not forced through the boxes, heat transfer is partly by natural convection between boxes and the surrounding air and partly by the turbulent airflow created by the cool air jets passing over the top of the boxes and through their pallet apertures. This rate of airflow is primarily

### Automation
An automated cooling system can be thought of as having three thermostats (temperature-operated switches) connected in series to the ventilation fan. The thermostats monitor temperatures as below:

![Diagram of an automated cooling system](image)

The fan can only run if the switches of all three thermostatically operated switches are closed or, in this example, the answer to the following three questions is YES.

1. Crop thermostat - crop temperature (set-point required) – is the crop too warm?
2. Differential thermostat - temperature difference between the crop and outside. This thermostat measures the condition of the air available in relation to the crop - is the outside air cold enough to cool the crop effectively?
3. Frost thermostat - outside temperature (low limit protection) – is the ambient air free from frost?
to aid distribution, rather than that required to remove the transferred heat.

Positive ventilation
To achieve more rapid drying and cooling, systems of positive ventilation may be used. These are especially suited to densely-packed, soil-contaminated potatoes and early-lifted crops. However, positive ventilation, including suction wall systems, is also a valuable tool for drying potatoes, maintaining close temperature control and application of sprout suppressant.

Cooling
Since cooling in space-ventilated stores is from above the box and below, with the greatest airflow being over the top of the upper layer of boxes, space ventilation encourages the undesirable temperature profile within the box – cool at the surface and warm in the centre – which is liable to result in surface condensation when ventilation stops. The reason this form of ventilation is so popular is that it is low in cost, utilises the otherwise unusable store headspace as a distribution duct and works in practice, so long as some provisos are adhered to. The cooling air should be no cooler than 4°C below the temperature of the crop to minimise the temperature profile in the box. The other requirement is that the air distribution should be as uniform as possible over the whole area of the stack of boxes.

When cooling space-ventilated stores, the store becomes flooded with cool air. The air within the boxes is now warmer than the surrounding air, so the rate of convection ventilation increases. However, this process is much slower than in positive ventilation systems, so cooling takes longer. As ambient cooling relies on taking advantage of cool air availability, positive ventilation will keep ambient stores cooler than those with space ventilation. In trials, the benefit of positive ventilation was c1.5°C cooler storage over a winter period.

ACTION POINTS

VENTILATION

Automate ventilation systems
Air can only be used effectively in stores if it is of the right quality for the job it is required to do. To ensure that this is always the case, there has to be control of the air delivery and this can only realistically be achieved through automation.

- Fit an automatic control system to all stores; consider upgrading any older systems.
- Avoid use of manual systems which are prone to human error and variations in climate which can quickly and irrevocably jeopardise crop quality.

Be positive!
Positive ventilation, where the air has to pass through the potato pile or box, is the best way to get effective results in storage.

- Use positive ventilation systems where possible, especially for drying.

Match supply to demand
- Consider installing controls (eg inverters) to supply variable amounts of air to match the demands of the store. They can offer potential energy savings too – for example, very high ventilation rates used for drying are not usually required in the holding period. Obtain specialist advice before retro-fitting to existing systems.
Free moisture
When a crop is brought into store, moisture in the adhering soil comes with it. Air surrounding a free water surface has a relative humidity (RH) of 100%. This free moisture must be evaporated off if the RH of the air is to reduce to the level associated with dry potatoes – about 96%. While this difference in RH would appear small, it is the key to having a dry, fresh-smelling store where every tuber has a dry skin rather than a dank one dripping with moisture.

Immature crops, harvested from dry soils, will become wet through condensation if there is insufficient rate of positive ventilation to remove the high respiration heat produced. Drying will then be necessary to remove this condensed moisture.

Water-holding capacity of air
Warm air can hold more moisture than cold air. A cubic metre of air can hold 17.5g of water at 20°C, but only 9.5g at 10°C and just 6.4g at 4°C. The drying of crops in warm weather, in September or early October, is therefore much quicker than if attempting to dry crops in cold weather in late November. The high heat output from the crop over the first few days after lifting will also warm the drying airflow, making drying even faster during this period.

Rate of drying
If a box or pile of potatoes is positively ventilated from bottom to top, the base layer dries first. A drying front forms, a few centimetres deep, over which the air becomes saturated which means it cannot take up any more moisture. This ‘drying front’ then progresses very slowly up through the crop, and, depending on the airflow rate may take between two days and a week to travel through the potatoes. Below the front the crop is dry, above it is still wet. The saturated air leaving the front passes up through the wet potatoes higher up, doing very little drying as it rises, so most effective drying actually occurs in this narrow drying front.

The rate of drying depends on:
- Airflow rate, which in turn depends on fan output and air leakage from the system
- Temperature of the air, which affects its water-holding capability
- Relative humidity of the air, which dictates the amount of water the air can take up
- Amount of moisture present on the potatoes and in the adhering soil

Figure 9.1 Ventilation through lateral ducts in a bulk store
Positive ventilation
- Drying is most effective if ventilation is positive – where the air delivered has to travel through the box or pile of potatoes.
- In bulk stores (Figure 9.1), virtually all of the air flows through the crop, whereas in positively ventilated box storage systems, at least 50% of the air typically escapes through gaps between the boxes.
- Letterbox systems (Figure 9.2) are limited to 8-10 boxes deep for effective drying. Suction wall systems are more suited to stores with more than 10 boxes per row.

Airflow rates for effective drying
- Use the highest airflow rate available for drying. Batch systems are very well suited to drying as airflow can be concentrated on a small tonnage at a time.
- Bulk stores require a minimum of 0.02 m³/s/t, rising to 0.04 m³/s/t for early lifted crop.
- Box stores need up to 0.08 m³/s/t to allow for air leakage.

Condensation risk when drying
The humid exhaust air from a crop being dried will be near 100% RH. If this air comes into contact with cold potatoes, it will condense.
- Ensure crop already in store is at same temperature as crop being lifted, to prevent warm humid air from one stack condensing on those already dried.

Dry, warm ambient air can still cause wetting if it comes into contact with cooler potatoes.
- Use external air for drying as long as it is ±4°C of crop temperature or where dew-point control of fans is available.

Free moisture on the crop or adhering soil will humidify air moving through the crop by convection, making condensation on other parts of the stored crop highly likely.
- Ensure there is air movement through, or around, the newly.lifted crop within two hours of the crop entering the store.

Optimising drying in space-ventilated stores
Air will always try to take the path of least resistance. Boxes should be stacked so that air cannot bypass boxes. Use can be made of pallet apertures to ensure drying airflow is always within 400 mm of every potato in store. Short circuiting of air can be a problem in part-loaded stores reducing effectiveness of drying.
- In box stores, stack boxes across the store, so that airflow has to flow through pallet apertures. Block return air paths around the store perimeter to force more air through the crop.
- Where varieties have to be stored in separate rows for access, start rows in centre of the store and use empty boxes or curtains to block any easy return path for the ventilating air.
Wounds as routes to infection

Wounds allow fungi and bacteria to develop in the flesh of the tuber. Suberin formation between and below damaged surface cells provides an initial barrier to disease entry and new cells form soon after into a more impenetrable barrier. Rate of wound healing is primarily influenced by temperature (Table 10.1), and is faster in recently harvested crops compared with physiologically old crops, such as those graded in the spring. Humidity plays little part in speeding wound healing.

Table 10.1 Wound healing rate in relation to tuber temperature.

<table>
<thead>
<tr>
<th>Tuber temperature (°C)</th>
<th>Initial suberisation (days)</th>
<th>Periderm complete (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5</td>
<td>7-14</td>
<td>21-42</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>7-14</td>
</tr>
<tr>
<td>20</td>
<td>1-2</td>
<td>3-6</td>
</tr>
</tbody>
</table>

The rate of moisture loss from fresh wounds is of the order of 100 times that from undamaged skin and weight loss over the first few days is inevitable. The faster the wounds heal the less this weight loss will be.

Risk-based approaches

Decisions on whether to cure crops or not will depend on the desired market and the potential for disease development. For example, a long duration at a relatively high temperature will be required for varieties and conditions where skin spot or gangrene development is likely (e.g. late-harvested, badly damaged King Edward) whereas curing could be omitted where markets demand low levels of silver scurf or black dot and pull-down could commence on loading.

Figure 10.2 illustrates that development of ‘low temperature’ diseases like skin spot is more likely where curing is omitted. Those diseases which favour higher temperatures, like silver scurf and black dot, can take advantage of conditions associated with traditional curing regimes. Figure 10.2 also shows that the initial effect can persist into long-term storage.

Dry curing

Dry curing, where crops are ventilated with suitable ambient air immediately on entering store, allows drying, heat removal and wound healing to occur simultaneously. Studies have shown disease development to be markedly slowed by dry-curing techniques compared with leaving the crop to ventilate naturally. As cooling is not desired during wound healing, ventilation control is normally set to manual. On manual, the automatic control box is switched out of circuit, and only the frost thermostat, if wired correctly, will stop ventilation should ambient temperature fall below its set point.

The aim of ventilation when dry curing is to dry the crop and keep it dry. Selection of suitable quality air is essential and short condensation events can undo the benefit from dry curing, as re-wetting can initiate diseases like silver scurf.

Figure 10.2 Effect of variety and curing strategy on development of different diseases

![Diagram of disease severity over time for Estima (second early) and Cara (late maincrop) varieties.](image-url)
Ventilation & recirculation

If conditions are not suitable for dry curing with ambient air, it is important to maintain air movement in the store to avoid temperature gradients becoming established. This can be achieved by regular recirculation (using automatic recirculation control if required), especially at night when the store is closed and there is less risk of drawing in unsuitable external air.

Pull-down

As soon as wound healing of the last crop loaded is complete, the crop should be brought down to its recommended holding temperature. Earlier commencement of pull-down is likely to be appropriate for some markets, as discussed above. The temperature of the cooling air should be kept in a band between 1-4°C below the crop temperature, no cooler. In fridge stores, cooling rates should average out at about 0.5°C/day.

