Final Report

Reducing the Energy Cost of Potato Storage

Ref: R401

Reporting Period: September 2009 – September 2010

Report Author: Jon Swain

Work carried out in collaboration with Sutton Bridge Crop Storage Research

Date report submitted: October 2010

Report No. 2010/14

The Potato Council is a division of the Agriculture and Horticulture Development Board.

Additional copies of this report and a list of other publications can be obtained from:

Publications

Potato Council
Agriculture & Horticulture Development Board
Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

Tel: 02476 692051
Fax: 02476 789902
E-mail: publications@potato.org.uk

Our reports, and lists of publications, are also available at www.potato.org.uk

CONTENTS

1. SUMMARY

This report covers the final year (2009/2010 season) of a three year energy monitoring project on 36 potato stores, selected to represent a typical cross section of those that might be found in the UK.

Eight sites were chosen to be part of the first project year (2007/08); these were four processing stores and four pre-pack stores of varying ages and conditions. A further twenty eight stores were selected to be part of the second year (2008/09) and, the third and final year (2009/10) of the project.

Monthly energy data has been gathered from electricity meters and quantities of stored produce logged. During the latter months of the second year and throughout the third year of the project, target temperatures were also recorded. The original four pre-pack stores and four processing stores were intensively monitored using real-time on-line data collection.

Regular reports on the energy consumption of all stores has been returned to the store managers and uploaded to the Potato Council's Energy Hub (www.potato.org.uk/energy).

During the last year of monitoring the following was noted:

Energy costs have risen by 8%.

2009 had a warmer autumn requiring more 'pull down' energy but a colder winter requiring processing stores to use additional heat to maintain target temperatures and lowering cooling energy requirement in pre-pack storage.

The specific energy consumptions achieved for the ***intensively monitored processing stores*** are given in table 1 below.

	kWh/tonne/day Achieved 2009/10	**kWh/tonne/day Achieved 2008/09**	**kWh/tonne/day Achieved 2007/08**
Min	0.1	0.1	0.08
Max	0.18	0.16	0.29*
Average	0.13	0.12	0.15*

*Note this value is from one store which is much greater than the rest of the group and has affected the average. Without this store the group has a maximum of 0.12 kWh/tonne/day and an average of 0.1 kWh/tonne/day

TABLE 1. SPECIFIC ENERGY CONSUMPTIONS ACHIEVED FOR INTENSIVELY MONITORED PROCESSING STORES

2009/10 was a demanding year for processing stores in terms of energy requirement. A milder early season did not favour ambient pull down and a colder winter caused store managers to use heating to avoid frost damage. 2009/10 measured energy consumptions were on average 8.3% greater than in 2008/09, but 15% less than in 2007/08.

The range of energy consumptions for the ***basic monitored processing stores*** was much wider at 0.04 kWh/tonne/day to 0.29 kWh/tonne/day (average performance of 0.13 kWh/tonne /day). Lower energy consumptions were realised by more modern stores running for fewer months and vice versa.

The specific energy consumptions of the ***intensively monitored pre-pack stores*** are shown in table 2 below.

	kWh/tonne/day Achieved 2009/10	**kWh/tonne/day Achieved 2008/09**	**kWh/tonne/day Achieved 2007/08**
Min	0.17	0.21	0.29
Max	0.37	0.33	0.64**
Average	0.31	0.26	0.38**

** Note this value is from one store which in 2007/08 performed so poorly that it was shut down early. The data for the period it ran has affected the average. Without this store the group has a maximum of 0.33 kWh/tonne/day and an average of 0.3 kWh/tonne/day.

TABLE 2. SPECIFIC ENERGY CONSUMPTIONS ACHIEVED FOR INTENSIVELY MONITORED PRE-PACK STORES

The energy consumptions are on average 19% greater than 2008/09 and 18% less than 2007/08. Higher energy consumption in 2009/10 can be partly explained by one store in this group which used Restrain as a sprout suppressant and could not make use of ambient cooling. Additionally there was a significant affect on the energy consumption of one store from part loading.

Again the spread of energy consumptions for the ***basic monitored pre-pack stores*** was much wider ranging from 0.15 kWh/tonne/day to 0.7 kWh/tonne/day (average performance of 0.34 kWh/tonne/day).

The energy requirement for potato storage contributes to the carbon footprint of the production of potatoes. The relative impact of typical processing and pre-pack storage is shown in table 3 below.

Months stored	Processing carbon emissions (kg/tonne)	Pre-pack carbon emissions (kg/tonne)
October - May	22	77.9
October - April	18	57
November - April	14	38.7
November - March	11	28.2

TABLE 3. CARBON EMISSIONS OF TYPICAL PROCESSING AND PRE-PACK STORAGE

Temperature data analysed for 2009/10 showed there were on average 20% more hours of ambient cooling for processing stores compared with 2008/09 and 72% more hours available for pre-pack stores.

The project has illustrated the benefit of simple storage energy monitoring and that, by using inexpensive electricity meters and temperature data from store control equipment or a retrofit monitor, comparative data on electricity consumption can be accurately recorded and compared.

2. INTRODUCTION

The energy review commissioned by Potato Council (PCL) in 2006 concluded that one of the key first steps to reducing storage energy consumption is to monitor comparative energy use and use this information to target potential energy savings.

Project R401 was commissioned to address this subject and demonstrate the techniques and value of energy monitoring applied to potato storage.

A summary of project objectives was:

- To demonstrate the application of energy data collection and analysis
- To develop an information resource and establish benchmarks for storage energy use
- To assess the impact of energy management strategies on usage
- To quantify the primary carbon footprint for storage energy use.

The project was progressed over three years, from 2007/8 to 2009/10, with the following programme:

Year 1 - Monitoring a small number of stores (eight in total) intensively and setting up procedures for handling data and reporting information to store managers.
Year 2 - Extending the study to encompass a further 28 stores.
Year 3 - Continuing the studies carried out in Year 2.

This report presents the results from the third year's work, establishing energy consumption of eight intensively monitored stores and 31 basic (monthly) monitored stores.

2.1. Energy Costs

The graph in Figure 1 below shows how wholesale electricity prices have changed since the beginning of the project.

FIGURE 1. ENERGY PRICE CHANGES (£/MWH)

Clearly price changes have been volatile over the last three years. Importantly following a fall through 2009 and early 2010 electricity prices began to increase from the middle of 2010. Table 4 gives typical prices in the commercial retail sector – rates which would have been available to potato producers.

Date	Contract energy cost (pence/kWh)	Annual cost of a 50,000 kWh site (£)	Percentage change from 2006 (%)
01/09/2006	8.25	4,125	0
01/09/2007	6.89	3,445	-20
01/09/2008	12.3	6,162	33
01/09/2009	8.99	4,495	8
01/09/2010	9.87	4,935	16

TABLE 4. TYPICAL ENERGY PRICES AND COST FOR A 50,000 KWH CONTRACT

A typical 50,000 kWh use site would pay around £440 more for energy in 2009/10 than in 2008/09 and £940 more than in 2006/07. The forecast move towards more renewable energy and the upgrade to a Smart Grid will lead to further price increases in the medium term. Therefore the need to understand and control the energy consumption in potato storage will become more important.

Knowing the cost of energy in potato storage is essential to establish financial viability of investments which will result in reductions in energy use.

2.1.1. Outside Temperatures

The graph in Figure 2 below shows the difference in outside temperature between 2009/10 and 2008/09. A negative value represents a colder period and a positive value a warmer period.

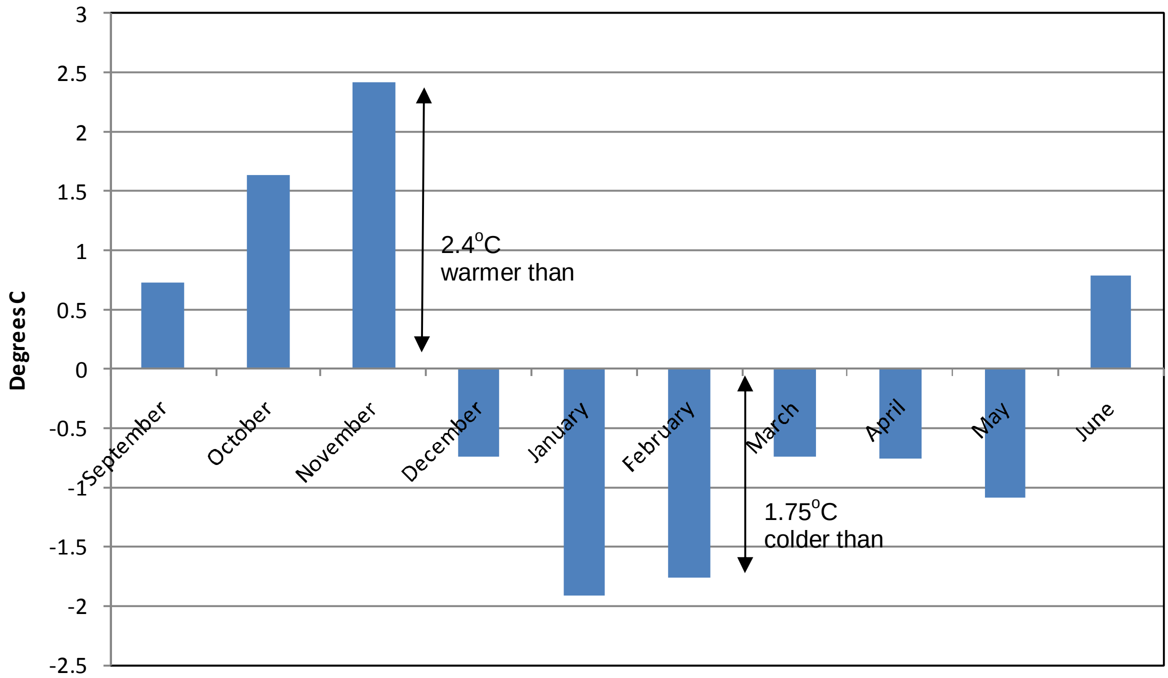


FIGURE 2. AVERAGE MONTHLY DIFFERENCE IN OUTSIDE TEMPERATURE BETWEEN 2009/10 AND 2008/09

Generally, the graph shows a warmer autumn giving way to a colder winter and spring.

This has had both positive and negative effects on energy consumption. More energy has been used through greater cooling demand at the beginning of the season and, for some processing stores, a requirement for additional heating in the winter months. However, in latter months less energy has been needed for pre-pack storage with lower temperatures giving more potential for ambient cooling, and a lower refrigeration load.

3. Material and Methods

3.1. Overview

In the 2007/08 storage season eight stores in total were monitored; 2008/09 saw this increase to 36. In 2009/10 there were 38 in total. Two groups were established dependent on the frequency of data collection.

Intensive monitoring

- Eight stores (these were the stores monitored originally in 2007/08)
- 50:50 split pre-pack and processing produce storage
- Variety of ages and conditions to reflect store types in the UK
- Electricity consumption and temperatures achieved recorded half hourly - data downloaded remotely
- Tonnes in store data returned every month.

Basic monitoring

- 30 further stores
- Split between pre-pack and processing produce storage
- Fitted with manual read electricity meters
- Electricity consumption, target temperature and tonnes in store data returned monthly.

As before the stores were grouped as either pre-pack or processing types.

1. ***Pre-pack produce stores*** – these store potatoes for raw sales at a target temperature between 2 and 3℃.
2. ***Processing produce stores*** – these store potatoes for the processing market (chips, crisps, etc.) at a target temperature of between 7.5 and 10℃.

All stores were surveyed at the start of the project. This was to gather information regarding:

- Store type and design
- Construction
- Condition and maintenance
- Age
- Target temperature and control type.

This information was then used in the project to categorise stores into groups and to make comparisons of performance.

3.2. Intensively Monitored Group

The first year's report comprehensively describes the monitoring processes with this group of eight stores. This year data continued to be collected from these stores in a similar manner.

Some minor changes from Year 2 were:

- Metering for Store 4 was compromised by the addition of another store to the electrical supply. Data regarding electricity consumption has been based on monthly readings alone.

- As the wireless temperature probe for Store 8 was lost, analysis has been based on data from the site.

3.3. Basic Monitored Group

Twenty eight of these stores were selected in 2008/09 and supplied with an electricity meter for fitting by their site electrician.

The meters supplied were:

- Universal fitting current transformer types
- Panel mounted for neatness
- Manually read for simplicity.

FIGURE 3 – SAMPLE METER INSTALLATION

This year there were some small changes to the group:

- One processing store dropped out
- Two additional pre-pack stores on a new site that already had meters fitted were included
- One existing combined pre-pack store was divided to form two stores and additional sub metering installed by the site
- One additional pre-pack store was included from an existing site.

This means that 30 stores were part of the basic monitored group in 2009/10.

3.4. Data Collected

3.4.1. All stores

All stores were asked to supply electricity meter readings and information about quantities of produce in store every month. A variety of methods were used to collect the data including:

- Postal returns
- Email
- Text message
- Telephone.

The data collection prompting regime was:
1. Request for data letter sent 28th of the month.
2. Text message sent on 1st of the month.
3. Reminder text sent on 5th of the month.

Data collection was not always reliable. Whilst every effort was made to make the return of data simple and easy for the site managers, sometimes it was necessary to follow up data requests with further letters and telephone calls.

A sample postal return is shown in Figure 4 below.

POTATO COUNCIL

Potato Storage Energy Project

This project is run for and on behalf of the Potato Council Ltd by FEC Services & Sutton Bridge Experimental Unit

07 JAN 2009

Data Collection Sheet

Company: | **Store:** | **Meter Code:**

Previous readings supplied

Period Start	Start Reading	Period End	End Reading	Storage Amount	Boxes/ Tonnes
29/08/2008	0	30/08/2008	0	0	Tonnes
01/09/2008	0	30/09/2008	0	0	Tonnes
01/10/2008	0	07/10/2008	0	0	Tonnes
08/10/2008	0	10/10/2008	0	0	Tonnes
11/10/2008	0	03/11/2008	3701.4	700	Tonnes

Readings from 03/11/2008 onwards

Date	Meter Reading	Storage Amount	Boxes/Tonnes
03/11/2008	3701.4	0.00	Tonnes
05/01/09	9757.0	700 Ton	

Please fill in the table above with your current meter reading and number of tonnes / boxes in store. If you have added or removed potatoes from your store since your last data submission, please fill in a separate line for each movement, making sure that you show the storage amount, as well as the start and end meter readings for the corresponding periods.

Please return this sheet in the enclosed pre-paid envelope or alternatively text to: 024 7610 0300 in the format 'METER CODE' + 'METER READING' + 'STORAGE AMOUNT' + 'BOXES / TONNES'. Please see the example below -

JONA1 + 12345 + 2000 + TONNES

FIGURE 4 - SAMPLE POSTAL RETURN

For the later months of the second project year and throughout this third year the store managers were also asked to provide target temperatures.

The majority of growers favoured text message data returns because of their simplicity and ability to instantly deliver the necessary information.

3.5. Methods of Expressing Store Energy Performance

On the face of it, expressing the efficiency of store energy can be done reasonably simply, and in terms of kWh of electrical energy used.[1]

However, if figures are to be used for meaningful comparison purposes then evaluation of energy use needs to be more sophisticated. How, for instance, might a grower compare his store with another of a different size, operating a different storage temperature, or over a different season period? In this case measurements need to take into account:

- Storage tonnage
- Length of storage period
- Storage temperature
- Ambient temperature.

Inevitably, the more reliable and meaningful the measure of energy efficiency, the more difficult it is to derive and the more additional information is needed to calculate a result. So there is a trade-off between simplicity and relevance.

The following paragraphs describe and discuss a number of evaluation methods.

3.5.1. Entire Season Specific Energy Consumption (kWh/tonne)

This measure provides the simplest approach to analysing the energy efficiency of a potato store and is used commonly as a simple way of expressing performance. To calculate the value, take the amount of electricity consumed during the storage season (in kWh) and divide it by the quantity of potatoes stored during the season (in tonnes). For example if the store uses 20,000 kWh during the season and 1000 tonnes were stored, then the *Entire Season Specific Energy Consumption* would be 20 kWh/tonne.

The advantage of using this measure is that it is easily calculated and understood and gives an instant ‘headline’ figure. It does however have a number of serious disadvantages in truly reflecting performance. These are:

- It takes no account of storage period
- It takes no account of the effect of part unloading of a store at some point during the season
- It takes no account of temperature or weather differences.

---

[1] kilowatt hour (kWh)

This is a unit of energy measurement and refers here to electricity. A kWh is sometimes referred to as a ‘unit’ of electricity. It is defined as the amount of energy used by a load of 1 kW in 1 hour. (So, a machine of power 2 kW or 2000 Watts) operating for three hours would consume 6 kWh (or 6 units) of electricity. The kWh is the common unit used by electricity utilities when billing electricity.

3.5.2. Average Daily Energy Consumption (kWh/tonne/day)

This measure takes the *Entire Season Specific Energy Consumption* and divides it by the storage period in days to give a daily average value. This makes comparisons between stores with different lengths easier. The disadvantage of this measure is that as a small value it may sometimes not be easily comparable. It may be useful to express this as kWh/100 tonnes/day.

3.5.3. Full Store Specific Energy Consumption (kWh/tonne/day)

This measure is calculated in the same way as the *Average Daily Energy Consumption* but it only covers the period when the store is **fully loaded**. So for a 1,000 tonne store which has used 10,000 kWh from the end of filling to the beginning of out-loading over 100 days and then a further 2,000 kWh over the part loaded period, the *Full Store Specific Energy Consumption* would only take into account the energy use in the 'full' period. Therefore, the *Full Store Specific Energy Consumption* in this case would be 0.1 kWh/tonne/day.

This measure provides a useful way of comparing the performance of stores when the stores are full. The obvious disadvantage of this measure is that it takes no account of the marginal performance of part loaded stores in either the loading period or the unloading period of storage and so cannot be used to reflect full season performance.

3.5.4. Cumulative Specific Energy Consumption

In order to calculate this number, each daily energy use is divided by the quantity of potatoes in the store during that day. These values are summated over the period of storage to give *Cumulative Specific Energy Consumption*.

As an example, if the first day's energy consumption was 4 kWh/tonne, the second day 3 kWh/tonne, the third day 2 kWh/tonne. The *Cumulative Specific Energy Consumption* for the period would be 4 + 3 + 2 = 9 kWh/tonne.

The advantage of this measure is that, over a season, it gives a 'weighted average' reflecting the disproportional effect of high energy use per tonne at the beginning and end of the storage period. Used to analyse the latter period of storage it can provide marginal costing information which can help in deciding the viability of storing a small quantity of potatoes for an extended period.

The disadvantage of using this measure is that any store part loaded for a long period is not readily comparable with a store that is kept full and then emptied rapidly. In this case it may be better to compare store performance using the *Full Store Specific Energy Consumption* metric.

3.6. Data Reporting

3.6.1. Monthly Reporting

All participants received a monthly report detailing the performance of their store. A number of key performance indicators were given in the reports, these were:

- Monthly kWh/tonne
- Monthly energy cost
- Season to date kWh/tonne
- Season to date cost
- Graphs of performance to date.

Figure 5 shows a sample monthly report as sent to the participants.