While a relatively small differential may reduce the cooling rate, a larger one can cause excessive temperature differences within boxes. This can result in condensation when warm humid air within the centre of the box rises and condenses on the cooled surface tubers unless positive ventilation is used.

ACTION POINTS

WOUND HEALING & PULL-DOWN

Decide on curing approach

- Consult risk assessment advice.
- Assess and compare market tolerances and risks for development of damage-related diseases (skin spot, gangrene, dry rot) and blemishes (black dot and silver scurf). In general, cure for the former and pull-down for the latter.

Pull-down

- Pull down will be most effective if air is passed through the potatoes, so avoid short-circuiting and make sure that pallet slots are not blocked.
- For crops harvested at low temperatures, do not ventilate with warmer ambient air unless you know there is no risk of condensation.

Cure – if necessary

- With ambient systems, ensure any outside air used to ventilate the crop is within 4°C of the crop temperature to avoid condensation.
- For crops harvested at low temperatures, do not ventilate with warmer ambient air unless you know there is no risk of condensation.
- For crops with rotting, or at high risk of it developing, omit wound healing, reduce temperature quickly and plan short-term storage only.

Consider using a controller with wound-healing condensation risk monitoring.

- Set recirculation to be activated when ambient air dew-point temperature is 1°C below crop temperature (e.g. if crop is at 14°C, recirculation will start when dew point temperature reaches 13°C).
- Set minimum ventilation temperature to 4°C below crop temperature.

Figure 10.3 Effect of curing strategy on subsequent development of black dot

SBEU trials
Condensation is a major concern in potato storage. In a sealed store, over just a matter of hours potatoes can naturally create an environment with a high relative humidity (RH) of 90% or higher. At such a high RH, condensation can occur on the crop or roof if the surface is only marginally colder than the air. Condensed moisture is pure water, highly available to micro-organisms residing on the tuber skin or in wounds, lenticels or sprout buds. A condensation period of just an hour may allow blemish disease development or rotting to begin.

**Some basic facts about condensation**

- Warm air can carry more moisture vapour than cool air. At 20°C, air can carry 17.5g/m³ but at 4°C, it can only hold a maximum of 6.4g/m³.

- Relative humidity is a way of expressing the amount of moisture in a given volume of air in relation to its maximum moisture-carrying capability. So if 1m³ of air at 4°C is at 50% RH, it contains 50% or 3.2g of the maximum 6.4g/m³ that air can hold.

- Air temperature and relative humidity are related. If the temperature of air rises, the moisture-carrying capacity increases and the RH will drop. Conversely, if the temperature of air falls, the RH will increase.

- In potato storage, warm, moisture-laden air coming into contact with cooler potatoes is a condensation risk as the air may be cooled sufficiently for it to become saturated with moisture (100% RH). The temperature at which this is reached is called the dew-point temperature. Below this temperature, any water the air can no longer carry will be deposited on the potatoes as condensation.

- In the same way, in meteorology, where warm and cool air masses meet in the sky, this moisture falls as rain. And when a shower is run in a bathroom, the warm, moist air will condense on cool surfaces, such as the window (Figure 11.1).

- Cool air coming into contact with warmer potatoes is not a condensation risk.

Condensation on the crop can occur in a number of situations, but will only do so directly if:

- the air surrounding the potatoes is warmer than the potatoes, and

- the potatoes’ surface temperature is below the dew-point temperature of the air.

As a general rule, a temperature difference of 4°C or more between the warm air and the cooler crop will cause condensation. But in some situations (eg at cold temperatures) this difference might only need to be as little as 1°C for condensation to occur.

**Note** that the lower the tuber surface temperature, compared with the air’s dew-point temperature, the more moisture will be deposited.
When condensation can occur

- Allowing warm, ambient air to drift into a store of cooler potatoes, such as through an open door, can result in the crop near the door becoming wet.
- Putting warm potatoes into a store with cooler crop already in it. If the temperature difference is not managed, there is a risk of warm air rising from the warm crop and condensing on the cooler potatoes.
- Recirculating warm, moisture-laden air coming out of the top of a stack back into the cooler base of the pile carries the risk of creating condensation in the lower levels of the stack.

ACTION POINTS

TO MINIMISE CONDENSATION ON THE CROP

**Store loading**

- Minimise temperature differentials by keeping the store temperature at that of the potatoes being loaded into store.

**Placement of sensors**

If at all possible, use temperature sensors to monitor differentials within the crop.

- In bulk stores, put sensors 100mm and 300mm down from the top surface.
- Top surface (100mm) sensor should be no more than 0.5°C cooler than sensor 300mm down.
- In box stores, monitor base to top box difference up the stack.
- Keep the difference between boxes below 4°C during loading and wound healing and below 1.5°C once the crop is down to holding temperature.
- If possible, in space-ventilated stores, place sensors in two top boxes 70mm and 300mm down from the surface. Keep differences in-box below 0.5°C.

**Drying or cooling the crop**

- Only introduce air into the store if the temperature difference between the air and the potatoes is less than 4°C.
- Only ventilate with air warmer than the crop if the crop temperature is above the air’s dew-point temperature.

Minimising temperature differential ventilating using outside air.

- Where outside air is suitable (i.e. between 1-4°C below crop temperature), ventilation rather than recirculation can be used to even out temperature differentials in the crop.

- After ventilating the top of a box store with cold air, the fans go off, allowing warm air to rise through the crop by convection. This warm air hits the cooler layer of crop at the top of the store and condenses on the (underside of) the tubers (Figure 11.2).
- During periods without ventilation, warm air rises by convection from the warmest part (usually the centre) of a store and is replaced by cooler air from the sides of the store. This, in turn, is replaced by the warm air from the crop which then condenses in the cooler crop along the shoulders.

**Crop warming**

- The dew-point temperature of the warming air must be above the crop temperature.
- Where possible warm crops in the cold store, where the above condition exists and ventilation or the refrigeration system will remove the heat that does not enter the crop.
- When returning warm graded material to the cold store (e.g. after seed grading).
- Pre-cool so that it is <4°C above crop in store.
- Positively ventilate until crop is down to temperature.

**Sprouting**

- If sprouting occurs, check it is not a result of condensation.

**Air leakage**

- Prevent warm air leaking into the headspace by sealing gaps in the structure and keeping store doors closed, especially in warm humid weather.

Set minimum inlet temperature at 4°C below crop temperature.

**Minimising temperature differential by air recirculation**

- Only recirculate when temperature sensors indicate a build up of differentials, and if
  - Headspace air is below temperature of potatoes at base of pile, or
  - Base potato temperature is not below headspace dew-point.

**Crop warming**

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Set minimum inlet temperature at 4°C below crop temperature.
Risk to crop

Condensation forming on the building structure can lead to problems in the crop. On the roof it forms on the underside, runs down to the purlins, and then drips, in lines, on to the potatoes below. The wet potatoes can start rotting or skin-surface disease may develop. Condensation on walls is only a risk in bulk stores, where the moisture can accumulate on the floor, wetting the tubers at floor level.

How condensation occurs

Condensation on the structure will occur if the internal surface temperature falls below the dew-point temperature of the air next to the surface. This may occur due to one, or more of the reasons below:

- The insulation is inadequate or has failed because it is wet
- Air movement across the roof internal surface is insufficient, allowing localised high RH at the roof surface
- A cold spell of weather causes heat, but not vapour, to escape from the store
- Internal store atmosphere is at or near 100% RH

Well sealed stores

If a sealed store is at 8°C, RH 92%, with an external temperature of 8°C, a steady state situation will result, where heat neither leaves nor enters the store (Figure 12.2). If the ambient temperature rises to 12°C, heat will enter the store, raising the store air temperature, reducing its RH. Heat can pass through the insulation, but vapour is trapped in store. If the external air reduces to 3°C, heat will leave the store, the store air temperature will drop and its RH will rise to 100%. Condensation will occur on the coldest surfaces within the store, usually the roof but it may also occur on cold sections of the crop. While this is a transient phenomenon, it can initiate disease and rotting in the crop. This is called interstitial condensation.

Condensation can also form within the structure and behind insulation. If moisture penetrates into the structure, boards can become physically detached and insulation values greatly reduced 2.
Prevention of condensation

Structural condensation will be minimised by:

- Good, low conductivity, insulation (fridge stores – U-value=0.3 W/m² °C for roof, 0.38 W/m² °C walls; ambient stores – 0.4 W/m² °C for roof, 0.45 W/m² °C for walls)
- Recirculating air in the headspace using fans (Figure 12.2) to prevent temperature differentials in layers of still air under the insulation, which can lead to localised cooling and increased RH. Fans should be installed so that the air movement creates a horizontal rotation within the headspace.

Check for condensation

- During cold weather (>6°C below the store temperature), look carefully for signs of structural condensation on e.g. underside of roof.
- Check for signs of dripping from insulation joints or sagging roof insulation caused by interstitial condensation. Seek specialist assistance to rectify any problems.

Insulation

- Check the thickness of insulation (usually at least 75mm thick for refrigerated stores, and 50mm for ambient cooled stores). Where it falls below these measurements, consider increasing its thickness.
- Replace any damaged insulation.

Roof-space heating

Better insulation, and air movement in the roof void reduce structural condensation, but roof-space heating is the only way to prevent it.

- Fit roof-space heating in stores that are prone to structural condensation during cold weather, especially those held at higher storage temperatures for processing.
- Automate systems to start when the headspace air temperature falls c1°C below crop (surface) temperature. Adjust exact settings to suit the store in question.
- Ideally, use a controller which can both operate and monitor roof-space heating independently.
- Where an existing control system cannot control roof-space heating, use a separate electric sensor with temperature differential control to bring on heaters.
- Fit an interlock to ensure any overhead cooling does not switch the roof-space heating on.

ACTION POINTS

TO MINIMISE STRUCTURAL CONDENSATION

Check for condensation

- During cold weather (>6°C below the store temperature), look carefully for signs of structural condensation on e.g. underside of roof.
- Check for signs of dripping from insulation joints or sagging roof insulation caused by interstitial condensation. Seek specialist assistance to rectify any problems.