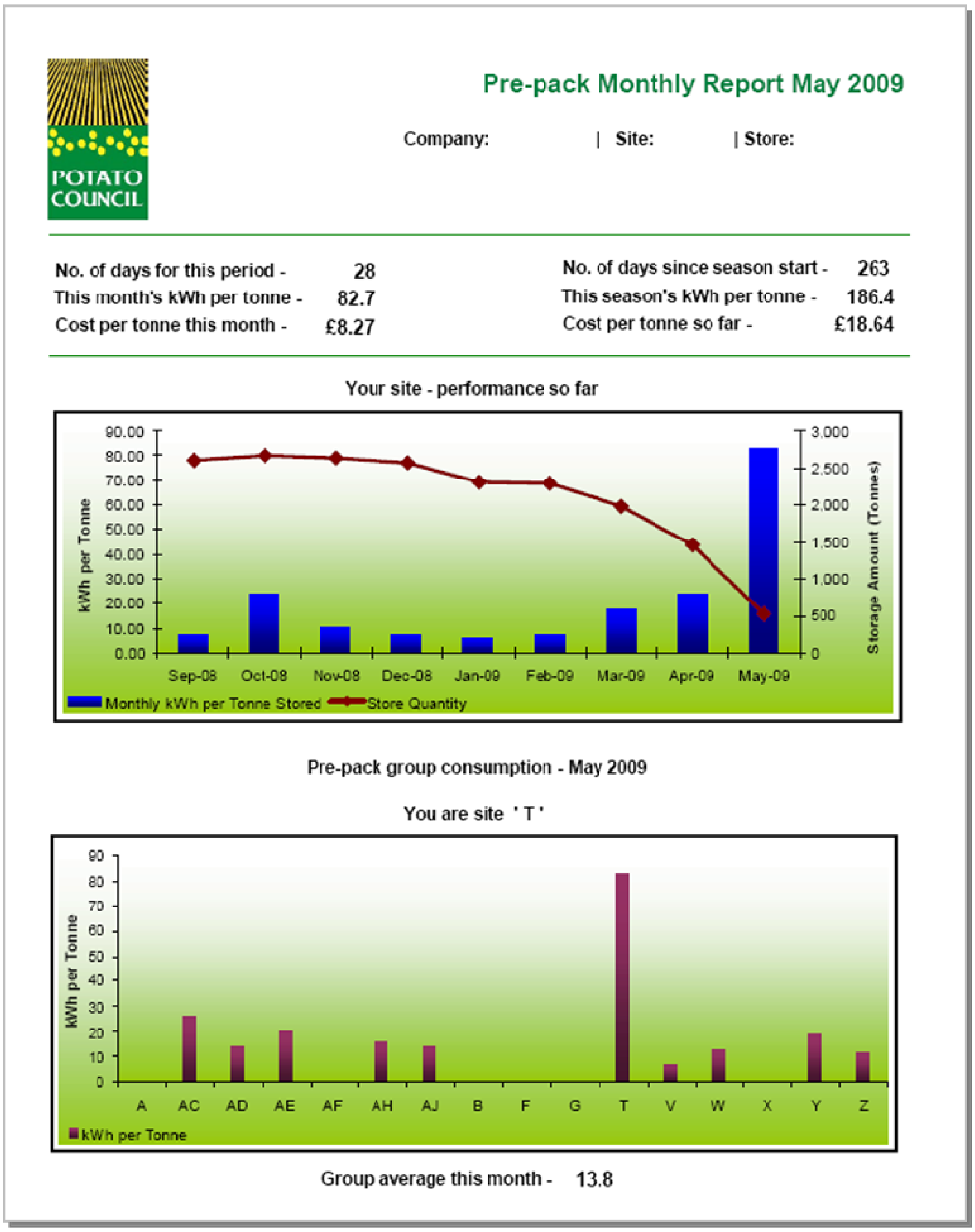


FIGURE 5 - SAMPLE MONTHLY REPORT

3.6.2. Group Reporting

Monthly reports were also produced grouping the performance of pre-pack and processing stores. The key performance indicators used were:

- Monthly kWh/tonne
- Season to date kWh/tonne
- Average kWh/day/100 tonne in the current month
- Average kWh/day/100 tonne the season to date.

These reports were uploaded to the Potato Council's website 'energy hub' section in order that all PCL members could access the results and benchmark their own stores performance. An example of a group report is given in Figure 6 below.

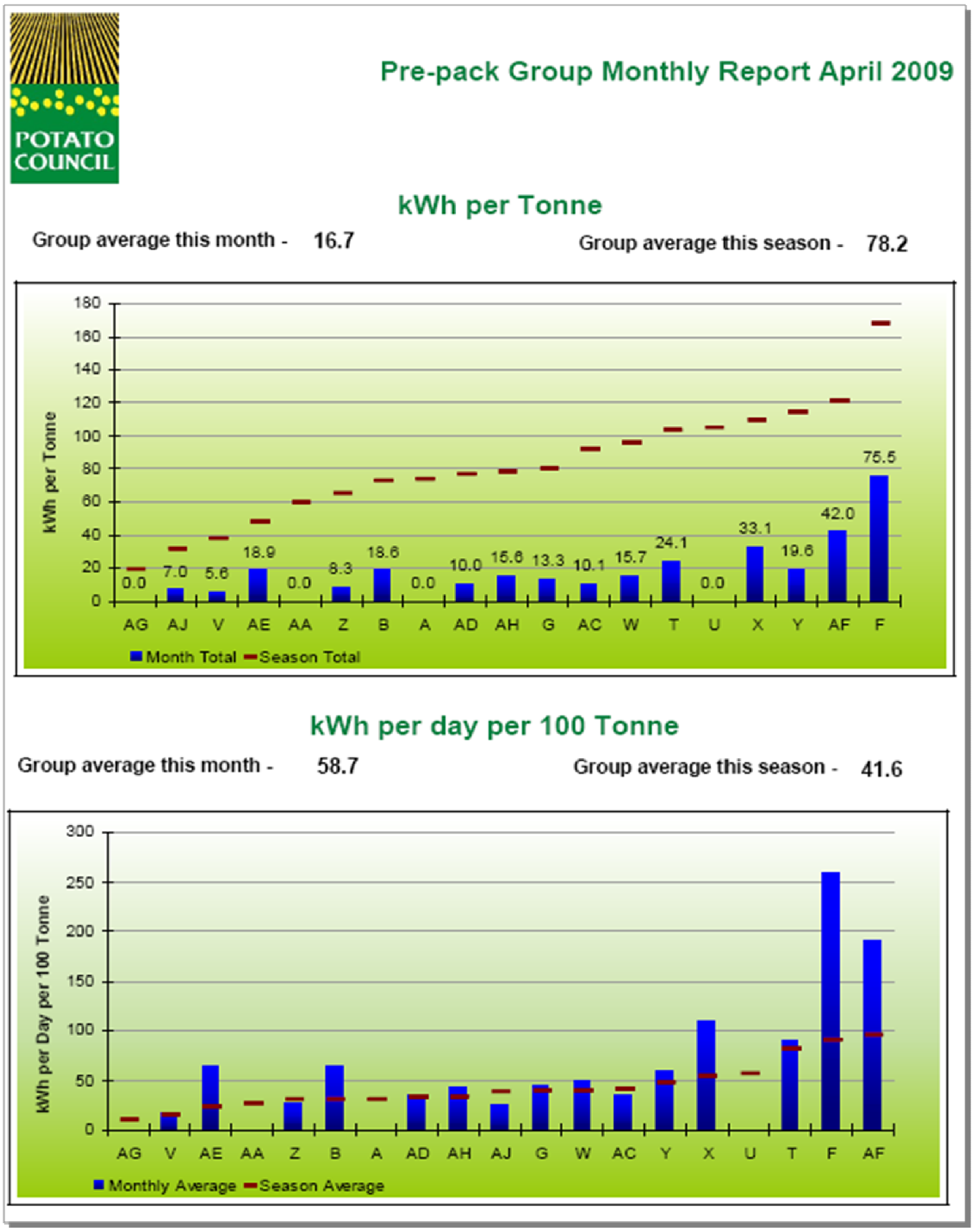


FIGURE 6 - SAMPLE GROUP REPORT

3.6.3. Degree Day Analysis

As discussed in previous years' reports, in many cases degree day analysis does not provide a good means of comparison for potato storage. This is because:

- Potato stores sometimes need heating as well as cooling
- It does not account for respiration and ancillary equipment heat.

Because of these issues, degree day analysis only provides a broad, unrefined approach to comparing potato store energy use with regards to outside temperature.

3.6.4. Hours of Ambient Cooling

A method that could be used to quantify the ability of a store to use ambient ventilation to cool the produce is called 'available hours of ambient cooling'.

Any hour where the average ambient temperature is less than 2°C below the target store temperature is one hour of ambient cooling.

If a store has the ability to use ambient air this can be used to reduce the dependence on mechanical cooling from conventional refrigeration.

Processing stores are able to make best use of ambient cooling because of their warmer target temperatures (around 9°C). Most processing stores rely heavily on ambient cooling to achieve their target temperatures. Stores fitted with mechanical refrigeration will tend to only use this facility during the warmer months of the year, towards the end of the season.

Pre-pack stores with target temperatures between 2 and 3°C have much more limited potential to use ambient air and are often not fitted with the necessary equipment to do this. There is, however, potential to use ambient cooling in many locations and stores with this facility will be able to reduce their energy use accordingly.

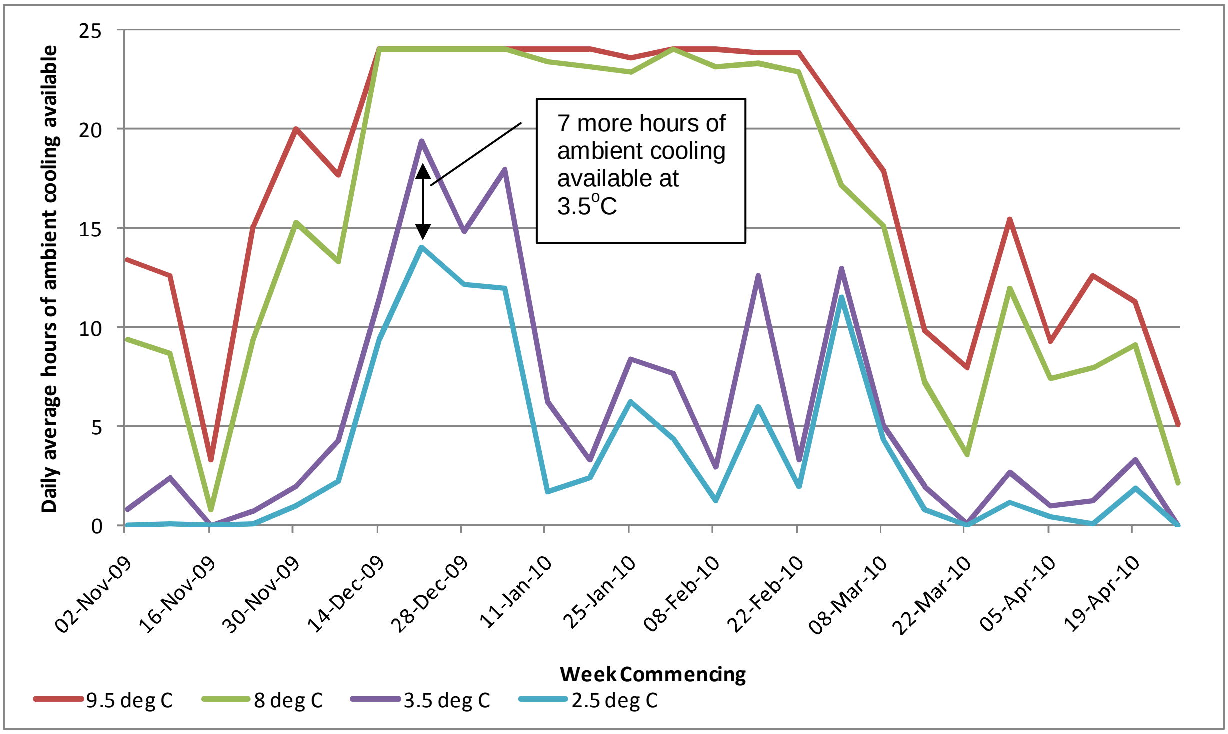


FIGURE 7 - DAILY AVERAGE HOURS OF AVAILABLE AMBIENT COOLING FOR DIFFERENT TARGET TEMPERATURES

The graph in Figure 7 above shows the affect on available hours of ambient cooling as the target temperature is changed. The data used to construct this graph is real outside temperature data taken from one of the intensive storage sites.

During the winter months there are likely to be more hours of available ambient cooling than can be used, so year on year variations of ambient temperature are not critical. However, available hours at the beginning and end of each season are fewer so the effect of annual average temperature changes becomes more important. If a store is to remain active into April/May greater potential for ambient cooling will be realised with higher target store temperatures. Increasing or decreasing the target temperature has a big effect on how many hours of ambient cooling are available, however this may cause crop quality issues and increased store management may be required. Table 5 gives the total available hours of ambient cooling for the period shown in the graph.

Store type	Total hours of ambient cooling available at target temperatures							
	9.5°C		**8°C**		**3.5°C**		**2.5°C**	
Season	2008/09	2009/10	2008/09	2009/10	2008/09	2009/10	2008/09	2009/10
Processing	398	456	319	398	-		-	
Pre-pack	-		-		101	147	49	96

TABLE 5 - TOTAL HOURS OF AMBIENT COOLING AVAILABLE

These data show that there were as many hours available for ambient cooling at 8°C in 2009/10 as there were in 2008/09 at 9.5°C and there were as many hours available for ambient cooling at 2.5°C as there were in 2008/09 at 3.5°C. Put simply, processing stores had an average of 20% more hours of ambient cooling available to them in 2009/10 compared with 2008/09 and pre-pack stores had 72% more.

Hours of ambient cooling can be used to see how a store that has both refrigeration and ambient cooling facilities performs, compared with its performance in a previous season or against another store in a different location. The fewer hours of ambient cooling available the greater the requirement for refrigeration and the greater the probable energy use.

Care should be taken when calculating hours of ambient cooling because the store may already be at the target temperature and not be able to use the ambient cooling available. In this case the potential for ambient cooling is less than the theoretical ambient cooling figure would suggest.

4. RESULTS

These results use the metrics described in the previous section.

4.1. Intensively Monitored Stores

4.1.1. Processing

Store Name	Store 1			Store 2			Store 3			Store 4		
Season	**2007/08**	**2008/09**	**2009/10**	**2007/08**	**2008/09**	**2009/10**	**2007/08**	**2008/09**	**2009/10**	**2007/08**	**2008/09**	**2009/10**
Storage length (days)	276	239	266	171	153	257	148	168	214	278	265	282
Target temperature (^oC)	9	10	10	8.5 – 9	12	9-10	10	11	10.5	8.1	9	7.5
Ambient cooling available	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Refrigeration available	✓	✓	✓	×	×	×	×	×	×	✓	✓	✓
Electricity consumption (kWh) CO_2 equivalent (t)	161,896 (90.7)	139,416 (74.9)	192,545 (103.4)	73,392 (41.1)	123,929 (66.5)	119,401 (64.1)	65,058 (36.4)	54,498 (29.3)	61,490 (33)	93,985 (52.6)	79,557 (42.7)	93,705 (50.3)
Store quantity (tonnes)	5,200	5,097	4,011	4,889	5,202	5,265	2,000	3,000	2860	2,700	2,900	2860
Average daily energy consumption (kWh/tonne/day) CO_2 equivalent (kg/tonne)	0.11 (0.062)	0.11 (0.059)	0.18 (0.097)	0.08 (0.045)	0.16 (0.322)	0.12 (0.063)	0.29 (0.162)	0.11 (0.059)	0.1 (0.054)	0.12 (0.067)	0.1 (0.054)	0.12 (0.062)
Full store SEC[2] per day (kWh/tonne/day) CO_2 equivalent (kg/tonne)	0.116 (0.06)	0.155 (0.08)	0.24 (0.13)	0.10 (0.05)	0.158 (0.08)	0.2 (0.11)	0.216 (0.12)	0.125 (0.07)	0.099 (0.05)	0.2 (0.11)	0.102 (0.055)	0.1 (0.054)
Cumulative SEC (kWh/tonne) CO_2 equivalent (kg/tonne)	64.4 (36.1)	62.7 (33.7)	67.1 (36)	32.5 (18.2)	60.0 (32.2)	N/A	55.3 (31)	23.6 (12.7)	26.7 (14.3)	63.5 (35.6)	30.1 (16.2)	N/A
Entire season SEC (kWh/tonne) CO_2 equivalent (kg/tonne)	31.1 (17.4)	27.4 (14.7)	48 (25.8)	15 (8.4)	23.8 (12.8)	30.1 (16.2)	32.5 (18.2)	18.2 (9.8)	21.5 (11.5)	34.8 (19.5)	27.4 (14.7)	32.8 (17.6)

TABLE 6 – INTENSIVE PROCESSING STORES' RESULTS

[2] SEC - Specific Energy Consumption

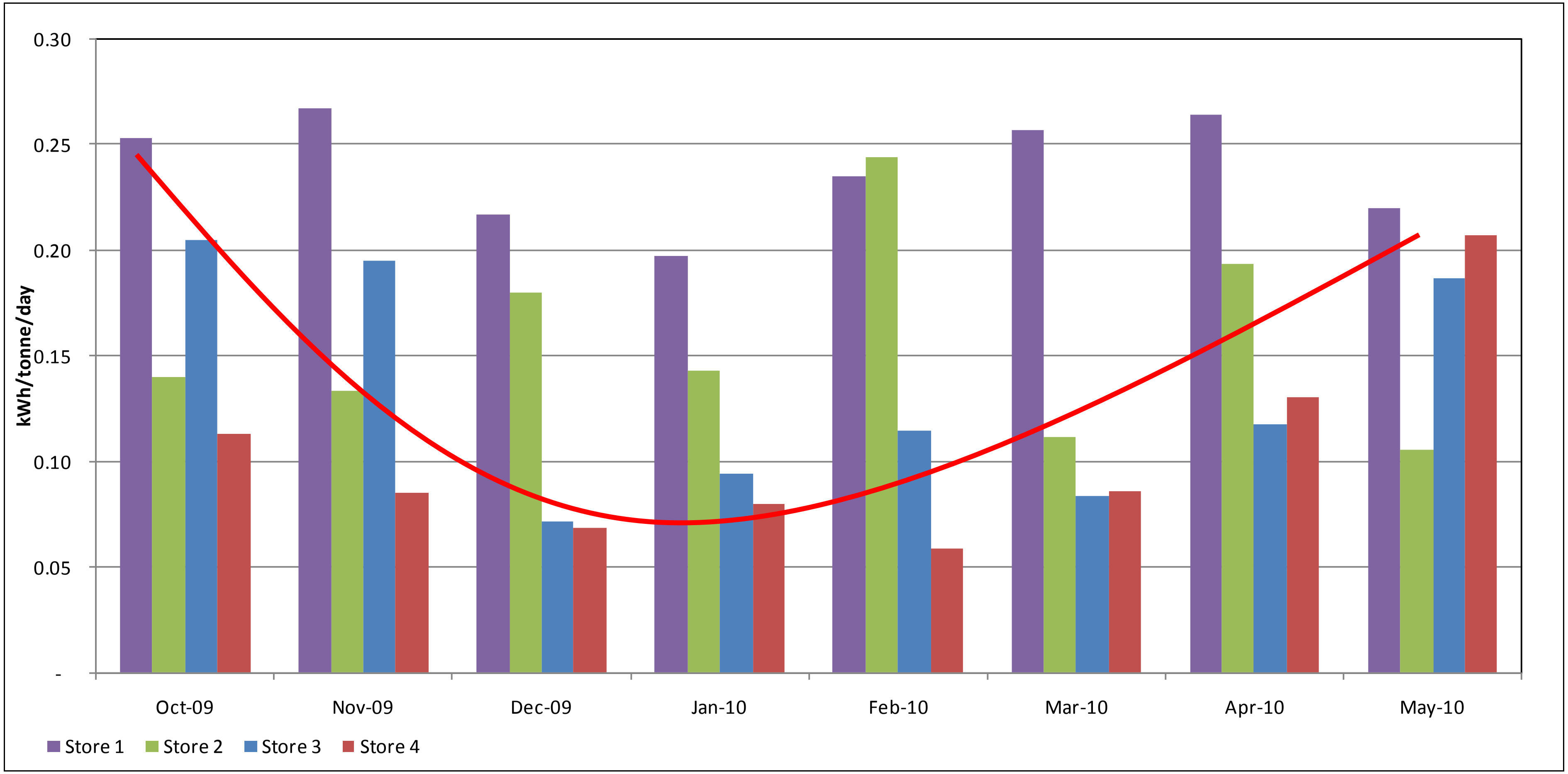


FIGURE 8 - INTENSIVE PROCESSING STORES MONTHLY PERFORMANCE

Figure 8 above compares the daily average energy consumption per month for each store. The trend line describes how the group has performed in this season. Incomplete tonnage information for this season contributed to the high energy consumption shown for Store 1. The high energy consumption achieved by Store 2 is attributable to a requirement for additional heating during December, January and February.