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- Where an existing control system cannot control roof-space heating, use a separate electric sensor with temperature differential control to bring on heaters.
- Fit an interlock to ensure any overhead cooling does not switch the roof-space heating on.
Refrigerated storage offers the scope for close environmental control. A combination of ambient air-cooling and refrigeration can reduce the energy required for drying and cooling when ambient conditions allow, while retaining the ability to control temperatures in store when warm winter temperatures prevail. With long term storage accounting for up to 100kWh of energy use per tonne, ensuring that systems work efficiently will not only preserve crop quality but help manage energy costs.

A refrigeration system consists of two heat exchangers: the evaporator or cooling coils inside the building and the condenser outside. These are connected by a circuit containing a liquid/gas refrigerant. Heat from the store is pumped out of the store in the refrigerant, to the condenser outside, by a compressor. Condensers often have banks of multiple fans fitted, for dissipation of heat, which are switched on sequentially according to demand. Fitting inverters (variable speed drives) can be a good way to reduce energy consumption on multiple fan condenser sets 15.

Air from the store passes over the evaporator and is cooled according to the size of the compressor. This cooled air is blown out of the fridge to recirculate around the store. The temperature difference between the air going into the fridge (the air-on), and the cooled air coming out (air-off), reduces as the store temperature falls (Table 13.2), but should not exceed 2.5-3°C.

**Refrigerated storage**

**Table 13.2 Typical air-on/air-off values for refrigeration systems**

<table>
<thead>
<tr>
<th>Air from crop (air-on)</th>
<th>Air from outlet duct (air-off)</th>
<th>Air-on / air-off temp. diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.0°C</td>
<td>9.0°C</td>
<td>3.0°C</td>
</tr>
<tr>
<td>8.0°C</td>
<td>5.5°C</td>
<td>2.5°C</td>
</tr>
<tr>
<td>3.5°C</td>
<td>1.5°C</td>
<td>2.0°C</td>
</tr>
</tbody>
</table>

**Maintenance and faults**

Refrigeration systems are complex and should be serviced annually by the supplier. However, operators can help ensure the equipment operates efficiently by carrying out the following simple checks before use:

- Compressor crankcase oil heater is switched on 24 hours before starting
- Condenser coils outside are free from leaves and dirt
- Refrigerant is dry and clear of air bubbles (use the sight glass or other monitoring device)
- Compressor is operating when the recirculation fans are operating
- Check the calibration of temperature and humidity sensors

Regular checks of the high and low refrigerant pressure switches need to be made during operation as these can trip out the compressor. Fans may operate while in practice no cooling is taking place.

**Combined ambient/refrigerated systems**

In cooling mode, simple control systems will tend to favour the use of refrigeration over ambient air-cooling. Indeed, the sole use of refrigeration to achieve a controlled pull-down is increasingly common in storage for pre-packing 11.

Ambient systems will use less energy and have lower running costs compared with intensive refrigeration. Combined ambient/fridge systems will have running costs somewhere between the two. More sophisticated control systems allow delays to be installed for fridge operation which either allow cooling to wait until night time low temperatures are available or enable lower cost energy tariffs to be used 17.

**Defrost**

The temperature of the evaporator (cooling coils) is c6°C lower than the crop temperature. The air flowing through the evaporator is cooled to a level between the air-on temperature and the evaporator temperature. At low storage temperatures (<2.5°C), condensate is likely to freeze on the evaporator coils, which will require periodic defrosting (Figure 13.3). Defrost is often only available as off-cycle (i.e. the system shuts down) but it is more efficient if defrost can be carried out on demand, avoiding unnecessary down time or heating of coils which have already been cleared of ice.

**Figure 13.1 Refrigerated storage**
The need for defrost can be avoided in many potato stores providing temperature control in the store is uniform. Storage at c3.5°C should be sufficient to limit the development of blemish diseases and prevent sprouting in all but the most prolific varieties.

**ACTION POINTS**

**REFRIGERATION**

**Store integrity**
Refrigeration costs can be reduced if stores are well sealed. Only one, preferably small, opening door should be required for winter access.
- Carry out a store assessment. 1.
- Close off and seal any doors or louvres not required for access or ventilation.
- Use controller with positive louvre-closing action; service system annually.

**Condensation risk during rapid pull-down**
Refrigerated stores have less condensation risk in the surface layers of box stores than ambient, as the cooling air is always around 1.5-2.5°C cooler than the crop. But too rapid cooling, i.e. >0.7°C/day, often aimed at limiting disease development, may result in temperature differentials which could lead to condensation 12.

- At high cooling rates, refrigerate for fewer hours per day, and recirculate air with the compressor off for other periods.
- If condensation is seen, shorten cooling periods and recirculate more.

- Ensure attempts to slow the onset of disease do not inadvertently cause condensation and disease initiation.

**Using a fridge to dry potatoes**
Where potatoes are wet, a fridge can be used to dry the crop. The circulating air in store absorbs moisture from the crop and as this humid air passes through the evaporator, moisture condenses out and drains away.
- Note that rapid removal of moisture by evaporation also cools the crop more.
- Use a heater to compensate for excess evaporative cooling — but only in extreme situations.

**Override thermostat protection**
A system with refrigeration should always be fitted with back-up protection against excess chilling in the event of controller failure.
- Fit an override thermostat which is independently wired to turn fridge off.

**CIPC use in fridge stores**
Circulating CIPC through refrigeration coils can cause damage to the coil 18.
- Bypass fridge coils if circulating CIPC fog.
Humidity and moisture loss

Potatoes have a high water content (over 70%) and, in storage, lose moisture over time through evaporation to the environment around them. At 4°C, tubers reach equilibrium (i.e. they neither lose nor gain moisture) when the surrounding air is at 98% relative humidity (RH), very close to saturation. As the RH of air surrounding stored potatoes falls, water loss increases.

Ventilating a potato store will, to some extent, dehydrate the crop. As air moves through the potatoes it picks up heat that lowers its relative humidity. Where the skin of the tuber is not intact, either due to poor skin set or un-healed wounds, increased moisture loss will occur.

The risks of dehydration from ventilation can be minimised by:
- Harvesting with set skins – this is a critical measure to minimise moisture loss from the tuber
- Optimising the ventilation time through regulating the quantity and temperature of the air used to attain the required storage condition. This is best done using an automatic ventilation controller, as this will only bring on the fans when ventilation is actually required and the air is suitable. As the potato’s skin acts as a regulator to the process of moisture loss from the tuber, the level of moisture lost will be proportional to the ventilation time during the holding period

The effects of dehydration can also be exacerbated by deep pile storage (>4m deep) where it is common to see some evidence of compression damage in crops removed from long-term storage. In severe cases, compression damage can be seen within boxes, where depths are seldom much more than 1m.

Humidification

By supplementing the moisture content of the air through humidification (Figure 14.1 and Figure 14.2), there is scope to increase its RH and reduce moisture loss from the crop. A range of systems (Table 14.3) is available. Advantages associated with the use of humidification include:
- Reduction in pressure bruising/compression damage at the base of a bulk pile
- Improved turgor and tuber integrity
- Enhanced temperature control due to adiabatic cooling (see below)
- Removal of disease spores from store air (with cell humidifiers)
Table 14.3 Humidification systems

<table>
<thead>
<tr>
<th>Type/description</th>
<th>Benefits/disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell humidifiers</strong></td>
<td>• Can be fitted retrospectively</td>
</tr>
<tr>
<td></td>
<td>• Do not require active control of humidification</td>
</tr>
<tr>
<td></td>
<td>• Can filter out some disease spores</td>
</tr>
<tr>
<td><strong>Atomiser systems</strong></td>
<td>• Can be fitted retrospectively</td>
</tr>
<tr>
<td></td>
<td>• Small risk of free water being carried in to the crop, requiring close monitoring at all times</td>
</tr>
<tr>
<td></td>
<td>• ‘Active’ or pulsed control of humidification is needed</td>
</tr>
<tr>
<td><strong>Spinning discs</strong></td>
<td>A further benefit of humidifying is evaporative cooling. If moisture is evaporated during the ventilation process, this has the effect of cooling the air at the same time. This means systems using humidified air can operate at lighter air/crop differentials as the differential is widened as a result of water evaporation. This is known as adiabatic cooling.</td>
</tr>
<tr>
<td></td>
<td>However, a humidifier should only be used in a well sealed building with a close level of temperature control (range &lt;0.5°C). Humidification cannot be expected to rectify major deficiencies caused by incorrect ventilation systems or poor refrigeration.</td>
</tr>
</tbody>
</table>

**ACTION POINTS**

**HUMIDITY**

**Prevention of surface condensation**

In high-humidity storage, crops can be affected by condensation when the external temperature suddenly drops.

- Fit roof space heating to provide automated control of headspace temperature.

**Moisture loss**

If moisture loss is a problem, the cause should be traced and cured directly if possible:

- Measure fan running times (moisture loss is proportional to ventilation time).
- Check for air leakage.
- Check fridge air on/air off temperature.

**Control**

Since it is difficult to measure RH accurately above 95%, where moisture is being actively added to ventilating air, it is best to do so by:

- Adding moisture on an intermittent basis (e.g. through pulsing) and/or
- Have ducting below the level of the floor so that any moisture falling out in the duct system can be safely drained from the store.
The biggest consumer of energy during storage, whether using ambient or refrigerated air, is for cooling the crop. With ever-increasing energy costs, a higher profile for environmental issues and the carbon footprint of storage, understanding energy use and exploring energy-saving options are now high priorities.

**Energy monitoring**

Monitoring consumption is a key factor in managing energy use successfully. It is a relatively cheap exercise to undertake and allows managers to identify high energy use equipment and times, spot where problems might be occurring and make rational investment decisions on energy-saving equipment.

**Refrigeration running cost example**

Sum of ratings of compressor and fan motors * = 20kW

Cost of electricity per kWh = 10p

Number of hours fridge runs in one week = 45 hrs

Total cost = 20 x 0.10 x 45 = £90

* Motors have a low power factor so use more metered power than their kW rating. But as they rarely run at full motor power this estimate is reasonable.

Energy monitoring can range from the regular, organised reading and manual recording of utility meters on site to the use of sophisticated data-logging equipment. It can be applied to whole sites or, by sub-metering, to individual buildings and individual pieces of equipment.

If metering each store separately is not practical, energy use per store can be estimated from fan and fridge hours run time. For each store, total the power rating in kW or hp stamped on the electric motors that run when the ambient air-cooling is operating and when the refrigeration is running.

Comparing the cost of current electricity suppliers with other suppliers, contracts or changing tariffs may be a way of saving money. Specialist energy brokers can assist with this process.

**Building improvements**

Leakage of warm ambient air into stores, through gaps in the structure, joints and doors is a primary cause of excessive cooling-fan or refrigeration running costs. Major air-leakage points are obvious, as daylight can be seen through the gaps from inside a dark store (Figure 15.3). Other leaks, such as gaps between composite panels, may only be identified by detecting draughts on a windy day or by use of equipment such as a thermal-imaging camera (Figure 15.2). Simple solutions can often help minimise air leakage and, consequently, reduce energy use. Use of inverters or variable-frequency drives (VFDs) on fans and pumps.

Inverters (Figure 15.4) can improve the energy efficiency of fans and fridge components, such as condensers, fans and compressors, by moving away from a ‘one size fits all’ approach. Instead, they match the performance of equipment to the store’s needs.

A fan will consume energy equivalent to its capital cost within as little as one season. When upgrading equipment, the extra cost of new technology or a more efficient motor needs to be offset against potential energy savings.

**Optimised energy savings**

Good control is essential in providing optimal storage conditions at the lowest energy cost. Compared with many capital investment options, control is generally quite cheap to integrate into an existing store. The ability to regulate

<table>
<thead>
<tr>
<th>Description/measure</th>
<th>Potential energy reduction</th>
<th>kWh per tonne saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy monitoring / management</td>
<td>10% overall</td>
<td>10 kWh</td>
</tr>
<tr>
<td>Building improvements</td>
<td>Up to 20%</td>
<td>15 kWh</td>
</tr>
<tr>
<td>Advanced control techniques</td>
<td>10%</td>
<td>7.5 kWh</td>
</tr>
<tr>
<td>Inverters on fans/pumps/compressors</td>
<td>30%</td>
<td>6 kWh</td>
</tr>
<tr>
<td>Cooling technique optimisation</td>
<td>20%</td>
<td>15 kWh</td>
</tr>
</tbody>
</table>

*Note: The savings are broad estimates relating to the technique in question. The cumulative saving from some of the measures is not necessarily additive, as some improvements may make others less effective.*
refrigeration to coincide with the cheaper night tariff can make significant cost savings.

Web-based forecasting systems are becoming available on some internet-connected store controllers to anticipate cool weather and delay cooling until cool ambient air is available.

**ACTION POINTS**

**ENERGY MANAGEMENT**

**Know where it is going**
- Install a sub-meter on the potato store or even individual pieces of equipment.
- Read meters regularly – either make manual records or use automated SMART metering.
- Analyse the information you gather and try to relate peaks to particular activities.

**Stop any leaks**
- Check doors, louvres and joints – seal gaps with brush seals, rubber flaps or spray foam.
- Check insulation – repair damaged areas.
- Consider improvements – where insulation is below 50mm, consider increasing its thickness.

**Be in control**
- Install tariff control to capitalise on cheap night-rate tariffs.
- Remote diagnostics and multipoint temperature sensing will help you monitor how your store is running and allow problems to be identified.

**Consider the running costs**
- When upgrading equipment balance the cost of equipment against its energy-saving potential – new technology or higher-efficiency options may offer significant cost benefit.

**Carry out an energy audit**
- Consider engaging a specialist energy-auditing service which will highlight where energy savings can be made.
Oxygen

Potatoes are living organisms, which require oxygen to metabolise their food reserves to maintain life. Respiration rates are usually higher in processing stores compared with pre-pack stores due to their higher holding temperatures. But respiration rate also increases the further the holding temperature falls below 5°C.

A lack of oxygen in a potato store can lead to blackheart (Figure 16.1), where the central core of the potato is starved of oxygen and the tuber effectively suffocates from the inside out. The result is an odourless, blackened area in the central pith tissue.

Under normal atmospheric conditions, the level of oxygen in air is 21%. A level of 19% oxygen is the minimum acceptable for worker safety (Confined Spaces Regulations, 1997).

Carbon dioxide

Normal respiration of potatoes in store produces carbon dioxide (CO₂) which will accumulate in the store atmosphere. The levels of carbon dioxide in a potato store are often in the region of 0.3–0.5% (3000–5000 parts per million), which is about 10 times the 0.04% level normally found in air.

Modern, highly sealed stores are more likely to have higher levels of carbon dioxide if the air within the store is not freshened daily. Carbon dioxide can accumulate to levels as high as 3% at times of high crop respiration. Crop respiration rates are higher immediately after harvest, following the thermal application of sprout suppressants and also when using ethylene in store.


Many storage control systems are now available with CO₂ sensors allowing measurement and control of the store atmosphere automatically. Portable CO₂ sensors (Figure 16.2) can also be used to monitor levels at times of high crop respiration, but are relatively expensive to purchase. The main priority for the potato crop is to control excessive build-up. A simple timer control can automate this process without the need to measure the carbon dioxide level. This can be achieved most simply by running continuously a small extractor fan, fitted in the store wall, or by ventilating for a few minutes each day to let some ambient air into the store. Many controllers now feature this type of control in the form of a ‘flush’ or ‘purge’ facility. Be aware of possible risks of problems such as condensation or chilling when flushing stores with ambient air.

Ethylene

Ethylene, a plant growth hormone, can be a component of the store atmosphere where it is used as a sprout suppressant treatment. Where it is used, ethylene can influence crop respiration rates so interactions are likely with other atmospheric components, eg oxygen and carbon dioxide.

Other gaseous components

In addition to carbon dioxide, there are other gaseous components in the store atmosphere (volatile compounds) which are associated with potatoes and the development of some diseases. Some of these have been identified but their influence on potato quality is still being investigated. However, it is known that volatile compounds (including ethylene) can be introduced to the store through processes such as thermal fog application and these may have a detrimental effect on crop quality if they are allowed to persist in the store.

The identity of other volatiles within a potato store remains unknown and their role is therefore not yet understood; some research has been undertaken and it is hoped in future to be able to use measurement of these chemical compounds to develop systems for early detection of diseases such as soft rot.
Crop respiration
Respiration rates are usually high at store loading so it is necessary to
• Maintain a good supply of fresh air.
• Reduce crop temperature quickly in very warm harvesting conditions (>20°C).
• If using ethylene, introduce gradually to reduce impact on respiration rate. Increased respiration results in more
   heat, which then requires more energy to remove.

Carbon dioxide
• Monitor CO₂ levels during critical phases such as store loading and curing.
• Avoid build-up by running a small fan to continuously bleed fresh air into sealed stores. This is best done by
  feeding external air into the fan to allow comprehensive mixing before delivery to the crop.
• Alternatively open personnel door daily to the outside.
• If possible automate flush/purge function on store controller.
• Ensure levels are within HSE guidelines for operator safety.

Thermal fog applications
• Flush store as soon as chemical has deposited – prolonged exposure to combustion gases results in darker fry
  colour.
Storage for markets

It cannot be stressed strongly enough that, when storing potatoes, this should be done with a firm knowledge of the market that will be supplied.

Storage is a specialist activity and, to achieve worthwhile and realistic returns, it is necessary to be able to deliver crop to the precise specification the market demands. If the market is not known, this simply cannot be achieved.

Specifications will vary widely within sectors depending on a range of factors including price, packaging, timeliness and qualitative measures such as skin finish, dry matter, tuber count, fry colour and sugar content. Some of these factors can be influenced by storage management, as outlined overleaf; others will not. However, if a crop does not meet specification before storage, it is not going to do so afterwards, and there is likely to be no value whatsoever in incurring the expense of storage in these circumstances.

So crops must always be assessed in relation to this market, both before and during storage to confirm that quality meets the market’s needs. The section on Quality Control (opposite) outlines procedures for doing this.

Costs

Storing potatoes can be an expensive process and it is important to have a clear appreciation of the true cost of storage before committing a crop to it.

The principal components of storage costs are:

Running costs – eg electricity, chemicals, property repairs, loading, equipment maintenance, monitoring and insurance. The more accurately these can be measured, the more realistic any estimate of costs will be. For example, installing a sub-meter in a store can give an accurate measure of electricity costs, which may only be estimated otherwise.

Storage losses – the production costs have to be carried by what can be sold, so allowances should be made for weight loss and outgrades which do not meet market specification

Capital depreciation – cost per tonne per season, eg a store costing £150 per tonne with a 25 year design life would cost £6/tonne/year. In a box store, the cost of the box will need to be added: boxes should realistically be costed over a 10-year life. Beyond this, repairs will generally be required to extend their use.

Finance – the cost of borrowing or opportunity costs of the money invested in the store and crop. This should include interest on the price differential between harvest and unloading.

Risk/profit – to be realistic, a cost should be included for the value of storage (ie to make it worthwhile).

Crop monitoring

Regular sampling and assessment of the stored crop is vital to monitor the consequences of any managerial action on potato quality. It will also save time, money and aggravation by avoiding rejected loads, helping to optimise storage conditions and minimising developing problems.