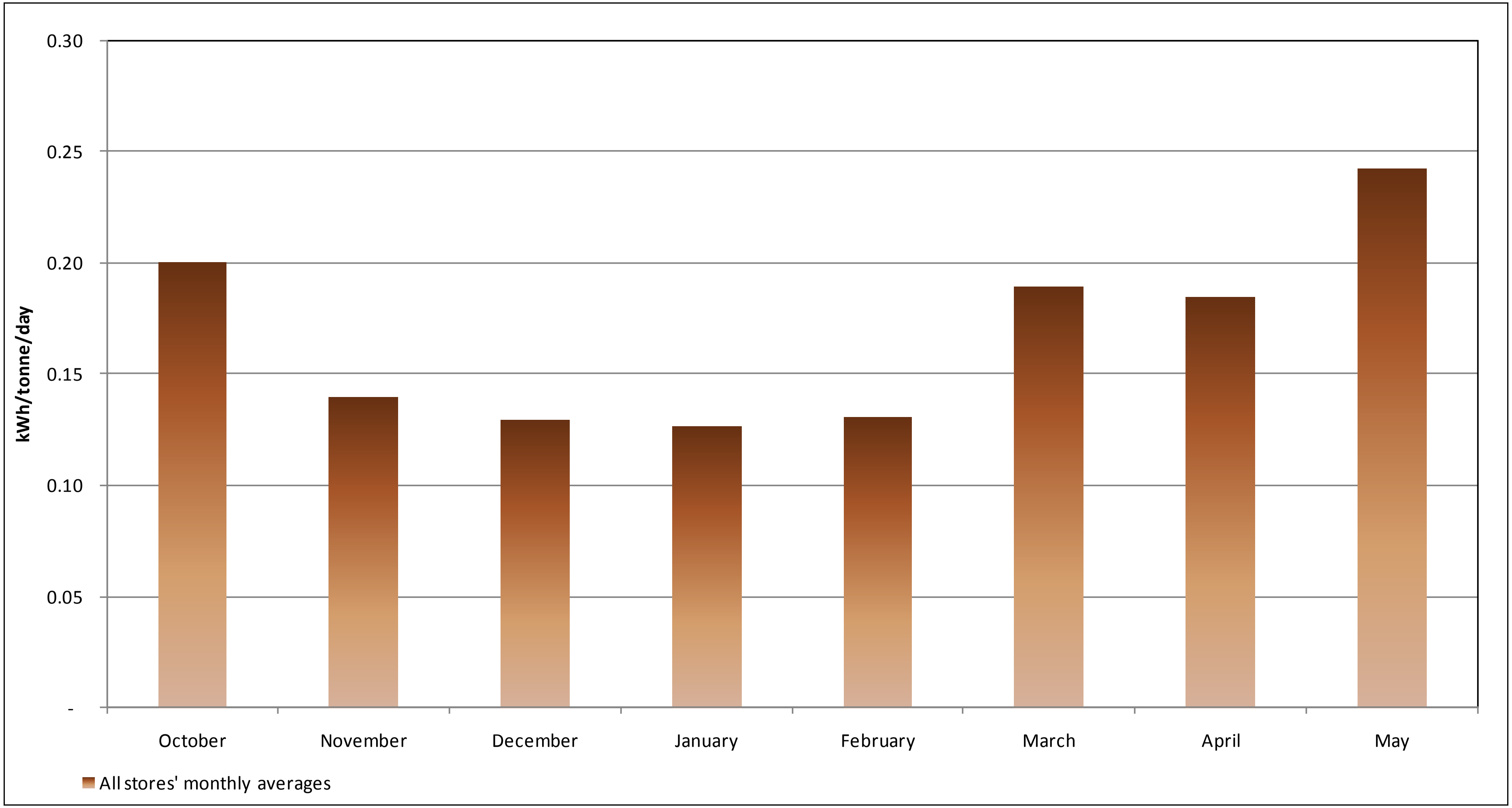


FIGURE 9 - THREE YEARLY AVERAGE OF DAILY ENERGY CONSUMPTION BY MONTH, PROCESSING STORAGE

Figure 9 above shows the monthly average energy consumption in kWh per tonne per day, achieved by the intensively monitored stores over the three years of monitoring. This gives a good indication of the 'typical' expected monthly energy consumption for a processing store. The values shown can be used to predict the likely energy consumption of a processing store for different season lengths as given in Table 7 overleaf.

Months stored	Number of days	Average kWh/tonne/day	Expected kWh/tonne	Cost/tonne @ 9.87p/kWh
October - May	241	0.17	41	£4.05
October - April	211	0.16	34	£3.36
November - April	180	0.15	27	£2.62
November - March	150	0.14	21	£2.07

TABLE 7 - ANTICIPATED STORAGE ENERGY CONSUMPTION AND COST

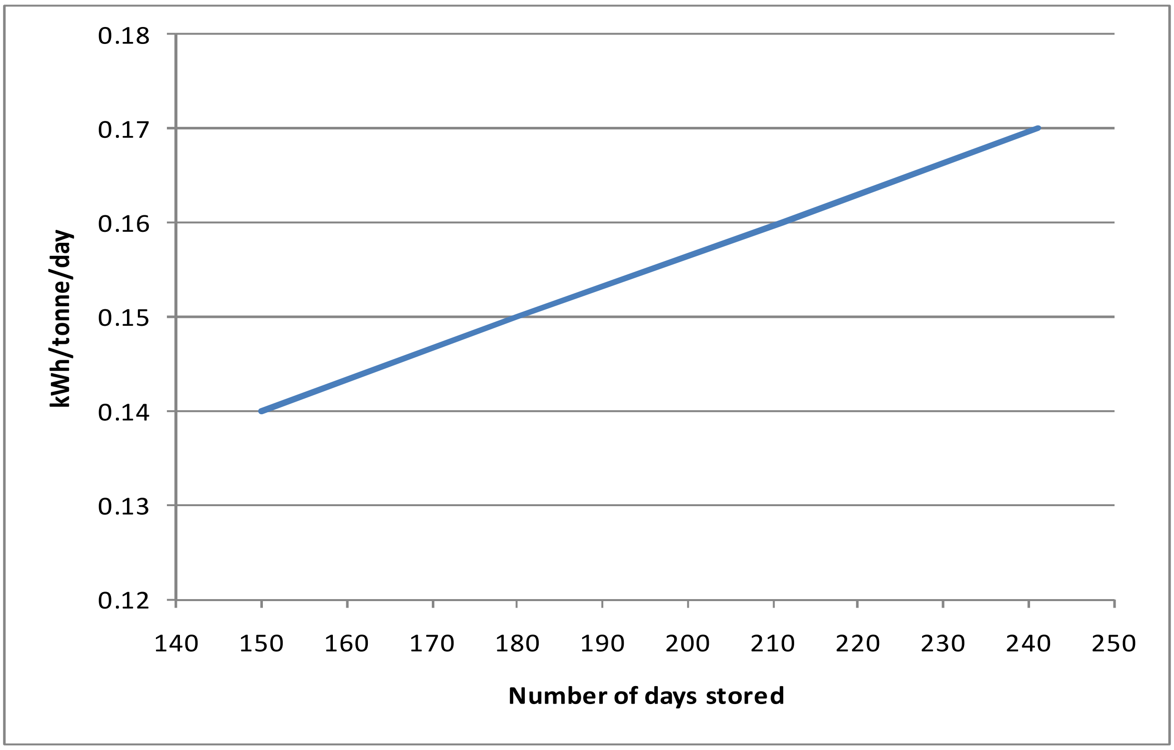


FIGURE 10 -ENERGY CONSUMPTION EXPECTED FOR DIFFERENT STORAGE LENGTHS

The values given in Table 7 can be used to derive the energy component of the carbon footprint of processing potato storage. Table 8 below shows the relative carbon impact that the storage periods have. This is shown in Table 8; the values are calculated using the 2010 Defra emission factor of 0.537 kg carbon emitted per kWh of electricity consumed.

Months stored	Number of days	Carbon emissions (kg/tonne)
October - May	241	22
October - April	211	18.3
November - April	180	14.5
November - March	150	11.3

TABLE 8 - CARBON FOOTPRINT OF 'TYPICAL' PROCESSING POTATO STORAGE

4.1.2. Pre-pack

Store Name	**Store 5**			**Store 6**			**Store 7**			**Store 8**		
Season	**2007/08**	**2008/09**	**2009/10**	**2007/08**	**2008/09**	**2009/10**	**2007/08**	**2008/09**	**2009/10**	**2007/08**	**2008/09**	**2009/10**
Storage length (days)	68	229	161	173	195	155	191	220	187	202	265	230
Target temperature (^oC)	2.5 - 3	4	2.5	2.5 - 3	4	2.5	2.5	9	3	2.5 - 3	5	4.1
Ambient cooling available	×	×	×	×	×	×	✓	✓	✓	✓	✓	✓
Refrigeration available	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Electricity consumption (kWh) *CO_2 equivalent (t)*	34,442 (19.3)	41,415 (22.2)	35,356 (19)	54,960 (30.8)	57,620 (30.9)	50,239 (27)	88,840 (49.8)	98,521 (52.9)	108,833 (58.4)	71,955 (40.3)	99,983 (53.7)	89,728 (48.2)
Store quantity (Tonnes)	790	810	790	1,091	1,398	1404	1,588	1,644	1,566	1,160	1,131	1,118
Average daily energy consumption (kWh/Tonne/day) *CO_2 equivalent (kg/tonne)*	0.64 (0.358)	0.22 (0.118)	0.28 (0.15)	0.29 (0.162)	0.21 (0.113)	0.25 (0.134)	0.29 (0.162)	0.27 (0.145)	0.37 (0.2)	0.31 (0.174)	0.33 (0.177)	0.35 (.187)
Full Store SEC[3] per day (kWh/Tonne/day) *CO_2 equivalent (kg/tonne)*	n/a	0.41 (0.22)	0.6 (0.32)	0.42 (0.22)	0.24 (0.13)	0.45 (0.24)	0.31 (0.17)	0.46 (0.25)	0.32 (0.17)	0.26 (0.14)	0.37 (0.2)	0.6 (0.32)
Cumulative SEC (kWh/Tonne) *CO_2 equivalent (kg/tonne)*	n/a	136.2 (73.1)	94.7 (50.9)	79 (44.2)	79.4 (42.6)	38.6 (20.7)	70 (39.2)	139.4 (74.9)	84.5 (45.4)	63 (35.3)	155.2 (83.3)	114.4 (61.4)
Entire Season SEC (kWh/Tonne) *CO_2 equivalent (kg/tonne)*	43.5 (24.4)	51.1 (27.4)	44.8 (24)	50.4 (28.2)	41.2 (22.1)	35.8 (19.2)	56 (31.4)	59.9 (32.2)	69.5 (37.3)	62 (34.7)	88.4 (47.5)	80.3 (43.1)

TABLE 9 - INTENSIVE PRE-PACK STORES' RESULTS

[3] SEC - Specific Energy Consumption

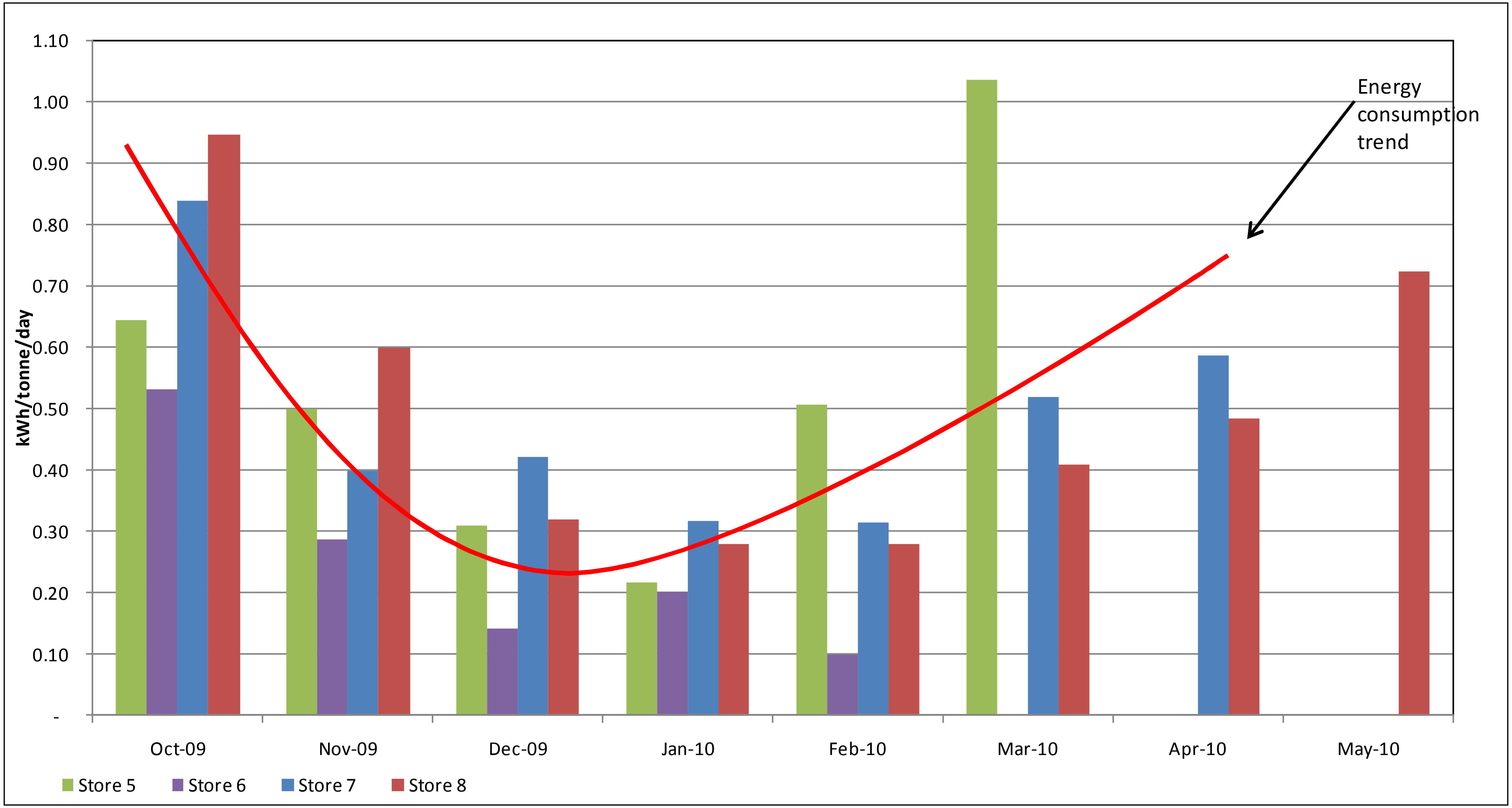


FIGURE 11 - INTENSIVE PRE-PACK STORES MONTHLY PERFORMANCE

Figure 11 above compares the daily average energy consumption per month for each store. The trend line describes how the group has performed in this season.

The high consumptions achieved in February and March for Store 5 is a part loading effect where small quantities of produce were kept in store. Store 6 was emptied in early February which has kept the energy consumption low for this month.

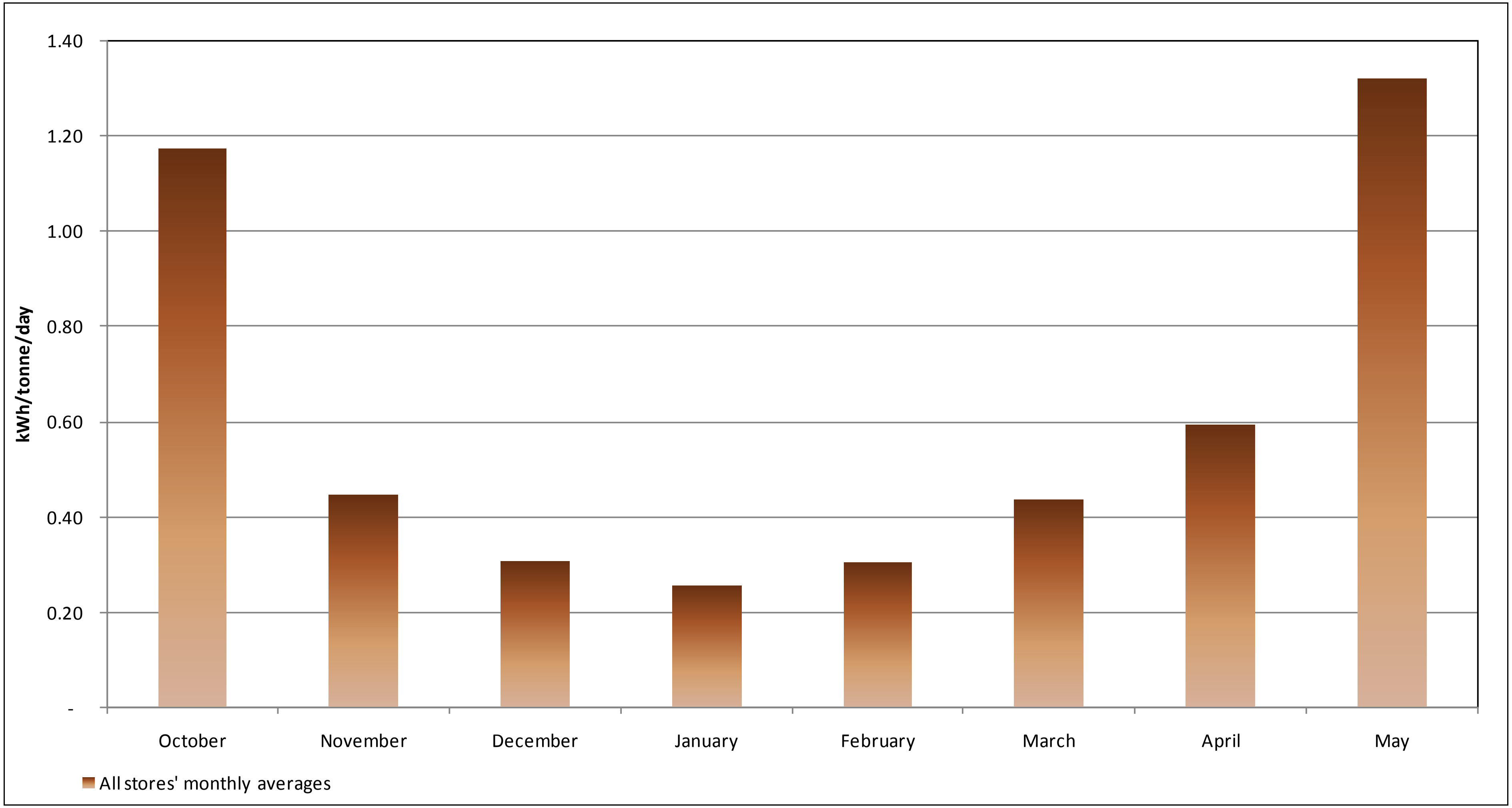


FIGURE 12 – THREE YEARLY AVERAGE OF DAILY ENERGY CONSUMPTION BY MONTH, PRE-PACK STORAGE

Figure 12 above shows the monthly average energy consumption in kWh per tonne per day, achieved by the intensively monitored stores over the three years of monitoring. This gives a good indication of the ‘typical’ expected monthly energy consumption for a pre-pack store. The values shown can be used to predict the likely energy consumption of a processing store for different season lengths as given in Table 10 below.