It is important to know the customer’s specifications. This means limits for factors such as tuber size, greening, damage, skin finish, blemish diseases, rots, internal defects and fry colour. Wherever possible, adopt the
Maximum level of defect permitted by market | Minimum number of tubers required to detect defect is present | Minimum number of tubers required to estimate the % level of the defect
---|---|---
20% | 15 tubers | 45 tubers
10% | 30 tubers | 90 tubers
5% | 60 tubers | 180 tubers
2% | 150 tubers | 450 tubers
1% | 300 tubers | 900 tubers

(Adapted from EC Directive 2002/63/EC at 95% confidence level)

Table 17.3 Number of randomly selected tubers required to find defects in a stock

Table 17.3 Number of randomly selected tubers required to find defects in a stock

Customer’s methods for assessing quality and ensure all aspects of the specification are tested. Use the same method for each sample, write it down and stick to it. Use results to supply only crops that meet the market’s specification. Identify ‘borderline’ crops and negotiate these separately, or supply them to a customer with the appropriate specification.

**Getting the best from QC**

Carry out a full inspection before storage. Storage is costly, so it is important to be sure that the crop going into store is worth storing. If it doesn’t satisfy the specification before storage, it won’t after.

Treat Quality Control (QC) as an investment. It will give useful feedback on changes to a crop in store, which will help decision-making later. Following a full initial inspection at harvest, continue to monitor only factors that are likely to change (eg sprouting, rots, fry colour and certain blemish diseases) every month. Fully assess loads being delivered to customers and use their intake reports as an audit of QC at the store. Any major differences will need investigating further.

**Sampling**

A sample should be large enough to represent a stock adequately. Table 17.3 provides a quick reference giving the number of tubers required to sample for a given tolerance.

Many store managers are guilty of sampling at a single point or level (eg the top of the store) but this is unlikely to give a sample that is representative. The more sub-sample locations the better. Take at least two sub-samples from each stock, but one sample is still better than none. A separate sample is required for each stock; crops from different fields, or stores, count as different stocks even if they are the same variety.
<table>
<thead>
<tr>
<th><strong>Storage for markets</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Market demands</strong></td>
</tr>
<tr>
<td>• Uniform and acceptable fry colour</td>
</tr>
<tr>
<td>• Low levels of rot and skin spot (increases peeling waste)</td>
</tr>
<tr>
<td>• Freedom from sprouting</td>
</tr>
<tr>
<td>• Dry matter appropriate for market</td>
</tr>
<tr>
<td>• Controlled use of sprout suppressant</td>
</tr>
</tbody>
</table>

| **Management principles in field** |
| • Plan to harvest mature crops before soil temperatures dips below 8°C |
| • Agronomy (eg canopy management, seed selection, planting density and nutrition) to contribute to achieving size and maturity that permits long term storage |

| **Store management: pre-holding** |
| • Maintain warm temperature at c10-15°C after harvest to ensure any damage is fully cured |
| • Only lower temperature very gradually (max 0.3°C/day) once curing is complete |
| • In crops at high risk of sweetening, keep temperatures high (10-13°C) for first weeks of storage (pre-conditioning) where disease levels and sprouting permit |
| • Monitor fry colours and sprouting regularly |

| **Store management: holding** |
| Temperature depends on use, variety and storage duration. |
| **Examples:** |
| Hermes | 9-12°C |
| Lady Rosetta | 8-10°C |
| Saturna | 8-10°C |
| Maris Piper | 7-11°C |
| Markies | 8-10°C |
| Pentland Dell | 8.5-10°C |
| Russet Burbank | 6.5-8.5°C |
| • The lower end of the scale is appropriate for 6-9 month storage; the higher end should be used for shorter durations |
| • Daily, controlled flushing with fresh air required to prevent build-up of CO₂ | 18 |
| • It is imperative that sprouting is avoided (in preparation for sprouting, tubers will convert starch to sugars and fry colour will be adversely affected) and application of sprout suppressant (eg ClPC) will be necessary for long term storage |
| • Following best practice guidance is essential to avoid exceeding Maximum Residue Levels | 18 |
| • Holding temperatures which are lower than recommended, often as a result of prolonged periods of low ambient temperature, can result in cold-temperature sweetening which will affect fry colour. This can be made worse by warming the crop |

<p>| <strong>Unloading</strong> |
| Poor fry colour at this stage is usually the result of one of two things:- |
| • Low temperature sweetening – this may be alleviated by reconditioning (storing at c15°C prior to unloading to increase respiration and “burn off” sugars) although this is very variable and further advice should be sought on a case-by-case basis |
| • Senescent (old age) sweetening – this is largely irreversible |</p>
<table>
<thead>
<tr>
<th>Fresh/Pre-pack</th>
<th>Seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Bright, shiny skins</td>
<td>• Specific size requirement</td>
</tr>
<tr>
<td>• Low levels of scuffing/damage</td>
<td>• Low levels of disease</td>
</tr>
<tr>
<td>• Low levels of blemish disease</td>
<td>• Freedom from sprouting</td>
</tr>
<tr>
<td>• Freedom from sprouting</td>
<td></td>
</tr>
<tr>
<td>• Minimal residues</td>
<td></td>
</tr>
<tr>
<td>• Plan to minimise time in field to avoid disease</td>
<td></td>
</tr>
<tr>
<td>development</td>
<td>• Plan to harvest crops with minimal</td>
</tr>
<tr>
<td>• Bearing above in mind, agronomy to focus on</td>
<td>damage and follow procedures to keep</td>
</tr>
<tr>
<td>achieving size and skin-set that allows lifting to</td>
<td>crops dry</td>
</tr>
<tr>
<td>minimise damage</td>
<td>• Fungicide application (for control of</td>
</tr>
<tr>
<td>• Harvest when dry</td>
<td>disease in the daughter crop) can take</td>
</tr>
<tr>
<td>• Minimise damage and bruising</td>
<td>place either at loading or unloading</td>
</tr>
<tr>
<td>• Curing and pull-down strategy depends on final</td>
<td></td>
</tr>
<tr>
<td>market and likelihood of disease development</td>
<td></td>
</tr>
<tr>
<td>• In general curing will be required for</td>
<td></td>
</tr>
<tr>
<td>damaged crops or skin spot-susceptible varieties,</td>
<td></td>
</tr>
<tr>
<td>whereas it can be omitted if preventing</td>
<td></td>
</tr>
<tr>
<td>development of silver scurf and black dot is</td>
<td></td>
</tr>
<tr>
<td>essential</td>
<td></td>
</tr>
<tr>
<td>• Aim to pull-down temperatures at c0.5°C per day.</td>
<td></td>
</tr>
<tr>
<td>Prevention of condensation is important during</td>
<td></td>
</tr>
<tr>
<td>curing and pull-down</td>
<td></td>
</tr>
<tr>
<td>• Holding temperatures vary from 2 to 5°C</td>
<td>• Prevention of sprout growth is</td>
</tr>
<tr>
<td>depending on variety, market, storage duration</td>
<td>important and requires the use of</td>
</tr>
<tr>
<td>and fridge capabilities.</td>
<td>refrigeration, especially for storage</td>
</tr>
<tr>
<td>• A sprout suppressant will be required in</td>
<td>after Christmas</td>
</tr>
<tr>
<td>higher temperature stores. Ethylene is an</td>
<td>• A holding temperature of 3°C is often</td>
</tr>
<tr>
<td>option for fresh market: introduce treatment</td>
<td>used to hold crops through to when seed</td>
</tr>
<tr>
<td>gradually to minimise any stress on the crop.</td>
<td>is removed from store in the spring</td>
</tr>
<tr>
<td>Consult with your ethylene specialist prior to</td>
<td>• Airflows may differ from fresh</td>
</tr>
<tr>
<td>use</td>
<td>storage because seed is generally</td>
</tr>
<tr>
<td>• Aim to warm crop (&gt;8°C) before harvesting to</td>
<td>small and packs together more tightly</td>
</tr>
<tr>
<td>reduce damage</td>
<td>within a box</td>
</tr>
<tr>
<td>• Warmed crops should be stood to equilibrate for</td>
<td>• As grading takes place, ensure main</td>
</tr>
<tr>
<td>a day; this allows skins to become more</td>
<td>doors within refrigerated holding</td>
</tr>
<tr>
<td>elastic and reduces thumb-nail cracking</td>
<td>stores stay closed whenever possible</td>
</tr>
<tr>
<td>• Prevention of condensation is important during</td>
<td>to reduce the risk of condensation</td>
</tr>
<tr>
<td>curing and pull-down</td>
<td></td>
</tr>
<tr>
<td>• Aim to warm crop (&gt;8°C) before harvesting to</td>
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</tr>
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<td>reduce damage</td>
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<tr>
<td>• Warmed crops should be stood to equilibrate for</td>
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<tr>
<td>a day; this allows skins to become more elastic</td>
<td></td>
</tr>
<tr>
<td>and reduces thumb-nail cracking</td>
<td></td>
</tr>
</tbody>
</table>

**STORAGE managers’ GUIDE**

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At harvest, potatoes are usually dormant and sprouting does not occur, even under conditions favourable for growth. The period of dormancy varies considerably by variety and season. After break of dormancy, sprouts grow at a rate primarily determined by temperature. Reducing storage temperature is therefore an effective way of controlling sprouting, by first prolonging dormancy and then limiting the rate of growth. To avoid use of sprout suppressants entirely, storage temperatures need to be consistently below 3°C. However, potatoes held at such cold temperatures will be affected by low-temperature sweetening which can adversely affect taste, texture and colour on roasting/frying. In potatoes stored for processing, where low-temperature storage is not an option (because of poor fry colour), the use of sprout suppressants will be necessary for all but the shortest storage durations.

Chemical treatments with chlorpropham (CIPC), maleic hydrazide and ethylene are available for sprout suppression. The principal characteristics of these compounds are shown in Table 18.2. Some production protocols restrict the use of certain active substances.

**Ethylene**

Ethylene is an effective sprout suppressant of low temperature stored crops. Its use is not controlled by the MRL, hence its ‘residue-free’ status favoured by some markets. Ethylene has little residual effect on sprout growth, which will resume soon after removal of crops from store.