Months stored	**Number of days**	**Average kWh/tonne/day**	**Expected kWh/tonne**	**Cost/tonne @ 9.87p/kWh**
October - May	241	0.6	145	£14.27
October - April	211	0.5	106	£10.46
November - April	180	0.4	72	£7.11
November - March	150	0.35	52.5	£5.18

TABLE 10- ANTICIPATED STORAGE ENERGY CONSUMPTION AND COST

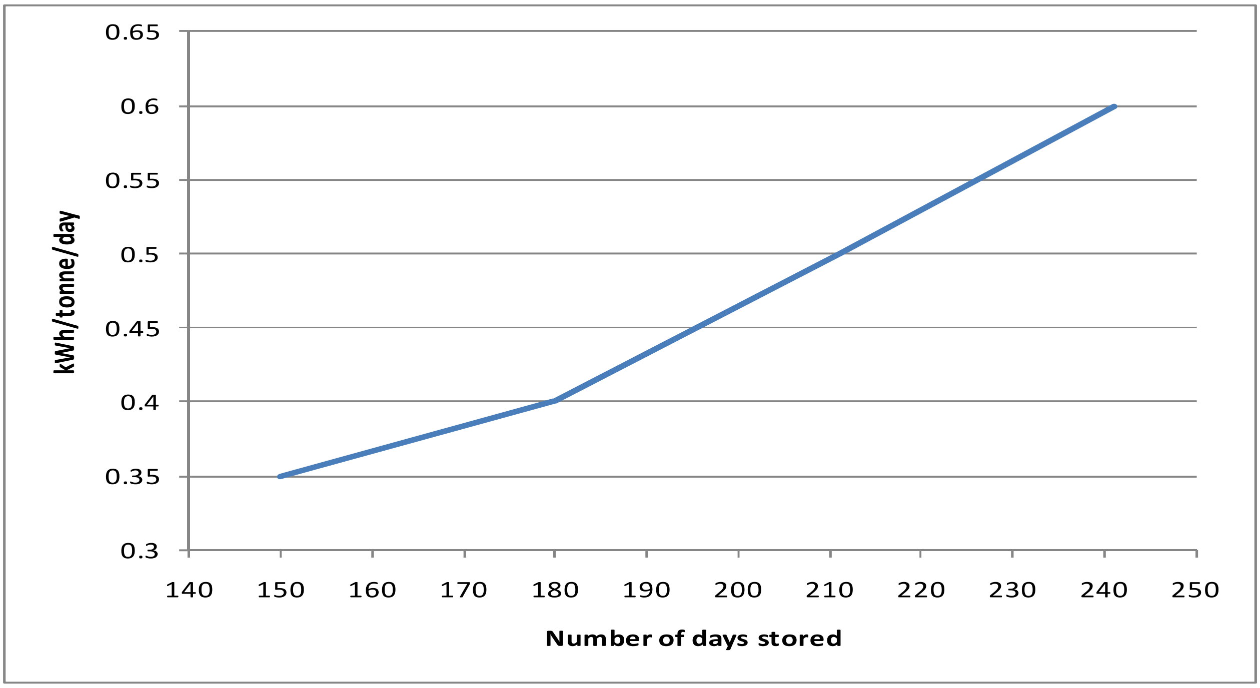


FIGURE 13 - EXPECTED ENERGY CONSUMP*TIONS FOR DIFFERENT STORAGE LENGTHS*

The values given in the table above can be used to derive the energy component of the carbon footprint of pre-pack potato storage. Table 8 below shows the relative carbon impact that the storage periods have. The values are calculated using the 2010 Defra emission factor of 0.537 kg carbon emitted per kWh of electricity consumed.

Months stored	Number of days	Carbon emissions kg/tonne)
October - May	241	77.9
October - April	211	57
November - April	180	38.7
November - March	150	28.2

TABLE 11 - CARBON FOOTPRINT OF 'TYPICAL' PRE-PACK POTATO STORAGE

4.2. Basic Monitored Stores Results

4.2.1. Processing

The results from the basic monitoring processing group contain information from sixteen stores. Data from one store has been omitted because the data was considered inaccurate.

The range of daily energy consumptions was 0.04 kWh/tonne/day to 0.29 kWh/tonne/day.

The season average specific energy consumption is often used as a comparator, the range of energy consumptions using this measure was 8 kWh/tonne to 65 kWh/tonne.

Store M shows typical performance for the group at 0.12 kWh/tonne/day and 33 kWh/tonne. This is a 5-10 year old building with 80 mm pre-insulated panel walls and 80 mm spray on foam insulation. 1,800 tonnes of produce can be stored in bulk on a ventilated floor.

Figure 13 shows the results from this group. The intensively monitored stores' results have also been shown to aid comparison.

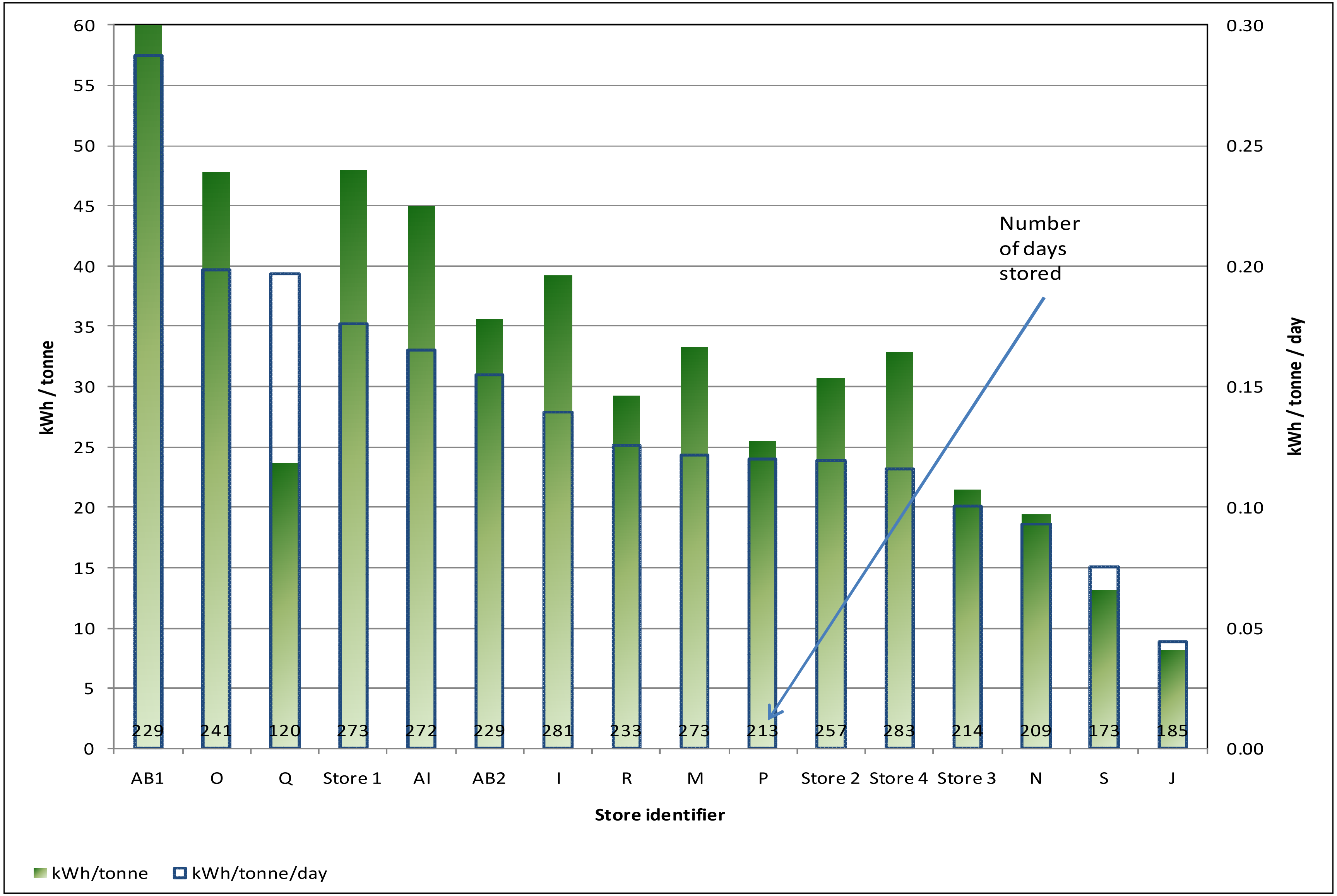


FIGURE 13 - BASIC MONITORED PROCESSING STORES PERFORMANCE

The data in Figure 13 have been ordered by daily energy consumption per tonne stored from left to right. Stores to the right hand side of the graph are typically of more modern design and/or run at warmer temperatures than those to the left.

Comparing store energy as daily averages helps to ensure comparisons are meaningful; however, those stores with longer storage periods will inevitably be storing during warmer months at the beginning and/or end of the season. This means that higher daily average energy consumption will occur. Additionally, stores with very short storage periods will show similar results because of a big effect of pull down.

Figure 14 compares the average kWh/tonne/day of the group for each month over the last two seasons. The graph contains only data from November to April to ensure the best comparison by minimizing the effects of part-loading.

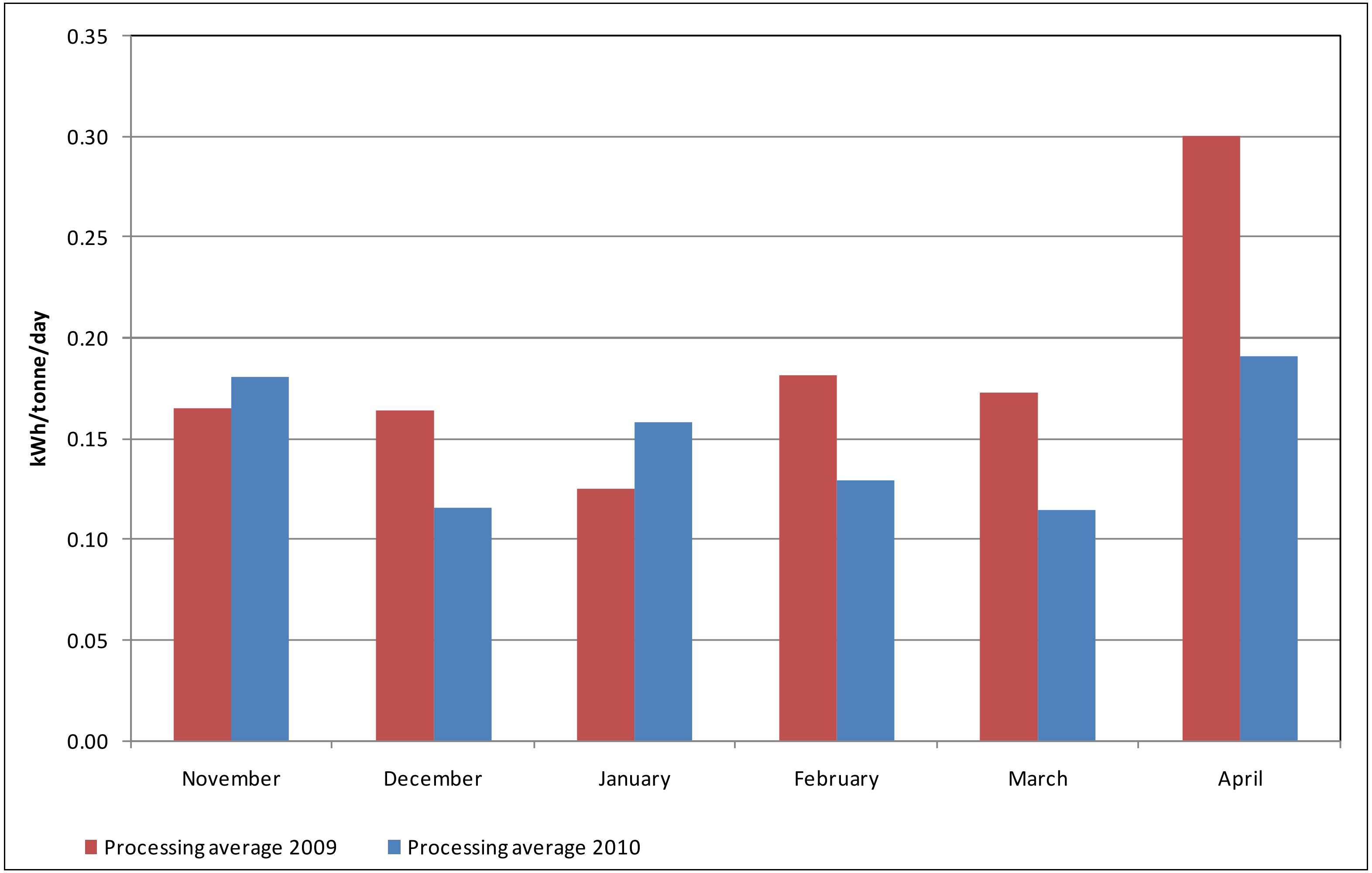


FIGURE 14 - COMPARISON OF MONTHLY ENERGY CONSUMPTION FOR PROCESSING STORES

Overall the energy consumption appears to be less in 2009/10 than 2008/09 although this difference is not as marked as expected. Higher energy consumptions in January (for heaters etc) are balanced by reduced energy consumptions in February, March and April as greater benefit was obtained from ambient cooling.

4.2.2. Pre-pack Stores

The results from the monitoring of the basic monitored pre-pack group contain information from twenty two stores.

The range of daily energy consumptions was 0.15 kWh/tonne/day to 0.7 kWh/tonne/day.

The season average specific energy consumption is often used as a comparator, the range of energy consumptions using this was35 kWh/tonne to 116 kWh/tonne.

Store AL shows typical performance for the group at 0.30 kWh/tonne/day and 61.7 kWh/tonne. This is a greater than 10 years old 2,300 tonne box store with 75 mm of spray foam and in average to poor condition.

Figure 15 overleaf summarises the results from this group. The intensively monitored stores' results have also been included to aid comparison.

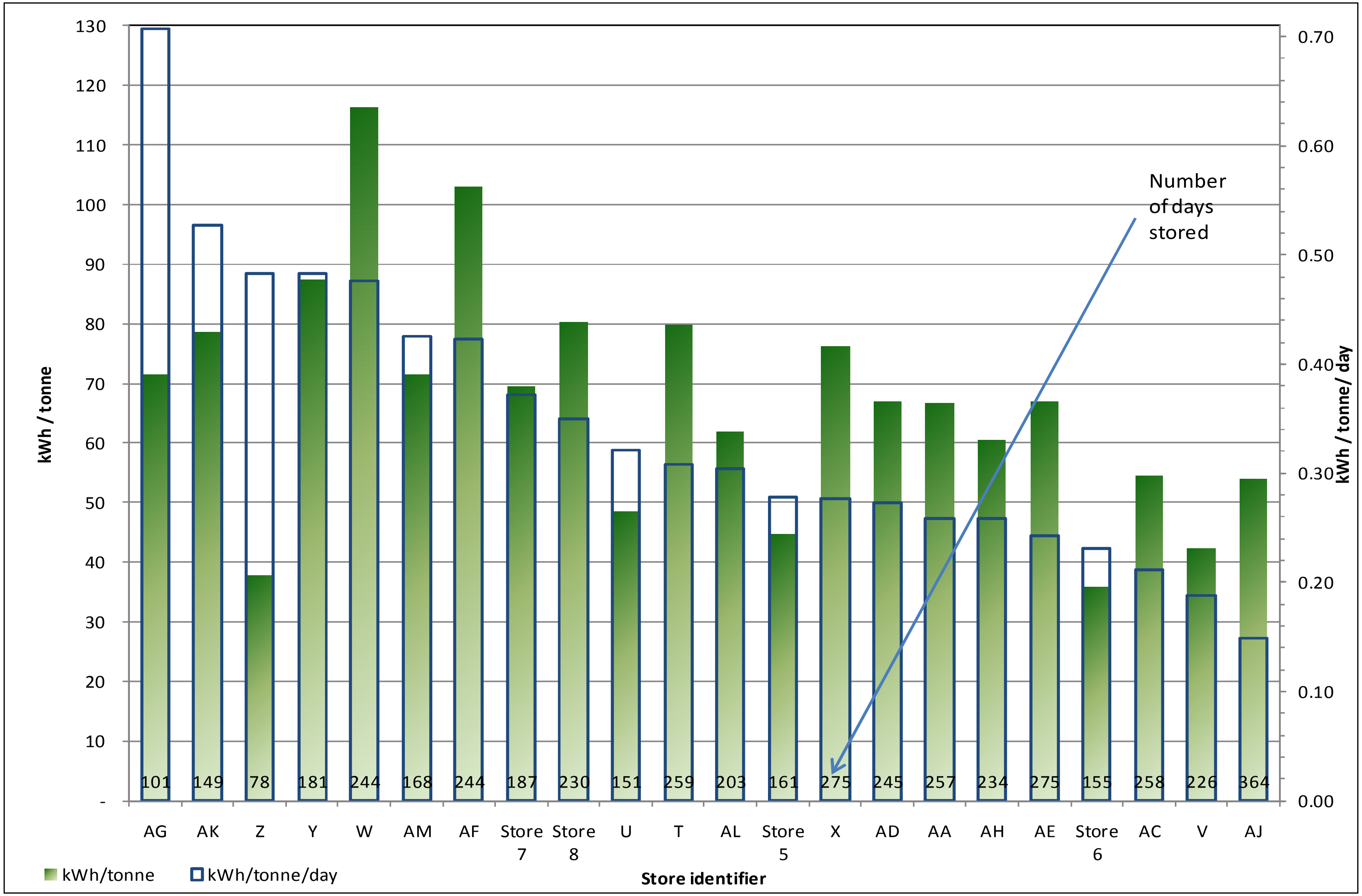


FIGURE 15 – BASIC MONITORED PRE-PACK STORES' PERF*ORMANCE*

Figure 16, below, compares the average kWh/tonne/day of the group for each month over the last two seasons. The graph contains only data from November to April to ensure the best comparison by minimising the effects of part-loading.

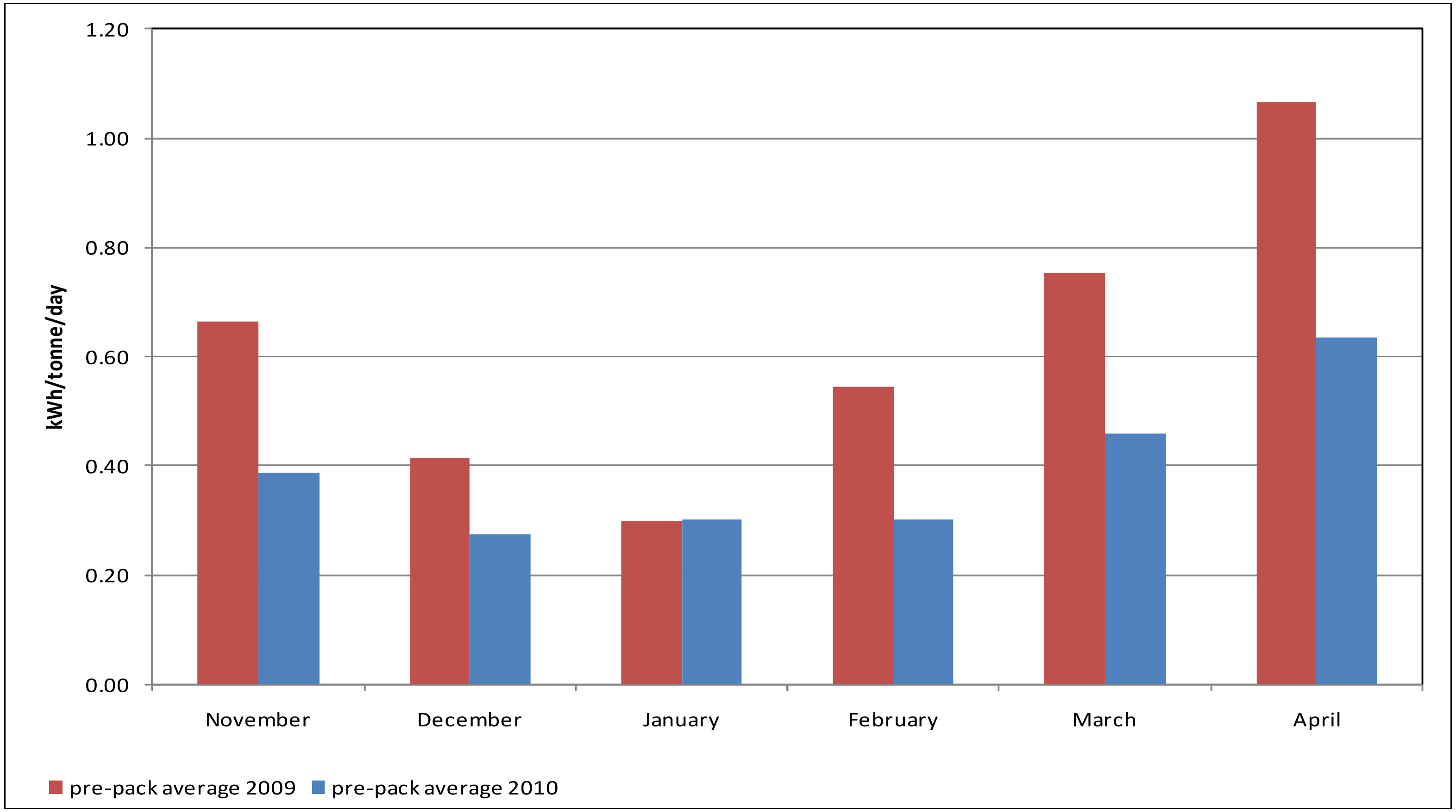


FIGURE 16 - COMPARISON OF MONTHLY ENERGY CONSUMPTION FOR PRE-PACK STORES

The values for this season (2009/10) are significantly less than in 2008/09. This is mainly due to the colder winter period when the demand for refrigeration was lower and there was greater potential for ambient cooling. Efficiency of refrigeration systems is also improved in colder periods because of improved condensing efficiency.

4.3. Assessment of Store Energy Consumption by Characteristic

The stores involved in the project have a wide variety of characteristics. Some of the important features that will have an effect on energy consumption are:

1. Storage temperature
2. Store age
3. Insulation level
4. Variable speed drives fitted (processing only)
5. Door type
6. Construction
7. Control.

During the store visits in mid-2008 each store was assessed for these aspects.

By grouping stores by characteristic and comparing their achieved energy consumptions it may be possible to identify trends to show the impact of each on the energy consumption. The following sections show and discuss these results for categories 1-5.

The energy data for the comparisons is the sum of the three months' consumption by each store for December, January and February of each season. This has been done to ensure the comparisons are of fully loaded stores.

4.3.1. Target Store Temperature

Target temperatures were not available for the 2008/09 period so the data shown below is for this year's storage only (2009/10).

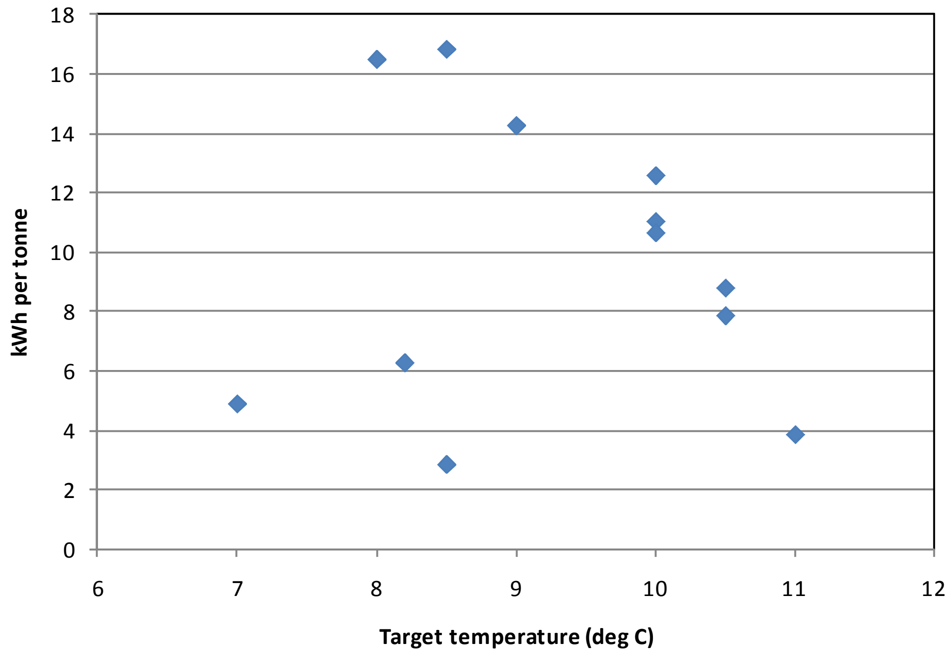


FIGURE 17 - EFFECT OF TARGET TEMPERATURE ON ENERGY CONSUMPTION FOR PROCESSING STORES

Figure 17 above shows the energy consumptions of each processing store for the 2009/10 season versus the target temperature in this period. These data show no marked trend and the correlation between temperature and energy consumption is weak.

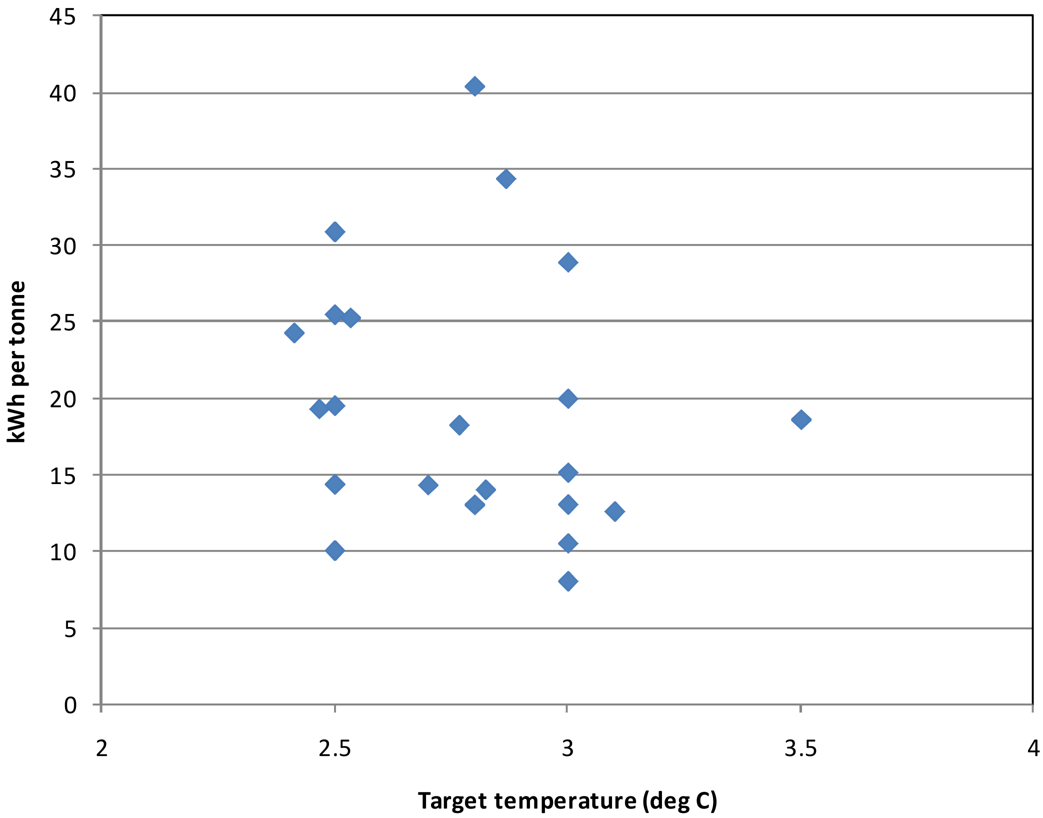


FIGURE 18 - EFFECT OF TARGET TEMPERATURE ON ENERGY CONSUMPTION FOR PRE-PACK STORES

Figure 18 shows the energy consumptions of each pre-pack store for the 2009/10 season versus the target temperature in this period. Again, there is no discernible correlation.

In both cases, the relationships between energy use and target temperature are not clear cut and the data do not permit meaningful or quantifiable comparisons. This weak correlation is symptomatic of the variety of ages, sizes, types and methods of construction in the stores monitored.

4.3.2. Store Age

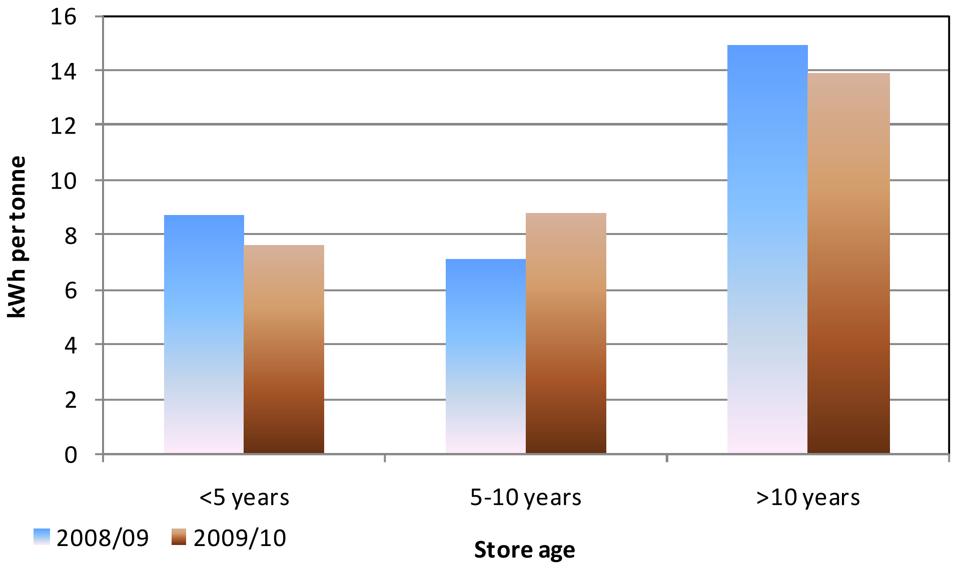


FIGURE 19 - RELATIONSHIP BETWEEN STORE AGE AND ENERGY CONSUMPTION FOR PROCESSING STORES

Figure 19 shows the relationship between store age and energy consumption achieved by the processing group. This shows an increase in energy consumption as the age of the store increases.

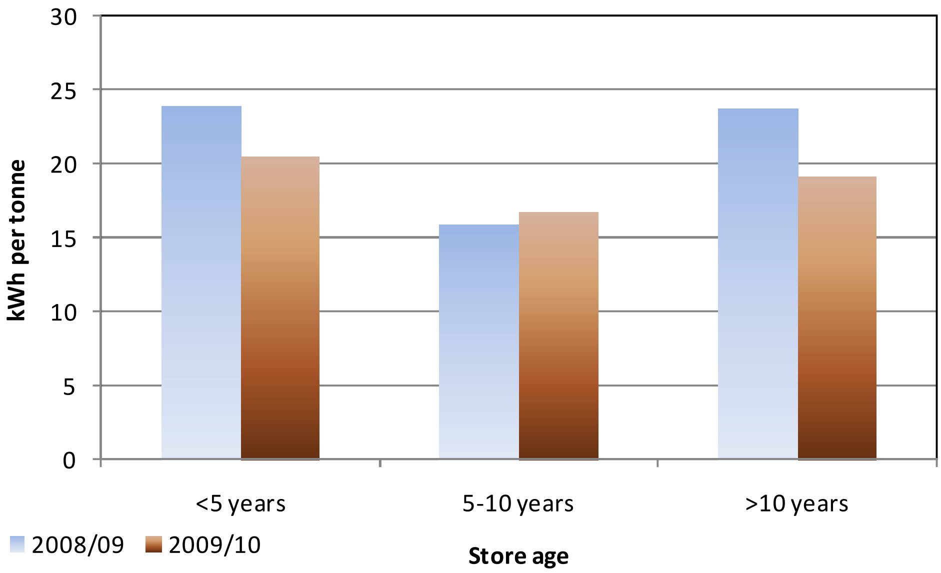


FIGURE 20 - RELATIONSHIP BETWEEN STORE AGE AND ENERGY CONSUMPTION FOR PRE-PACK STORES

Figure 20 shows the energy consumptions achieved by the pre-pack stores in three age groups. This does not show any significant differences in energy use between the groups.

4.3.3. Wall Insulation Thickness

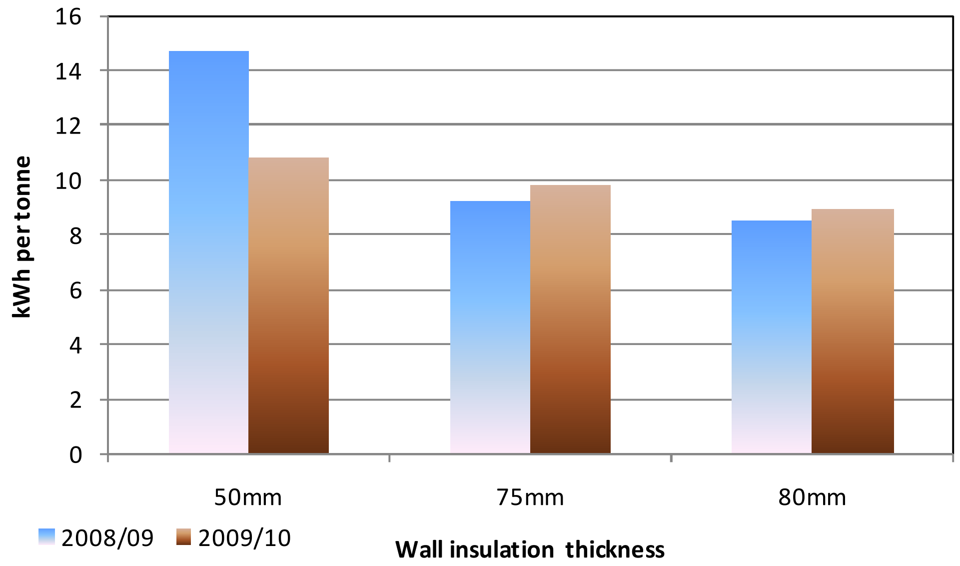


FIGURE 21 - RELATIONSHIP BETWEEN WALL INSULATION THICKNESS AND ENERGY CONSUMPTION FOR PROCESSING STORES

Figure 21 above shows the energy consumptions achieved by the processing stores with different wall insulation thickness. The data suggest a decrease in energy consumption with increasing insulation thickness.

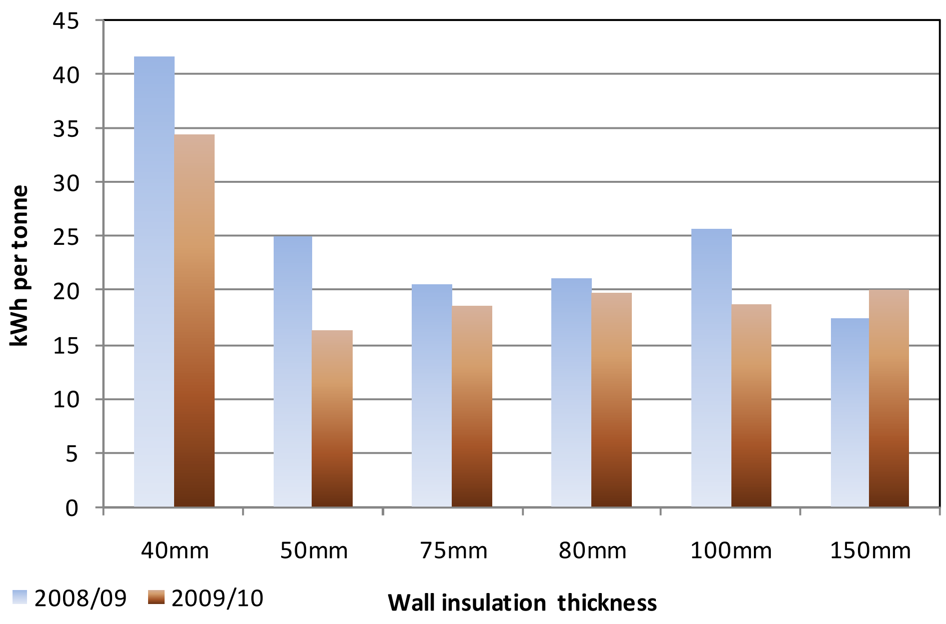


FIGURE 22 - RELATIONSHIP BETWEEN WALL INSULATION THICKNESS AND ENERGY CONSUMPTION FOR PRE-PACK STORES

Figure 22 above shows the energy consumptions achieved by the pre-pack stores with different wall insulation thickness. The data shows that increasing thickness of the wall insulation does not appear to have a tangible effect on energy consumption at levels above 75 mm.

4.3.4. Inverter Drives

Inverter drives are an energy efficiency technology that has emerged with good potential for potato storage, and are discussed in more detail in PCL funded project R402 carried out by Sutton Bridge Crop Storage Research and Crop Systems Ltd. Their application is predominantly suitable for bulk processing storage and inverters are fitted to the main cooling fans (especially in ambient stores).

The graph in Figure 23 below shows the difference between the achieved energy consumptions as average values for those stores fitted with inverter drives compared with those without.

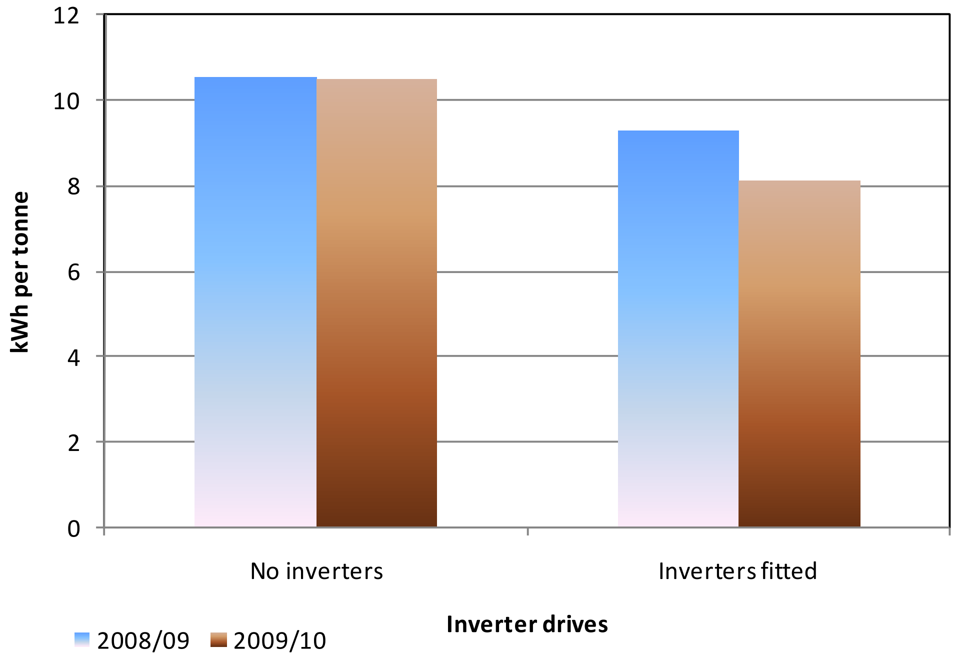


FIGURE 23 - RELATIONSHIP BETWEEN STORES FITTED WITH AND WITHOUT INVERTER DRIVES AND ENERGY CONSUMPTION FOR PROCESSING STORES

Figure 23 shows that stores with inverter-driven fans tended to perform better than those without. This relationship should be treated with caution as the number of stores with inverter drives was limited in this project and they were almost all fitted to newer or refurbished stores that may have naturally performed better.