Ethylene is a plant hormone which has the potential to markedly increase tuber respiration rate and, as a consequence, increase store carbon dioxide levels. Problems with taste and texture modification, previously associated with ethylene in some varieties, are believed to have been caused by interaction with high levels of carbon dioxide. New guidelines require ethylene concentration to be increased very gradually up to the 10ppm holding concentration to limit respiratory responses. As it is a relatively new method of sprout control, it is important for store managers to follow suppliers’ instructions closely.

**Maleic hydrazide**

Maleic hydrazide is applied to the growing crop in the field. Canopy condition and weather conditions at the time of application are important factors governing uptake and therefore its successful use. MH can be used to limit subsequent CIPC use, but is useful as a stand-alone sprout suppressant only in situations where sprouting risk is relatively low.

**Chlorpropham**

Chlorpropham (CIPC) is the main sprout suppressant used in Britain and virtually all is applied as a hot fog (Figure 18.1). CIPC is suitable in both processing and pre-packing storage systems. The chemical is found as a residue and its use is now subject to a Potato Industry Stewardship Action Plan (see www.potato.org.uk/cipc). CIPC use is limited to 36 g/tonne/season in pre-pack stores and 63.75 g/t/season in processing stores or where the crop will be peeled.

These additional restrictions were introduced to help ensure compliance with the MRL. Store managers should be aware that any breaches of the MRL are likely to result in tighter restrictions on CIPC use and could extend to its complete removal. Although most CIPC is applied by a contractor, it remains the store manager’s responsibility to ensure that applications are justified and all statutory conditions of use are met.

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**Figure 18.1 Hot-fog application of CIPC**
Minimisation strategies

- Segregate by dormancy – varieties with contrasting dormancy characteristics should be held in separate stores so that only crops requiring suppressants are treated.
- CIPC requirements can be limited by use of ethylene (ware) and maleic hydrazide (ware & processing) – but check market acceptability first.
- Varieties with long dormancy and low temperature tolerance reduce need for suppression.

CIPC Application

**Store selection**

- Bulk stores fitted with inverters (variable frequency drives) for fog recirculation are most efficient for CIPC use and preferable for vigorous sprouting and/or long-term storage.
- Use the fans operating at slow speed to assist the application process.
- In ‘overhead throw’ box stores, an open stacking pattern, with pallet slots aligned, aids dispersal. Create a covered plenum to apply fog into. This will stop fog entering the roof space (see Potato Council Growers’ Advice).
- For positively ventilated box stores, it is best to use the ventilation system for application, but this is likely to need some way of slowing fan speeds down. Consult the contractor/chemical supplier.
- Minimise sprouting pressure by selecting stores most able to maintain the desired temperature (ie with effective insulation, low leakage, refrigerated) for long term storage.

**Store loading**

- Loose and adhering soil increases CIPC requirement by limiting movement of the chemical. Only harvest under suitable conditions and take all reasonable steps to extract soil.
- In box stores, align pallet slots as far as possible and leave space around the application port for fog to disperse. The duct carrying fog into a store must never be directed at crop.

When to apply

- Crops should be dry, cured and have an even temperature (ideally within 1°C) at the time of application, Temperature differentials can be reduced by an extended period of recirculation.
- Do not delay CIPC use just because a crop is not at holding temperature – it is better to apply to a crop that is warm and dormant than cool and sprouting.
- Refrigeration and humidification systems should be disabled 12-24 hours before fogging.

**Application**

- Initial treatment will only be successful if applied to dormant crop. If spraying is evident at time of application, use a higher (label) rate and prepare for a reduced storage duration.
- Re-application should take place when signs of fresh sprout growth are observed. ‘Timed’ routine applications should only be made in a low CIPC dose regime.
- Store leakiness is dramatically increased in windy conditions. Seal stores and do not allow applications to be made under windy conditions.

**Processing quality**

- The process of hot-fogging introduces by-products (including ethylene) to the store, which darkens fry colour. For processing crops, ventilate the store as soon as the fog has settled.

---

**Table 18.2 Sprout suppressants for use in potato storage**

<table>
<thead>
<tr>
<th>Active substance</th>
<th>Application method</th>
<th>Notes</th>
<th>MRL* mg/kg</th>
</tr>
</thead>
</table>
| Ethylene               | Gas applied by direct release or generated in-store | • Effective on crops held at temperatures <5°C  
• Not used on processing because results are unpredictable and there is an effect on fry colour | none       |
| Maleic hydrazide (MH)  | In-field foliar spray       | • Provides volunteer control  
• A modest suppressant, often followed by CIPC  
• Results from MH vary depending on weather and canopy condition at time of application | 50         |
| Chlorpropham (CIPC)    | Hot-fog                     | • Commonly used sprout suppressant in GB  
• Rates of use limited across products  
• Stewardship plan in place  
• Treated stores cannot be used for any seeds | 10         |

*maximum residue level permitted in potatoes for sale

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**ACTION POINTS**

**SPROUT SUPPRESSION**

Minimisation strategies

- Segregate by dormancy – varieties with contrasting dormancy characteristics should be held in separate stores so that only crops requiring suppressants are treated.
- CIPC requirements can be limited by use of ethylene (ware) and maleic hydrazide (ware & processing) – but check market acceptability first.
- Varieties with long dormancy and low temperature tolerance reduce need for suppression.

CIPC Application

**Store selection**

- Bulk stores fitted with inverters (variable frequency drives) for fog recirculation are most efficient for CIPC use and preferable for vigorous sprouting and/or long-term storage.
- Use the fans operating at slow speed to assist the application process.
- In ‘overhead throw’ box stores, an open stacking pattern, with pallet slots aligned, aids dispersal. Create a covered plenum to apply fog into. This will stop fog entering the roof space (see Potato Council Growers’ Advice).
- For positively ventilated box stores, it is best to use the ventilation system for application, but this is likely to need some way of slowing fan speeds down. Consult the contractor/chemical supplier.
- Minimise sprouting pressure by selecting stores most able to maintain the desired temperature (ie with effective insulation, low leakage, refrigerated) for long term storage.

**Store loading**

- Loose and adhering soil increases CIPC requirement by limiting movement of the chemical. Only harvest under suitable conditions and take all reasonable steps to extract soil.
- In box stores, align pallet slots as far as possible and leave space around the application port for fog to disperse. The duct carrying fog into a store must never be directed at crop.

When to apply

- Crops should be dry, cured and have an even temperature (ideally within 1°C) at the time of application, Temperature differentials can be reduced by an extended period of recirculation.
- Do not delay CIPC use just because a crop is not at holding temperature – it is better to apply to a crop that is warm and dormant than cool and sprouting.
- Refrigeration and humidification systems should be disabled 12-24 hours before fogging.

**Application**

- Initial treatment will only be successful if applied to dormant crop. If spraying is evident at time of application, use a higher (label) rate and prepare for a reduced storage duration.
- Re-application should take place when signs of fresh sprout growth are observed. ‘Timed’ routine applications should only be made in a low CIPC dose regime.
- Store leakiness is dramatically increased in windy conditions. Seal stores and do not allow applications to be made under windy conditions.

**Processing quality**

- The process of hot-fogging introduces by-products (including ethylene) to the store, which darkens fry colour. For processing crops, ventilate the store as soon as the fog has settled.
Potatoes graded below 8°C are susceptible to impact damage, splitting or bruising. Any wounds that result will heal slowly at cooler temperatures and may make a crop unsuitable for market. To minimise tuber damage and speed-up wound healing, particularly for disease control, it is recommended that crops below 6°C are warmed before grading.

Physics of warming

To warm potatoes to 10°C, the warming air should also be at 10°C. The rate of warming is dependent on the flow of air between the tubers. If boxes of potatoes at 3°C are placed in a grading area at 10°C, natural, convective ventilation will warm them up in about four days. However, if air is forced through the boxes, the rate of warming will increase with the rate of airflow.

At a delivered airflow rate of 0.8 m³/s/t (around 0.4 m³/s/t through the potatoes, after leakage is taken into account), warming a crop by 6°C will take 10-12 hours. But if the crop temperature is below the dew point of the warming air, the whole process is extended. This is because water vapour in the air will condense on the crop. This moisture will then need to be dried, cooling the potatoes by evaporation, before the crop starts to re-warm.

Warming occurs progressively in each box, like a drying front, with the warming front moving vertically in letterbox warming systems (Figure 19.1) and from side-to-side in suction wall systems.

Warming systems

Heated air can be delivered either by forced delivery (blowing) or extraction (suction). In blowing systems, heat can be fed into the fan to bring the temperature of the warming air up to 8-10°C. Warming can be done within the cold store, or in a non-heated building. In suction systems, the air being sucked into the crop needs to be warmed to 8-10°C, which means that the atmosphere surrounding the crop being warmed must be kept at this temperature.

Allowing boxes to warm naturally over four days in a building kept at 8-10°C is the simplest way of warming, but this requires a buffer storage area four times the daily grading rate. If the crop is below the ambient-air dew point temperature, condensation may form on the crop, extending the warming time and exposing the damp potatoes to infection by disease. Forced warming systems, like the letterbox, suction wall or drying tent, which take a night to warm and 24 hours to recover skin moisture, require a warming area twice the daily rate of grading.

Drying of skins when warming

When ventilating the crop with warm air, the tuber skins lose moisture. This makes the skins inelastic and more liable to tearing, giving rise to “fingernail” damage (Figure 19.2). In rapid warming systems, skins should be given 24 hours to recover and rehydrate, prior to grading.
Figure 19.3 Warming the crop prior to handling can significantly minimise bruising

ACTION POINTS

WARMING

Warming for fresh/pre-pack
When warming for pre-pack, it is important to prevent impact damage, bruising and “fingernail” marks. Fingernail marking should be less of an issue where potatoes are washed, as the skins are slippery and the tearing action of dry skin on a dry surface is not a problem. In this situation, a 24-hour skin-recovery period is unnecessary.

- If potatoes are to be graded wet, crop can be warmed overnight for grading next morning.
- If crop is to the graded dry, allow a 24-hour recovery time after overnight warming before handling.
- If natural warming by convection is an option, then grade once the crop is at 8-10°C.