4.3.5. Door Type

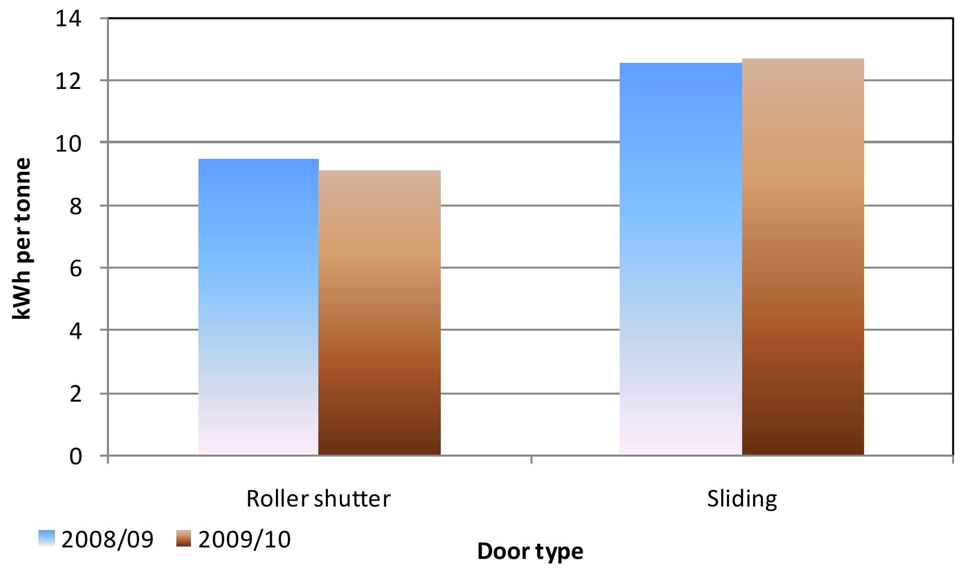


FIGURE 24 - RELATIONSHIP BETWEEN DOOR TYPE AND ENERGY CONSUMPTION FOR PROCESSING STORES

The relationship between door type and energy consumption (Figure 24) for the processing stores. This graph indicates that stores with roller shutter doors tend to use less energy than those with sliding doors. This influence can more than likely be attributed to newer, better built stores having roller shutters rather than the influence of the door alone.

4.3.6. Alternative Assessment of Characteristics

The previous section illustrates the difficulty of deriving meaningful correlation between the energy performance of individual stores and their structural characteristics because of the wide variation in performance and design

An alternative approach of assessing the influence of each characteristic on energy consumption is to use a theoretical heat balance model on a single store over a single time period.

Such a model has previously been used by Farm Energy engineers for a PCL funded project on Ground Sink Cooling CP57 - *Crop store and packhouse cooling: a commercial demonstration & economic evaluation of ground sink refrigeration*. This same simulation has been used to provide the results given below.

4.3.6.1. Simulation Inputs - Pre-pack Store

The simulation was based on Store 5, a typical modern, well built, refrigerated store (see Table 12 below), and was run for a season from October - April (inclusive) using external temperature data from the north east of England. It is possible to run the store simulation for a whole season because the influences can be exactly replicated.

Store type	Box, overhead throw
Cooling type	Refrigerated no ambient capacity
Dimensions	23 m x 26 m height, 7.4m to ridge
Tonnes stored	1,100

TABLE 12 - SIMULATED STORE DETAILS

The simulation was run for the following changes to the store:

A. Increase in target temperature from 2.5°C to 3.5°C
B. Increase in insulation from 50 mm to 100 mm
C. Reduced air leakage by for example a better fitting door, improved louvres, sealing panel gaps etc
D. All three improvements.

These changes have been chosen because they are the typical improvements that may be considered. Table 13, below, details the results.

	Energy consumption (kWh/tonne)	% reduction in energy use	Energy and cost saving
Original	52.33	0	Nil
Increased temperature	48.90	6.6%	3,773 kWh, £372
Improved insulation	50.05	4.4%	1,958 kWh, £193
Reduced air leakage	46.55	11.0%	6,358 kWh, £627
All three improvements	43.70	16.5%	9,493 kWh, £937

TABLE 13 - SIMULATION RESULTS FOR PRE-PACK STORE

The results show that reducing air leakage has the biggest effect on store energy consumption. The combined improvement from all three measures is significant at 16.5% and reduces the store energy cost by approximately £940 per annum.

4.3.6.2. Simulation Inputs - Processing Store

The simulation was run for a season from October - April (inclusive) using external temperature data from the north east of England.

Store type	Bulk underfloor laterals
Cooling type	Ambient with refrigerated capacity
Dimensions	23 m x 26 m height, 7.4m to ridge
Tonnes stored	1,100

TABLE 14 - SIMULATED STORE DETAILS

Refrigeration capability was suppressed except for March and April when warmer ambient temperatures meant ambient cooling was limited.

The simulation was run for the following changes to the store:

A. Increase in target temperature from 8.5°C to 10°C
B. Increase in insulation from 50 mm to 75 mm
C. Reduced air leakage by, for example, a better fitting door, improved louvres, sealing panel gaps etc
D. All three improvements.

These changes have been chosen because they are the typical improvements that may be considered. Table 15 below details the results.

	Energy consumption (kWh/tonne)	**% reduction in energy use**	**Energy and cost saving**
Original	34.24	0	nil
Increased temperature	27.47	20%	7,447 kWh, £735
Improved insulation	32.34	6%	2,090 kWh, £206
Reduced air leakage	32.56	5%	1,848 kWh, £182
All three improvements	30.26	12%	4,378 kWh, £432

TABLE 15 - SIMULATION RESULTS FOR PROCESSING STORE

The results show that reducing increased temperature has the biggest effect on store energy consumption. Increased insulation and reduced air leakage show smaller but still important energy reductions.

The heat balance of a potato store ensures that, as insulation increases and air leakage reduces, the structural and dynamic heat losses of the building falls. This reduces incidental cooling so the main cooling fans are required to operate longer to cool the store.

Clearly, if these conditions prevailed, then insulation could be minimised and leakage ignored. In practice however, this would result in:

- Uneven temperature distribution in the store
- Uncontrolled ventilation and condensation forming on the crop.

Additionally, when the outside temperature is well below the target temperature, a poorly sealed and insulated store would over-cool and heating (usually from electric heaters) would be required to maintain target temperatures.

It is important therefore to have a well sealed and insulated store not just to reduce energy use, but to help maintain correct storage conditions.

5. DISCUSSION

Energy consumption levels in 2009/10 showed significant differences from those recorded in 2008/09; this was mainly as a result of ambient temperatures differences. Interestingly, a colder winter does not always lead to reduced energy consumption as heating is sometimes needed to prevent store temperatures from falling too low, especially in the processing sector. Pre-pack storage benefits most from colder conditions because of reduced store losses, increased efficiency of refrigeration systems and, where it is fitted, the use of ambient cooling in preference to refrigeration.

Processing storage benefits from colder conditions so long as the temperatures do not fall much lower than 5-6°C below target temperature. When much lower temperatures are encountered, energy consumption increases because heating is required to maintain the correct storage temperatures. This effect is greatest in stores with poorer insulation and greater air leakage.

To recall, the energy used in the ***intensively monitored processing stores*** was as follows:

	kWh/tonne/day Achieved 2009/10	**kWh/tonne/day Achieved 2008/09**	**kWh/tonne/day Achieved 2007/08**
Min	0.1	0.1	0.08
Max	0.18	0.16	0.29
Average	0.13	0.12	0.15

TABLE 16. SPECIFIC ENERGY CONSUMPTIONS ACHIEVED FOR INTENSIVELY MONITORED PROCESSING STORES

The energy consumption levels were on average 8.3% greater than 2008/09. The greater energy consumption is mostly attributable to a milder autumn which extended the pull-down period and a colder winter which caused processing stores to need electric heating to maintain the stores at the correct temperature.

The range of energy consumptions for the ***basic monitored processing stores*** was much wider at 0.04 kWh/tonne/day to 0.29 kWh/tonne/day (average performance of 0.14 kWh/tonne /day). The average energy consumption of this group was 7% greater than 2008/09.

The energy used in the ***intensively monitored pre-pack storage*** was:

	kWh/tonne/day Achieved 2009/10	**kWh/tonne/day Achieved 2008/09**	**kWh/tonne/day Achieved 2007/08**
Min	0.17	0.21	0.29
Max	0.37	0.33	0.64**
Average	0.31	0.26	0.38**

TABLE 17. SPECIFIC ENERGY CONSUMPTIONS ACHIEVED FOR INTENSIVELY MONITORED PRE-PACK STORES

The energy consumption is on average 19% greater in 2009/10 than in 2008/09 and 18% less than in 2007/08. Higher energy consumption in 2009/10 can be partly explained by one store in this group which used ethylene sprout suppressant and, to prevent loss of the chemical, did not make use of ambient cooling. Additionally there was a significant effect on the energy consumption of a further store from part loading.

Again the spread of energy consumptions for the ***basic monitored pre-pack stores*** was much wider at 0.15 kWh/tonne/day to 0.70 kWh/tonne/day (average 0.34 kWh/tonne /day). The average energy consumption of this group was 15% greater in 2009/10 than in 2008/09.

The energy requirement for potato storage contributes to the carbon footprint for potato production. The relative impact of typical processing and pre-pack storage is shown below:

Months stored	Number of days	Processing carbon emissions (kg/tonne)	Pre-pack carbon emissions (kg/tonne)
October - May	241	22.0	77.9
October - April	211	18.3	57.0
November - April	180	14.5	38.7
November - March	150	11.3	28.2

TABLE 18. A COMPARISON OF THE CARBON EMISSIONS OF PROCESSING STORAGE AND PRE-PACK STORAGE

Unsurprisingly, shorter term storage reduces the impact of energy on the carbon footprint of potato storage. This is an effect that could be used by the industry to reduce its collective emissions but, clearly, continuity of supply has to be maintained.

The construction and design of stores had an important effect on energy consumption. The use of variable speed drives was seen to have a notable impact, albeit that this is confounded by them being fitted in the most modern stores. Increasing levels of insulation – up to a point – also show benefits but are perhaps then overridden by factors such as air leakage. The store simulation shows these benefits; increased insulation, reduced air leakage and increased storage temperatures are all measures that can be taken to reduce energy consumption.

6. CONCLUSIONS

This work has provided a valuable opportunity to quantify the range and extent of energy consumption for typical British potato storage. Energy monitoring need not be expensive as demonstrated by the installation of 28 electricity meters for this project. Simple analysis such as kWh/tonne/day can quickly highlight stores or periods when efficiencies fall.

Data from this project have been made available to levy payers both as monthly data returns to participants and to a wider audience via the PCL energy hub website. This has become a useful resource where impacts on energy consumption of a wide range of factors can be discussed and disseminated.

The 38 stores monitored for this project provide a representative cross section of British store stock and the monitored energy results from these showed that there is as much as a three-fold difference in energy consumption between the highest and the lowest users. With such large variations, there is clearly a need for more focused work on the measures that can be taken to reduce consumption as, whilst the financial gains are often relatively easy to achieve, a significant portion of the potato storage within the industry is still incurring higher running costs than necessary.

7. REFERENCES

1. Swain, J. (2008) R401 Reducing the Energy Cost of Potato Storage. Interim Report, 30 September 2008. Undertaken by FEC Services Ltd for and on behalf of SBCSR and PCL.

2. Swain, J. (2009) R401 Reducing the Energy Cost of Potato Storage. Interim Report, 30 September 2009. Undertaken by FEC Services Ltd for and on behalf of SBCSR and PCL.

3. Kneeshaw, A. (2006) Energy Status Report: GB Potato Storage. Undertaken by FEC Services Ltd for Potato Council, Oxford. 18 pp.

4. Cunnington, AC and Pringle, RT. (2008) Store Managers' Guide, 2008, Potato Council, Oxford for AHDB.

5. NPower RWE, Energy Market Pulse, weekly energy price report.

6. Pringle, RT, Bishop, C and Clayton, R. (2009) Potatoes Postharvest, CABI press.

7. Swain, J (2009) CP57 Crop Store and Packhouse Cooling: a commercial demonstration & economic evaluation of ground sink refrigeration. Undertaken by FEC Services Ltd for and on behalf of SBCSR and PCL, funded by Defra through WHRI.

8. KNOWLEDGE TRANSFER ACTIVITIES

Shown below are the knowledge transfer activities carried out over the lifetime of the project (2007 - 2010).

8.1. Open Days

- BP2007 seminar, Harrogate – 28th November 2007
- Winters Lane Storage, Members' Meeting – 13th May 2008
- W. Midlands Potato Event – 4th June 2008
- PCL/SEPA Potato Event – 24th June 2008
- East Midlands Potato Day – 8th July 2008
- PCL Potato Storage Day –16th July 2008
- East Anglian Potato Day – 4th September 2008
- Project data used in presentation by Dr M Storey at CUPGRA Conference, Cambridge - 18 December 2008
- West Midlands Potato meeting - Nuneaton 9th March 2009
- St Nicholas Court Farm Growers' meeting – Kent, 10th March 2009
- PCL/FERA Yorkshire Potato Day at FERA, Sand Hutton, York, - 11th March 2009
- PCL East Midlands Potato Day, Holbeach, 30th June 2009
- British Potato 2009 seminar - Harrogate 25 – 26th November 2009
- McCains grower group meetings, Staffordshire, 12th and 13th January 2010
- PCL Energy event, Huntingdon, 11th February 2010
- McCains energy consumption review by Richard Mussett 31st March 2010
- Project included in presentation given at iPPSC 2010, Edinburgh, 22 June 2010:Potato storage: challenges and solutions for the industry. Adrian Cunnington, SBEU
- Sutton Bridge Crop Storage Research open day, 2nd September 2010
- Winters lane storage group discussion day, February 2010

8.2. Publications

- Potato storage energy guide – 16th July 2008
- SBEU June storage bulletin.
- Farmers Weekly article – November 2009

8.3. Website

- Potato energy hub July, August and September 2008
- Project data monthly reports October 2008 – June 2009
- Energy Hub articles for January, February, March, April, May, June and September 2009
- Project data monthly reports 2010

9. APPENDIX 1

9.1. Store Descriptions

9.1.1. Processing Stores

Store Identifier	Tonnage	Bulk or Box	Tonnes/ box	Cooling type	Age (years)	Condition	Notes
AB1	1,250	Box	1	Refrigerated	05-Oct	Average	Letterbox system, part of a complex of stores
AB2	1,250	Box	1	Refrigerated	05-Oct	Average	Letterbox system, part of a complex of stores
AI	3,000	Bulk		Refrigerated	<5	Good	
C	4,500	Bulk		Ambient only	>10	Average	1980's store under-floor vented split into three sections
D	2,800	Bulk		Ambient only	<5	State of the art	Under-floor vented with humidification and inverters
E	2,800	Bulk		Refrigerated	<5	State of the art	State of the art under-floor vented with humidification refrigeration and inverters
H	5,000	Box	2	Refrigerated	05-Oct	Good	Large box store split into two sections
J	1,300	Box	1	Ambient only	05-Oct	Average	1970's frame refurbished cladding 1990's old air handling unit
K	1,600	Box	1	Refrigerated	>10	Poor	
L	1,200	Box	1	Refrigerated	05-Oct	Average	Converted cattle building possible bulk conversion 2009
M	1,800	Bulk		Ambient only	05-Oct	Average	Converted silage clamp, inverters added 08/09
N	2,000	Bulk		Ambient only	<5	State of the art	Under-floor vented with humidification and inverters
O	2,000	Box	1	Ambient only	>10	Good	Newly refurbished
P	2,400	Bulk		Ambient only	<5	State of the art	Under-floor vented with humidification and inverters
Q	1,500	Bulk		Ambient only	>10	Poor	Very old but new controller, short-term
R	1,100	Bulk		Ambient only	05-Oct	Good	Chipping store using A-Frame ducts and portable fan units
S	1,600	Bulk		Ambient only	05-Oct	Good	Chipping store shared duty as grain store
A	1,100	Box	1	Refrigerated	05-Oct	State of the art	Purpose built good condition store
AA	1,200	Box	1	Refrigerated	<5	State of the art	Newly built, inverter driven condensor and evaporator fans and has a curtain to allow better air distribution

9.1.2. Pre-pack Stores

Store Identifier	Tonnage	Bulk or Box	Tonnes/ box	Cooling type	Age (years)	Condition	Notes
AC	1,200	Box	1	Refrigerated	<5	Good	Old machinery shed but newly converted with new fridge unit and good insulation
AD	935	Box	1	Refrigerated	>10	Average	Old round topped barn as good conversion
AE	2,200	Box	1	Refrigerated	<5	State of the art	Brand new store completed during 08/09 season
AF	1,400	Box	1	Refrigerated	<5	Good	Good condition modern store
AG	1,400	Box	1	Ambient only	>10	Poor	Short term ambient only store
AH	2,100	Box	1	Refrigerated	<5	State of the art	Has a meter already (but includes grading area) required extra meter
AJ	1,560	Box	1	Refrigerated	<5	State of the art	Good condition modern store
AK	2,600	Box	1	Refrigerated	>10	Good	Glycol pack cooling system
AL	2,300	Box	1	Refrigerated	>10	Bad	Glycol pack cooling system
AM	1,100	Box	1	Refrigerated	05-Oct	Good	Newly refurbished store with new refrigeration units
B	800	Box	1	Refrigerated	>10	Poor	Converted grain store with portable fridge units
F	1,600	Box	1	Refrigerated	Unknown	Good	Older design brick built store
G	1,200	Box	1	Refrigerated	Unknown	State of the art	Good purpose built store
T	2,720	Box	1	Refrigerated	05-Oct	State of the art	Good condition modern store
U	800	Box	1	Refrigerated	>10	Poor	Converted grain store compromised air flows potential leakage of air to other stores
V	1,500	Box	1	Refrigerated	>10	Poor	Poor store bounded two smaller stores big gaps in doors and insulation
W	9,000	Box	1	Refrigerated	<5	Special	Complex of 9 separate stores built 2006
X	2,500	Box	1	Refrigerated	>10	Poor	Seed store poorly insulated
Y	1,200	Box	1	Refrigerated	>10	Poor	Poor condition store in a complex of others
Z	1,100	Box	1	Refrigerated	>10	Average	Old machinery shed brick walls and fibre cement sheets walls and roof converted 2006

9.2. Appendix 2 - Case Studies

This appendix contains 4 new case studies and 5 case studies reproduced from the second year annual report.

9.2.1. Case 1 – Pre-pack Intensive

	Store 5	Store 6
Type	Converted grain store >10 years old.	Purpose built potato store 5 - 10 years old.
Capacity	800 tonnes.	1100 tonnes.
Condition	Reasonable.	Excellent.
Cooling	Refrigerated using portable fridge units.	Refrigerated using purpose built fridge units.
Storage	Box store for pre-pack produce.	Box store for pre-pack produce.
Insulation	Glued panel board insulation 100 mm thick on walls and 50 mm thick roof. Spray foam insulation to 50 mm added for this season.	Tongue and grooved panel board insulation 75 mm thick all round.

TABLE A1 – STORE COMPARISONS

9.2.1.1. Previous History and Modifications

In 2007/08 season Store 5 was shut down in December because the energy consumption was double that of Store 6. During the summer of 2008 the store was reinsulated with an additional 50 mm of spray foam insulation to improve its performance.

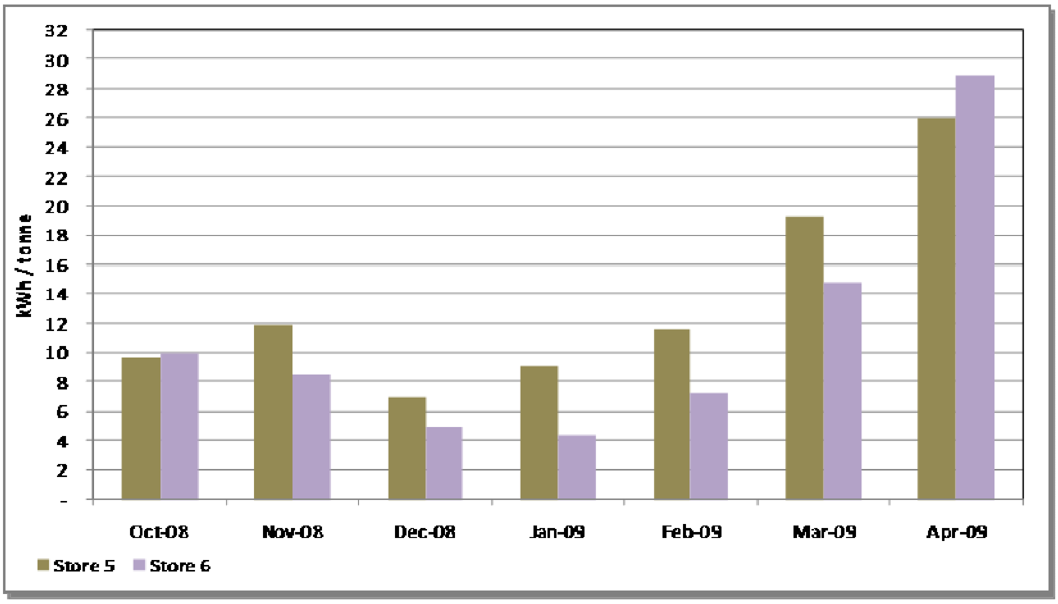


FIGURE A1 - COMPARISON BETWEEN STORE 5 AND STORE 6 FOR 2007/08

9.2.1.2. 2008/09 Performance

Figure A2 shows the monthly performance of both stores during the period that both stores are comparable.

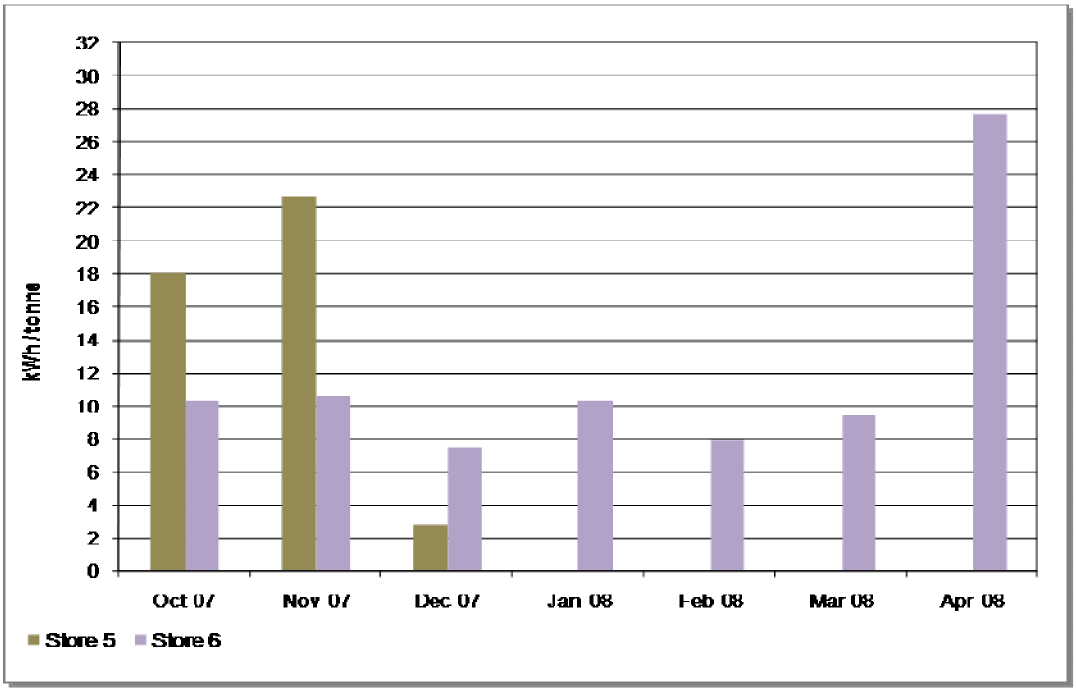


FIGURE A2 - COMPARISON BETWEEN STORE 5 AND STORE 6 FOR 2008/09

Although for the majority of the season Store 5 had higher energy consumption per tonne than Store 6, the differences were much smaller than during the 2007/08 season. The average difference between the stores was 28%.

Both Store 5 and Store 6 had energy consumptions at the lower end of the pre-pack group with specific energy consumptions for the entire season of 51.1 and 41.2 kWh/tonne, respectively.

9.2.1.3. Conclusion

The improved performance of Store 5 demonstrates that it is possible to obtain reasonable performance from older stores if they are well maintained and attention is focused on good insulation and reducing store air leakage.

The performance of Store 6 is still much better and there may be several reasons for this, for example:

- More efficient fridge unit.
- Less air leakage.
- Better air distribution in the store.

All of these can affect store energy consumption over and above insulation levels alone.

9.2.2. Case 2 - Pre-pack Basic 1

	Store Y	Store AH
Type	Purpose built potato store >10 years old.	Purpose built potato store erected 2005.
Capacity	1200 tonnes.	2100 tonnes.
Condition	Poor.	Excellent.
Cooling	Refrigerated using purpose built fridge units.	Refrigerated using purpose built fridge units.
Storage	Box store for pre-pack produce.	Box store for pre-pack produce.
Insulation	Glued panel board insulation 75 mm thick all round.	Insulated composite panel to 80 mm.

TABLE A2 – STORE COMPARISONS

9.2.2.1. 2008/09 Performance

The following graph shows the performance of the two stores for the 2008/09 season.

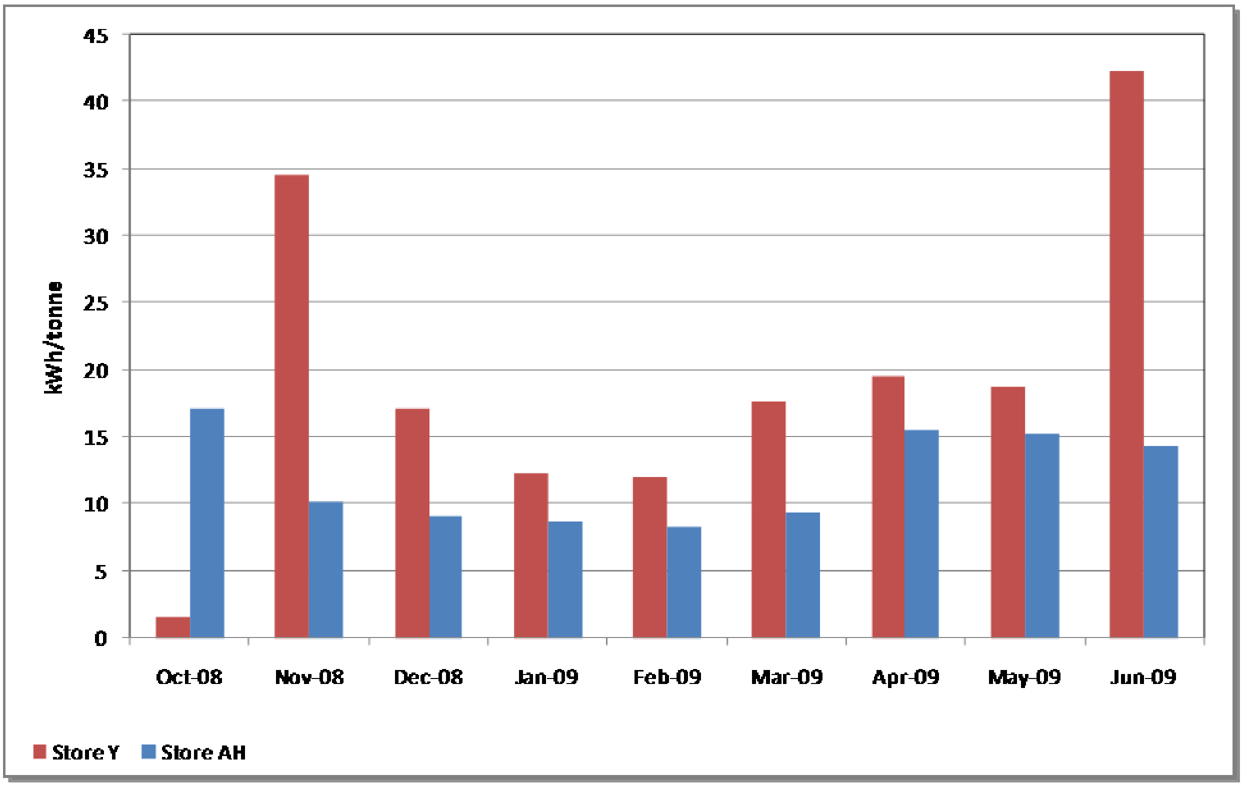


FIGURE A3 - PERFORMANCE FOR STORE Y AND STORE AH IN 2008/09

Whilst the energy performance of Store Y follows the expected trend (i.e. more energy during warmer months at the beginning and end of the season), the monthly energy consumption is, on average, 40% greater than Store AH. This is borne out by an entire season specific energy consumption of 128.4 kWh/tonne compared with 103.6 kWh/tonne for Store AH.

9.2.2.2. Conclusions

The difference in energy consumption is primarily because of the differences in store construction.

- Store AH is a modern built store with good attention to detail with regards to insulation and sealing.
- Store Y is not as well maintained and during the store visit large areas requiring sealing were noticed.

9.2.3. Case 3 - Pre-pack Basic 2

	Store AJ
Type	Purpose built potato store <5 years old.
Capacity	1,560 tonnes.
Condition	Excellent with state of the art equipment.
Cooling	Refrigerated using purpose built fridge units. Fitted with inverter drives and heat recovery system to improve refrigeration efficiency.
Storage	Box store for pre-pack produce.
Insulation	Pre insulated panels 80 mm thick all round.

TABLE A3 – STORE DETAILS

Store AJ was the best performing store of the pre-pack group. This is in spite of being a year round store based at a factory site where there are regular movements in and out of the store during spring and early summer.

9.2.3.1. 2009/10 Performance

The following graph shows the performance of the store for the 2009/10 season against the typical pre-pack store (derived from the average performance of the group monitored in 2008/09 and 2009/10).

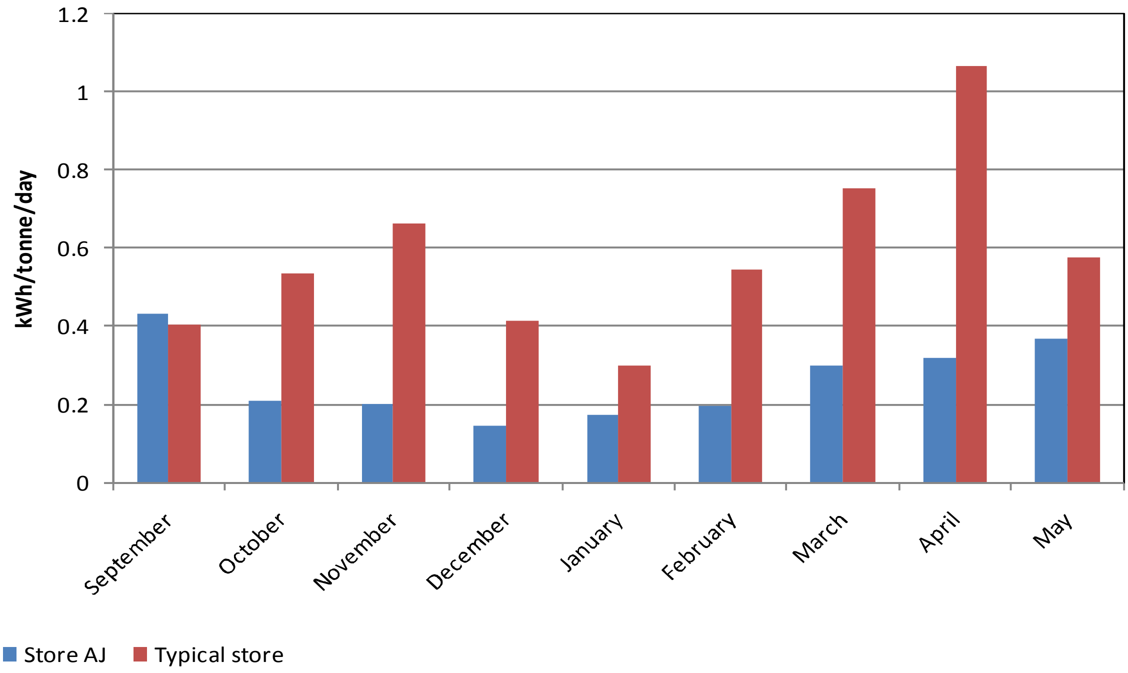


FIGURE A4 - PERFORMANCE FOR STORE AJ AND THE TYPICAL STORE

The performance of Store AJ is much better than the typical store. On average the store used 50% less energy.

9.2.3.2. *Conclusions*

The difference in energy consumption is the exceptional design and construction of the store. Modern equipment and a well constructed building are also supplemented by the almost year long operation meaning the store is maintained at near target temperature conditions.

9.2.4. Case 4 - Pre-pack Basic 3

	Store AC
Type	Old machinery shed converted to a potato store for 2008/09 season.
Capacity	1,200 tonnes.
Condition	Excellent with modern refrigeration equipment.
Cooling	Refrigerated using purpose built fridge units.
Storage	Box store for pre-pack produce.
Insulation	Spray on Urethane foam 75mm all throughout, roller shutter door.

TABLE A4 – STORE DETAILS

Store AC showed the third best performance for the 2009/10 season. This is in spite of being a conversion of an old brick built machinery shed.

9.2.4.1. *2009/10 Performance*

The following graph shows the performance of the store for the 2009/10 season against the typical pre-pack store (derived from the average performance of the group monitored in 2008/09 and 2009/10).

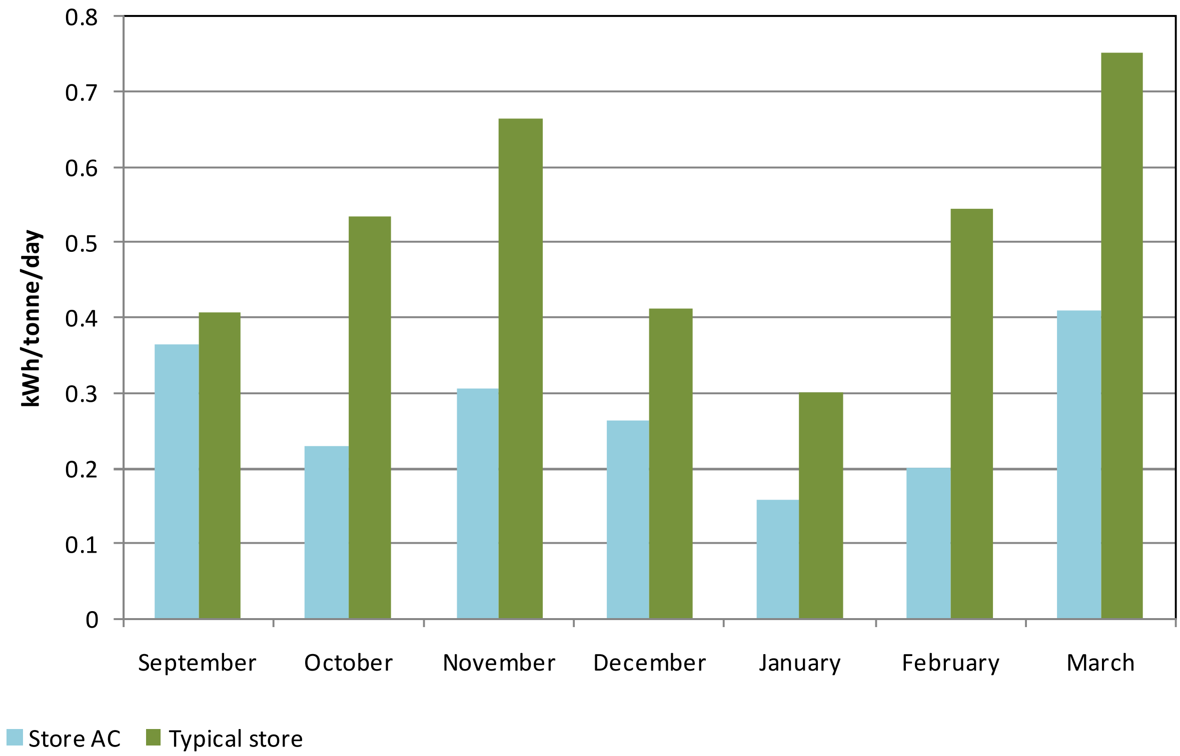


FIGURE A5 - PERFORMANCE FOR STORE AC AND THE TYPICAL STORE

The performance of Store AC is much better than the typical store. On average the store used 55% less energy.

9.2.4.2. Conclusions

The performance of this store is unexpected however the following reasons can be proposed:

- The store operated at 3^{o}C
- The store is a good conversion and well sealed and insulated.

This shows that it is not always necessary to build a new store to get good performance.

9.2.5. Case 5 – Processing Intensive 1

	Store 3	Store 4
Type	Purpose built potato store <5 years old.	Purpose built potato store <5 years old.
Capacity	3000 tonnes.	3000 tonnes.
Condition	Excellent.	Excellent.
Cooling	Ambient only.	Refrigerated and ambient using purpose-built fridge units.
Storage	Bulk store for processing produce.	Bulk store for processing produce.
Insulation	Insulated composite panel to 80 mm.	Insulated composite panel to 80 mm.

TABLE A5. STORE COMPARISONS

9.2.5.1. *Previous History and Modifications*

The performance of the stores for 2007/08 is given in the graph below.