Warming for seed
Seed, being smaller than ware, is less prone to damage. But as seed is graded dry, fingernail damage is more likely, and for subsequent disease control, fast wound healing is vital.

- Follow dry-grading recommendations above.
- After grading, keep seed warm and ventilated for 2-3 days to allow any fresh damage to cure properly before returning to cooler storage.

Safe warming
The safest way to warm potatoes is to ensure that the crop temperature is never below the dew-point temperature of the warming air. This will avoid any wetting but the only place that this condition exists is in the cold store. If the crop is at 3.5°C, the dew-point temperature must be less than 3.5°C. If the crop is warmed in the store, the ventilation or refrigeration system removes any heat that does not enter the crop.

- Warm seed potatoes in cold store to prevent condensation and possible disease initiation.
- If seed is removed from store cold without warming, warm rapidly to minimise length of time crop is wet from warming.
- Use indirect, diesel space heating to warm most economically. Use an electric heater in mobile-heating systems, fitted with RCB protection for safety.
- Always use a thermostat for safety and to minimise energy use when heating.
Quality assurance

Potato production and storage is increasingly subject to quality-assurance procedures, such as the Assured Produce Scheme, which include traceability, care for the environment, and minimisation of risk to the consumer. Good record keeping is also a benefit to management, as it can quickly identify weak points in a production system.

Record keeping should be designed so that all information on a batch of potatoes is kept together. Reasons for any problem can then be rapidly identified. All action taken should be recorded on the log for a batch.

Store diary

It is important to keep a store diary to record general store management information related to all the stocks held within the store. This will include major events such as loading or a chemical application and regular store inspections for condensation, dehydration, rots or blemish diseases. Where detailed individual stock records are kept, it is unlikely that they and the store diary will come together, unless there is some system set up to link the two. This can be resolved by keeping a detailed record or plan showing where each stock is located in the store. Inspection information can then be linked to stocks located in the problem areas.

Store monitoring

Store temperatures and controls should be checked daily. Temperature information is the most critical and a simple log of key probe readings can be kept manually or printed off daily. It is also useful to know how long the hardware has actually been running. Hour meters can be easily fitted to most equipment to provide this information. Stocks of potatoes should be checked weekly. Permanent ladders and walkways should be fitted to allow sampling from the top of the store in safety.

Many store-control systems now offer facilities to log information on a computer (Figure 20.1). Make sure the output is clear or in an easy-to-interpret, graphical format. Increasingly systems also offer computer-based control, in addition to monitoring and logging. These offer useful and user-friendly features such as touch-screen operation, graphical-user interfaces, remote dial-up monitoring and text alerts.

In addition to routine monitoring, there should also be procedures in place to assess the crop regularly.

Figure 20.1 Computerised systems offer comprehensive control options
### POTATO STORAGE RECORD SHEET

**STORE:** Farmyard 2  
**CROP:** Maris Piper, Field 10

<table>
<thead>
<tr>
<th>Date &amp; Time</th>
<th>CROP TEMP °C</th>
<th>AIR TEMP °C</th>
<th>FANS</th>
<th>FRIDGE</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Set-pts Ave Min sensor Max sensor</td>
<td>External Store ave Hours Run</td>
<td>Hours Run</td>
<td></td>
<td></td>
</tr>
<tr>
<td>149 8.00</td>
<td>120 13.4 132 51 139 58</td>
<td>131 136 1235</td>
<td>- 7.39</td>
<td>Dry curing</td>
<td></td>
</tr>
<tr>
<td>159 8.40</td>
<td>120 13.0 129 51 133 56</td>
<td>128 132 1255</td>
<td>20 747 8</td>
<td>Fridge OK</td>
<td></td>
</tr>
<tr>
<td>169 8.15</td>
<td>120 12.7 125 51 130 56</td>
<td>165 137 1279</td>
<td>24 754 7</td>
<td>Ext air off</td>
<td></td>
</tr>
</tbody>
</table>

#### ACTION POINTS

**STORE MONITORING**

**Quality assurance records**
Records are needed to satisfy quality-assurance protocols such as the Assured Produce Scheme, Nature’s Choice, UKROFS, or in-house schemes. They demonstrate to buyers that a crop is being produced according to an agreed protocol.

- Keep records available for inspection by buyers at any time.
- Update records daily (Figure 20.2) to give fast access should problems occur.
- Ensure store diary records can be linked to stock records to find problems relating to store design or management.

**Records to assess crop standard**
It is important to know the quality of product before it leaves the storage premises. This may include fry colour tests, blemish disease and skin-damage assessments. Good sampling before dispatch can help avoid the problem of rejection on delivery.

- Assess product before it leaves the store, using methods as near as possible to those the buyer will use on receipt.
- Keep samples of all product sold for the period over which any problems may occur, e.g. a week for pre-pack, 6-8 weeks for seed.

**Seed passports**
Since many diseases on crops can have origins in the seed used, seed passports are increasingly being recommended. While husbandry factors such as date of planting and lifting are useful, a disease assessment of stock BEFORE grading is essential.

- Provide all seed with seed passports including key agronomic dates plus variety, grade and size.
- Record disease levels before grading.
- Record seed treatment (if any).
- Record temperature on dispatch.
  - Send leaflet with load detailing action to be taken by grower on receipt.

**Service store equipment**
Regular servicing of store equipment reduces the chance of breakdowns which can compromise quality if they occur at crucial times.

- Ensure all equipment is serviced and checked annually.
- Keep service records to demonstrate due diligence.
There are a significant number of regulations which cover health and safety in and around the potato store. Store owners, operators and employees working in potato stores, must do everything possible to ensure the safety of themselves and others. The easiest way to do this is to complete a risk assessment. Specialist help is available to advise on this process in detail.

When assessing risk, it is best to keep matters simple wherever possible to ensure any measures to improve safety are followed. So questions asked to find out what the risks are and what steps are being taken to minimise those risks should be straightforward. If measures are inadequate, additional controls may be required. Remember: not doing something simply to save time or expense is not an acceptable course of action where safety is compromised.

**Risks in stores**

Risk assessment is a statutory requirement as part of health and safety legislation. It is relatively straightforward to make and record an assessment of risks in each store. Follow the process shown in the risk management ‘wheel’ below. (Figure 21.1). Risks which commonly occur in a potato store include:

- Climbing & falling
- Tripping
- CO₂ accumulation
- Chemical use
- Electric shock
- Vehicle movement
- Lighting
- Box stacking

An important aspect of the risk management process is the feedback it provides, so if a particular risk is measured and continues to present problems, it can be re-evaluated and further measures taken to minimise it.

For more information see the Health & Safety Executive website at www.hse.gov.uk/pubns/indg401.pdf or call the Potato Council’s storage advice line: 0800 02 82 111

**Working at height**

The most significant new piece of legislation to affect potato storage in recent years has been the Work at Height Regulations 2005. Potato storage is not deemed to be a short-term activity, so one of the main changes resulting from these regulations has been the ban placed on the use of ladders in stores. While a ladder can still be used for temporary access, such as changing a light bulb, using a ladder for regular access to the top of a store over two metres high is not legal. If access to the top of boxes is required, an alternative means of access must be provided. Once on top of the stack, it is also necessary to provide a physical barrier to alert someone to any gaps between boxes or proximity to the edge of the stack.
In box stores, (Figure 21.2) stepped ladders can be employed to good effect. Each ladder allows the operator to climb two boxes to a covered box/platform, followed by another two box climb and so on, to the top of the stack. Using a ladder for regular access to the top of a store over two metres high is not legal.

Insist that all persons on site are highly visible and well equipped to work in a store.

Be sure to log visitors in and out so that they can be accounted for in an emergency.

Do not allow external personnel to access the store without a detailed briefing on the store conditions and any associated risks.
ADVICE & PUBLICATIONS

Potato Council Sutton Bridge Crop Storage Research Potato storage advice and information. Tel: 0800 02 82 111.
e-mail: sbscr@potato.ahdb.org.uk. www.potato.org.uk/sbscr

Potato Council publications

- Project Summary Sheets & Research Reports – information on levy funded R&D projects
- Growers’ Guides – seed production and storage advice
- Pests & Diseases Handbook – reference guide
- Product Guide – potato sprout suppressant active substances and dose rates

Available from Publications Dept., Agriculture & Horticulture Development Board (AHDB), Stoneleigh Park, Kenilworth, Warwickshire. CV8 2TL. Potato Council is a division of AHDB.
Tel: 0247 669 2051. E-mail: publications@potato.ahdb.org.uk. www.potato.org.uk

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Cunnington, AC; Briddon, A; Duncan, H J; Jina, A; Lane, AG & Miller, PCH (2001). Optimisation of CIPC application and distribution in stored potatoes BPC Sutton Bridge Crop Storage Research, Silsoe Research Institute & University of Glasgow research report for BPC, no.2001/6, Potato Council.

Cunnington, AC; Briddon, A; McGowan, G; Jina, A and Duncan, HJ (2005). Developments in CIPC application and its effects on processing quality. In: Abstracts, 16th Triennial Conference of European Association for Potato Research


Hede, GA (1992) Towards integrated control of potato storage diseases In: Protection & Production of Potatoes. Aspects of Applied Biology 33 197-204

Hyldø, B; Persson, T; Wickberg, C & Sparks, WC (1975). The heat balance in a potato pile. I & II. Acta Agriculture Scandinavica, 25 81-91


Park, LJ, Duncan, HJ; Briddon, A; Jina, A; Cunnington, AC & Saunders, SR (2006). Review and development of the CIPC application process and evaluation of environmental issues. Study 243: final report British Potato Council, Oxford. 60pp

Peters, JC; Lees, AK; Cullen, DW; Sullivan, L; Stroud GP & Cunnington AC (2008). Characterisation of Fusarium spp. responsible for causing dry rot of potato in Great Britain. Plant Pathology 57: 262-271


OTHER INFORMATION


Potato Industry CIPC Stewardship Group. Stewardship guidance on the use of CIPC. www.potato.org.uk/cipc

SAC. Seed storage information, Craibstone, Bucksburn, Aberdeen. AB21 9TR. Tel: 01224 711000. www.sac.co.uk
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air mixing/blending</td>
<td>Mixing or blending of recirculated and ambient air controlled by regulation of the duct temperature</td>
</tr>
<tr>
<td>Air on/off TD</td>
<td>Temperature difference (TD) between air coming on and off a fridge coil</td>
</tr>
<tr>
<td>Ambient air</td>
<td>Air external to the building structure</td>
</tr>
<tr>
<td>Anaerobic conditions</td>
<td>Where no air is present</td>
</tr>
<tr>
<td>Blemish diseases</td>
<td>Diseases which cause unsightly marks on the skin of the tuber</td>
</tr>
<tr>
<td>Bloom</td>
<td>Reflective shine on tubers</td>
</tr>
<tr>
<td>Composite panel</td>
<td>Factory-made insulation panel, which should have a non-flammable core, injected between two metal skins, made of polyisocyanurate (PIR).</td>
</tr>
<tr>
<td>Crop set-point</td>
<td>Target or desired crop temperature</td>
</tr>
<tr>
<td>Curing period</td>
<td>As wound-healing period</td>
</tr>
<tr>
<td>Dead band</td>
<td>Tolerance either side of a crop set-point</td>
</tr>
<tr>
<td>Dew point</td>
<td>Temperature at which water vapour in air will start to condense</td>
</tr>
<tr>
<td>Differential</td>
<td>Difference in temperature between one area in a store and another. For example, crop/ambient air differential would be the difference between the temperature of the crop and air drawn from outside</td>
</tr>
<tr>
<td>Disease expression</td>
<td>Display of visible disease symptoms</td>
</tr>
<tr>
<td>Disease infection</td>
<td>Entry into the flesh of the tuber by bacteria or fungus</td>
</tr>
<tr>
<td>Dormancy</td>
<td>Period between tuber initiation in the soil and growth of sprouts</td>
</tr>
<tr>
<td>Dormancy break</td>
<td>When 50% or more of tubers have sprouts of 3mm or more in length</td>
</tr>
<tr>
<td>Duct lower limit</td>
<td>Minimum allowable temperature of air in main duct</td>
</tr>
<tr>
<td>EEP</td>
<td>Expanded extruded polystyrene (board insulant)</td>
</tr>
<tr>
<td>Fridge TD</td>
<td>Temperature difference (TD) between air coming onto coil and evaporating gas temperature within the coil</td>
</tr>
<tr>
<td>Hot box</td>
<td>Insulated cabinet warmed to 32-36°C, and humidified with water, used for samples of potatoes to speed expression of bruising or to accelerate rotting</td>
</tr>
<tr>
<td>Inoculum</td>
<td>Infective agents of disease, eg fungal spores, bacteria etc.</td>
</tr>
<tr>
<td>Interstitial condensation</td>
<td>Condensation forming within the building structure</td>
</tr>
<tr>
<td>Latent heat of evaporation</td>
<td>(Hidden) heat required to change water from liquid phase to vapour phase with no increase in its temperature (2.4MJ/kg). Half of cooling of potatoes with cool air results from heat removed by evaporation.</td>
</tr>
<tr>
<td>Lateral</td>
<td>Secondary delivery duct off main air duct, usually beneath a bulk pile</td>
</tr>
<tr>
<td>Mummify</td>
<td>The process of drying a rotten tuber to a dry shrivelled mass</td>
</tr>
<tr>
<td>Periderm</td>
<td>Corky outer skin layer of potato</td>
</tr>
<tr>
<td>PU</td>
<td>Polyurethane (board or spray insulant) unsuitable for composite panels</td>
</tr>
<tr>
<td>Relative humidity (RH)</td>
<td>Mass of water vapour in air at a defined temperature compared with the maximum vapour it can hold at that temperature, expressed as percentage</td>
</tr>
<tr>
<td>Saturation humidity</td>
<td>Point where air contains the maximum mass of water vapour which can be held per unit mass of air at any given temperature (≈100% RH)</td>
</tr>
<tr>
<td>Soft rots</td>
<td>Bacterial wet rots</td>
</tr>
<tr>
<td>Split-grading</td>
<td>Separating tubers into two or more size fractions, usually at harvest</td>
</tr>
<tr>
<td>Stack condensation</td>
<td>Condensation forming within the crop</td>
</tr>
<tr>
<td>Structural condensation</td>
<td>Condensation forming on the building structure</td>
</tr>
<tr>
<td>Suberisation</td>
<td>Laying down of the chemical suberin between damaged surface cells of tuber as first part of periderm formation in the wound healing process</td>
</tr>
<tr>
<td>U-Value</td>
<td>Heat conductivity of a building material (W/m²·°C). The lower the value, the better insulated the material</td>
</tr>
<tr>
<td>Wet rots</td>
<td>Tubers where the flesh has been invaded by disease organisms to form a liquid mass with little structural strength. The wet mass collapses on unaffected neighbouring tubers, providing inoculum and anaerobic conditions, which can lead to further rotting</td>
</tr>
<tr>
<td>Wound-healing period</td>
<td>Period for wounds on crop to heal, to form a barrier against disease ingress to the flesh of the tuber</td>
</tr>
<tr>
<td>© number</td>
<td>Cross-reference to the relevant numbered section of this Guide</td>
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</table>
### Metric equivalents

<table>
<thead>
<tr>
<th><strong>Temperature conversions</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
</tr>
<tr>
<td>°F</td>
</tr>
</tbody>
</table>

°F = \frac{5}{9} \times (°C - 32)

°C = \frac{9}{5} \times (°F - 32)

Note: the conversions tabulated are accurate to ± 0.2°C. For greater accuracy the appropriate formula should be used.

### Other conversion factors

<table>
<thead>
<tr>
<th><strong>Length</strong></th>
<th>in x 25.40</th>
<th>= mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in x 0.254</td>
<td>= m</td>
</tr>
<tr>
<td></td>
<td>ft x 0.3048</td>
<td>= ft</td>
</tr>
<tr>
<td><strong>Area</strong></td>
<td>in² x 645.2</td>
<td>= mm²</td>
</tr>
<tr>
<td></td>
<td>ft² x 0.0929</td>
<td>= m²</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td>ft³ x 0.0283</td>
<td>= m³</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>lb x 0.4536</td>
<td>= kg</td>
</tr>
<tr>
<td></td>
<td>cwt x 50.802</td>
<td>= kg</td>
</tr>
<tr>
<td></td>
<td>ton x 1.0162</td>
<td>= tonne</td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>lb/ft³ x 16.0185</td>
<td>= kg/m³</td>
</tr>
<tr>
<td></td>
<td>ft³/ton x 0.0279</td>
<td>= m³/tonne</td>
</tr>
<tr>
<td><strong>Velocity</strong></td>
<td>ft/min x 0.0051</td>
<td>= m/s</td>
</tr>
<tr>
<td></td>
<td>m/s x 196.9</td>
<td>= ft/min</td>
</tr>
<tr>
<td><strong>Volume Flow</strong></td>
<td>ft³/min x 0.00047</td>
<td>= m³/s</td>
</tr>
<tr>
<td></td>
<td>ft³/min x 1.699</td>
<td>= m³/h</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>in WG x 250</td>
<td>= N/m² (Pa)**</td>
</tr>
<tr>
<td></td>
<td>in WG x 0.250</td>
<td>= kN/m² (kPa)</td>
</tr>
<tr>
<td></td>
<td>in WG x 2.5</td>
<td>= bar</td>
</tr>
<tr>
<td></td>
<td>Atmosphere (STD)* x 1.013</td>
<td>= bar</td>
</tr>
</tbody>
</table>

| **Flow rates** | lb/h x 0.4536| = kg/h |
|                | ton/h x 1.0162| = tonne/h |
| **Power**      | hp x 746| = W |
|                | W x 0.0013| = hp |
| **Heat Flow**  | Btu/h x 0.293| = W |
|                | W x 3.412| = Btu/h |
| **Heat energy content** | Btu/lb x 0.556| = kcal/kg |
|                | kcal/kg x 1.8| = Btu/lb |
| **Moisture content** | gr/lb x 0.00014| = kg/kg |
|                | kg/kg x 7142.0| = gr/lb |
| **Thermal conductance or Thermal transmittance** | Btu/ft²h.deg F x 5.678| = W/m².°C |
|                | W/m².°C x 0.176| = Btu/ft²h.deg F |
| **Thermal conductivity** | Btu.in/ft²h.deg F x 0.144| = W/m.°C |
|                | W/m.°C x 6.94| = Btu.in/ft²h.deg F |

*STD = Standard, **1 Pascal (Pa) = 1 Newton/ m² (1 N/m²)

### Examples of how to use the table

1) If the airflow rate is 85ft³/min, the metric equivalent = 85 x 0.00047 = 0.0399m³/s

2) If air pressure is 150 Pa, the imperial equivalent = 150 x 0.004 = 0.6 in Water Gauge (WG)
The dew-point temperature of air based on its temperature and relative humidity

Use this dew-point table to determine condensation risk.

<table>
<thead>
<tr>
<th>(Dry bulb) temperature (°C)</th>
<th>60</th>
<th>62</th>
<th>64</th>
<th>66</th>
<th>68</th>
<th>70</th>
<th>72</th>
<th>76</th>
<th>80</th>
<th>84</th>
<th>88</th>
<th>92</th>
<th>96</th>
<th>100</th>
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<td>1.0</td>
</tr>
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</table>

Source: CIBSE

Example 1:

- If air’s (dry bulb) temperature is 15°C and its relative humidity is 70%, the dew-point temperature of that air is 9.7°C

Example 2:

To determine condensation risk:

e.g.
- If external air at 8°C and 84% RH enters a store, will it condense on potatoes with a temperature of 5°C?
- Check dew-point of air at 8°C at 84% RH. It is 5.5°C
- Therefore the air will condense on any surface with a temperature below 5.5°C and so condensation on the crop will occur