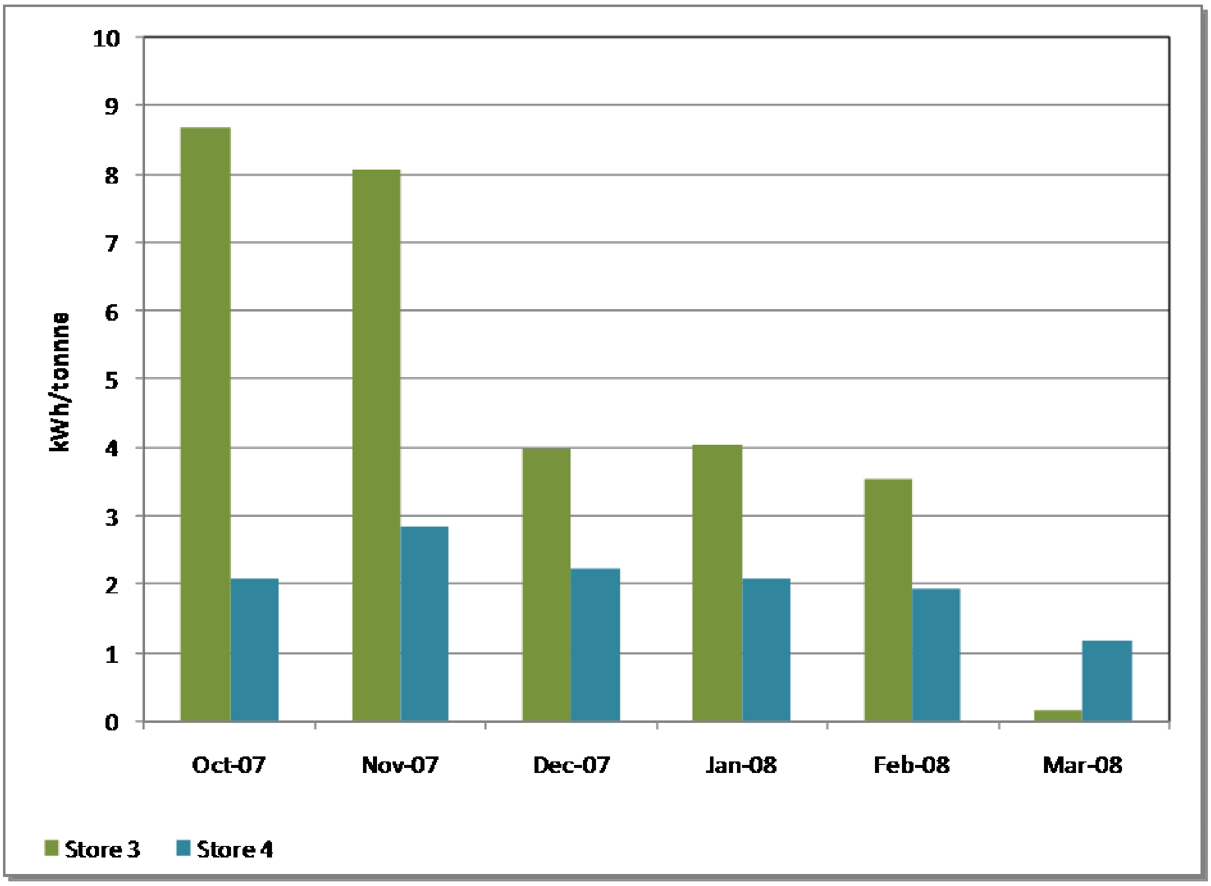
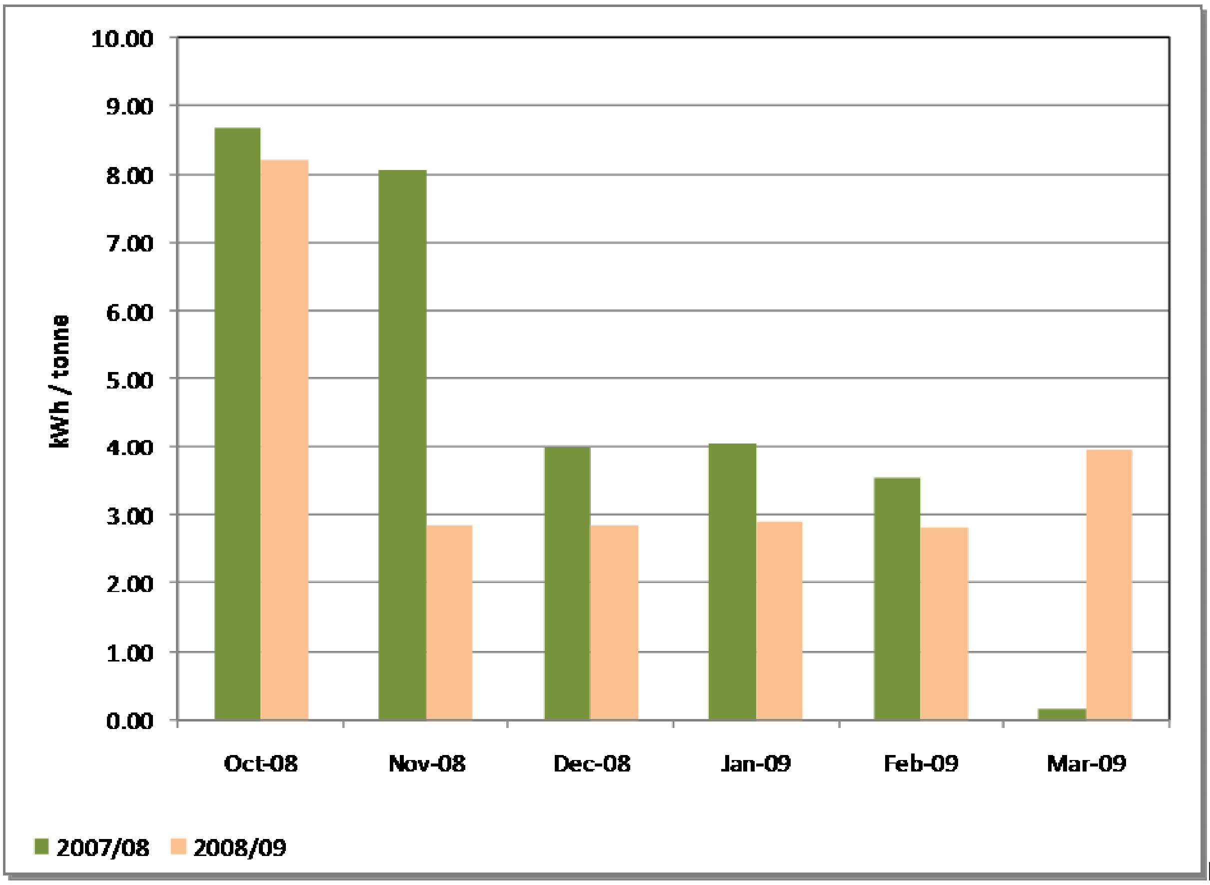


FIGURE A6 -PERFORMANCE OF STORE 3 AND STORE 4 FOR 2007/08

This graph clearly shows that Store 3 was using significantly more energy than Store 4. This is because there were problems with crop quality in Store 3 that required the store fans to be operated for longer hours than necessary to achieve cooling alone.

9.2.5.2. *2008/09 Performance*



F

FIGURE A7 - STORE 3 PERFORMANCE COMPARISON

Store 3 this year shows a much reduced energy consumption to 2007/08. The entire season specific energy consumption for the 2007/08 season was 32.5 kWh/tonne compared with this 2008/09 value of 32.5 kWh/tonne. The average energy consumption for the season per month was 35% less than 2007/08.

9.2.5.3. *Conclusions*

Problems with crop quality generally cause higher energy consumptions, as more management of the crop usually requires more air movement and temperature control. This can mean that results are not always comparable between stores. It is important, however, to factor in this additional energy cost when calculating whole season storage costs.

9.2.6. Case 6 – Processing intensive 2

	Store 2	Store 3
Type	Purpose built potato store >10 years old.	Purpose built potato store 5 -10 years old.
Capacity	5,200 tonnes.	2,600 tonnes.
Condition	Average - poor.	Excellent.
Cooling	Ambient only	Ambient only
Storage	Bulk store for processing produce.	Bulk store for processing produce.
Insulation	Spray foam to 50mm and deteriorating condition	Insulated composite panel to 80 mm.

TABLE A7 – STORE COMPARISON

9.2.6.1. 2009/10 Performance

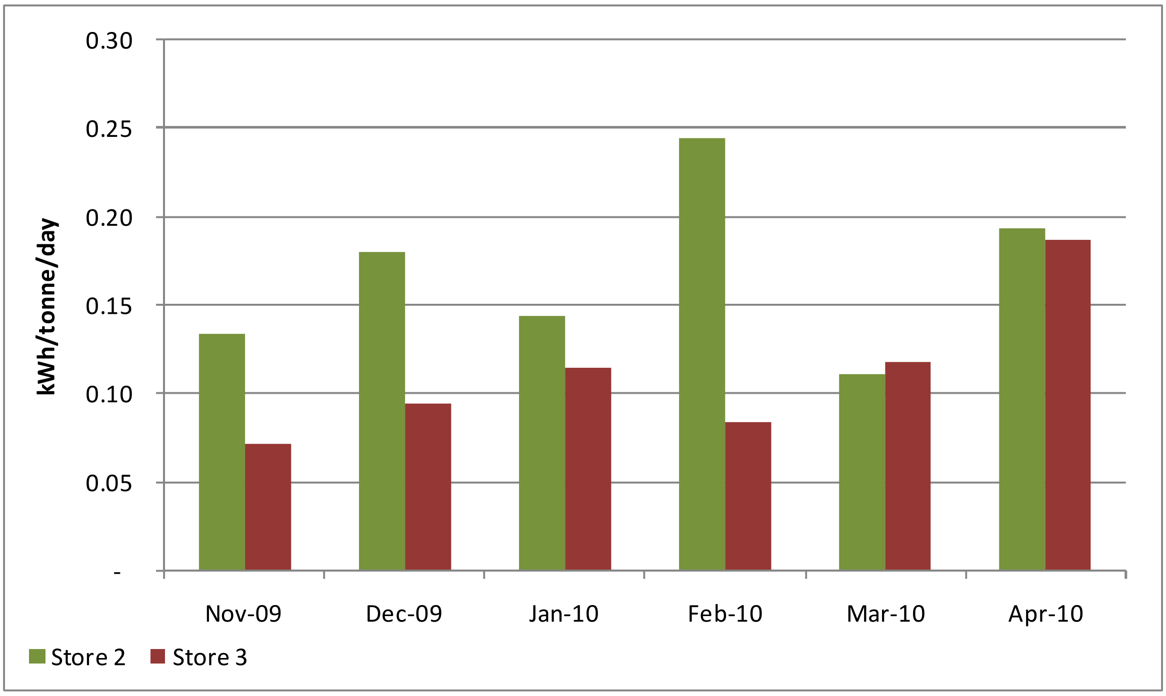


FIGURE A8 - PERFORMANCE FOR STORE 2 AND STORE 3 2009/2010

Both stores were attempting to achieve similar target temperatures (around 10.5 ^{o}C) Store 2 used significantly more energy during Nov - Feb. this is because the store is not as well sealed or insulated so fans had to run longer in November to keep the store cool and roof heating was required in Dec - Feb.

9.2.6.2. Conclusions

Store 2 energy consumption has always been greater than the other processing stores in the intensive group. As a result of this project the store management have re-insulated the store and replaced the louvres and the doors.

9.2.7. Case 7 – Processing intensive 3

	Store 1
Type	Purpose built potato store 5 -10 years old.
Capacity	5,000 tonnes.
Condition	Excellent.
Cooling	Refrigerated and ambient using purpose built fridge units.
Storage	Box store for processing produce.
Insulation	Insulated composite panel to 80 mm.

TABLE A8 – STORE DETAILS

9.2.7.1. Store Performance

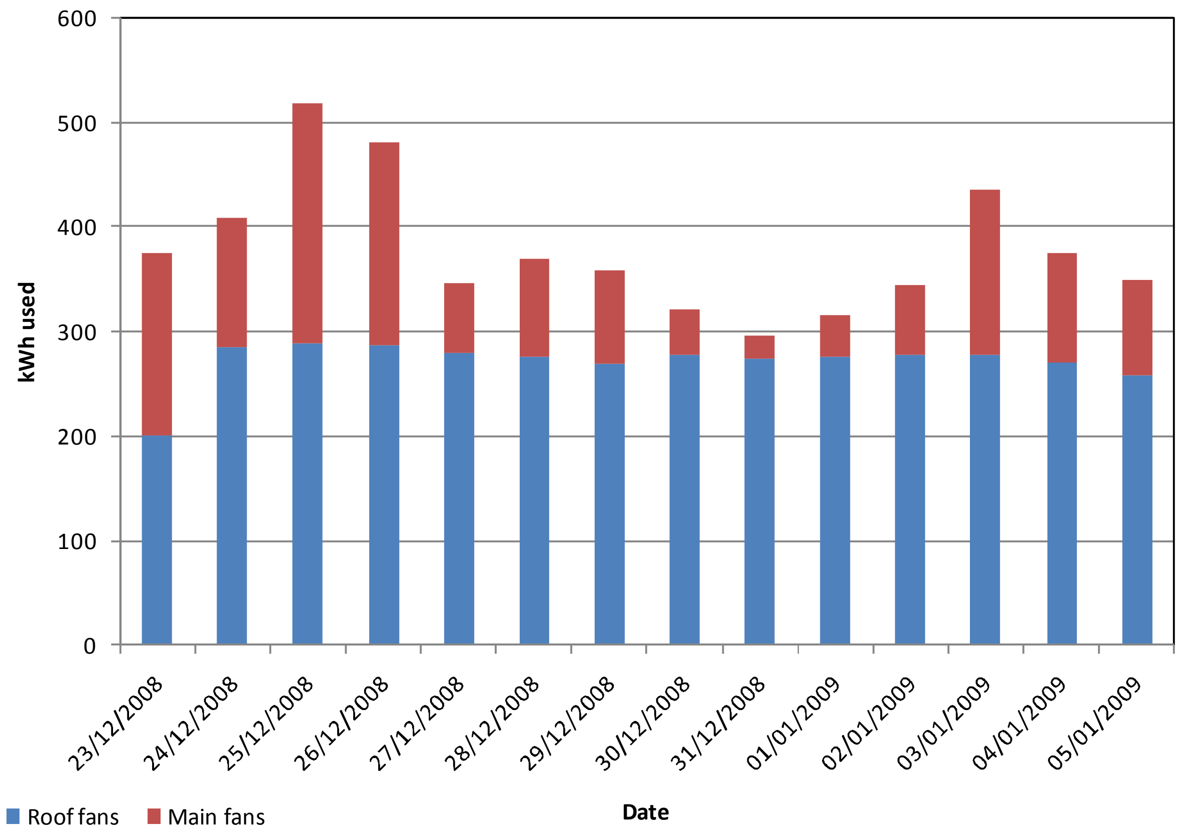


FIGURE A9 - ENERGY USED BY STORE 1 23 DEC 10 TO 5 JAN 09

The graph above shows the kWh used by the store for 23 Dec 08 to 05 Jan 2009. This shows how much energy was used for the roof fans compared with that required for cooling. On average 72% of the energy consumption in this period was for the roof fans.

9.2.7.2. Conclusions

A lot of energy in processing stores is used for roof fans. These tend to be uncontrolled and once turned on they are left on. As this energy contributes significantly to the cost of potato storage during winter months especially, there is good potential to reduce this by better control.

9.2.8. Case 8 – Processing basic 1

	Store I	Store K
Type	Purpose built potato store <5 years old.	Purpose built potato store >10 years old.
Capacity	3000 tonnes.	1600 tonnes.
Condition	Excellent.	Reasonable.
Cooling	Refrigerated and ambient using purpose built fridge units.	Refrigerated and ambient using purpose built fridge units.
Storage	Box store for processing produce.	Box store for processing produce.
Insulation	Glued panel board insulation 75 mm thick all round.	Spray foam insulation to 50 mm.

TABLE A9 – STORE COMPARISONS

9.2.8.1. 2008/09 Performance

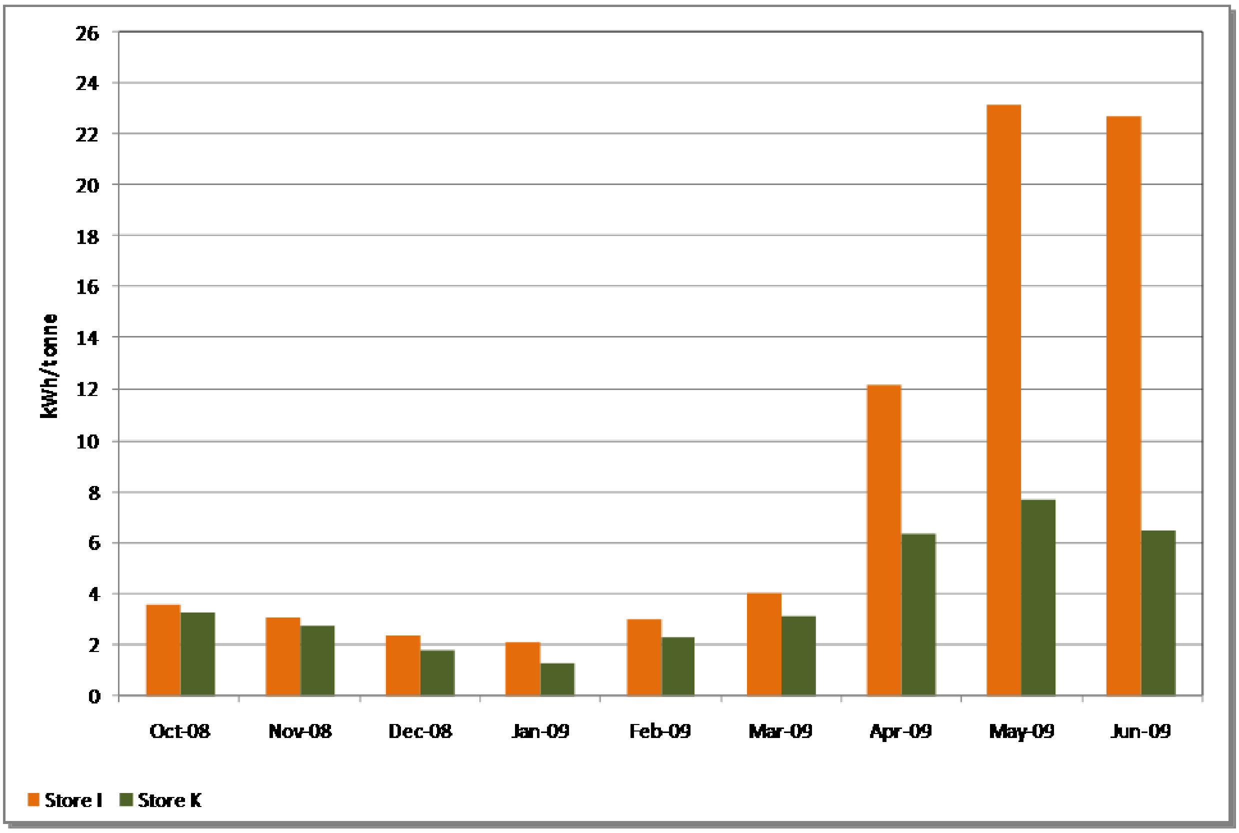


FIGURE A10 – PERFORMANCE OF STORE I AND STORE K FOR 2008/09

For the majority of the season both stores performed very similarly. This is a surprise as the condition of the two stores would lead to the conclusion that Store I should perform better than Store K.

The kWh/tonne value increase shown by Store I at the end of the season is attributable to a reduction in store quantity (to less than 2000 tonnes from April and less than 1500 tonnes from May).

The exact reason why Store I showed poorer performance to Store K is difficult to pinpoint. However some possible explanations are given below:

- Differences in management approach.
- Poorer air distribution giving longer fan run hours.
- Larger stores are more difficult to control.
- Store fabric losses are more significant causes of energy consumption.
- More movements in and out of the store result in greater air exchange.

9.2.8.2. Conclusions

This case study shows that a modern well-built store does not always perform better than an older store in not such good condition. Additionally, the part-loading effect can have significant impact on energy use per tonne of produce, especially when the stored volume falls below half of the store capacity.

9.2.9. Case 9 – Processing basic 2

	Store O (basic)	Store 1 (intensive)
Type	Purpose built potato store 5 - 10 years old.	Purpose built potato store 5 -10 years old.
Capacity	1000 tonnes.	5000 tonnes.
Condition	Reasonable.	Excellent.
Cooling	Refrigerated and ambient using purpose built fridge units.	Refrigerated and ambient using purpose built fridge units.
Storage	Box store for processing produce.	Box store for processing produce.
Insulation	Glued panel board insulation 75 mm thick all round.	Insulated composite panel to 80 mm.

TABLE A10 – STORE COMPARISON

9.2.9.1. 2008/09 Performance

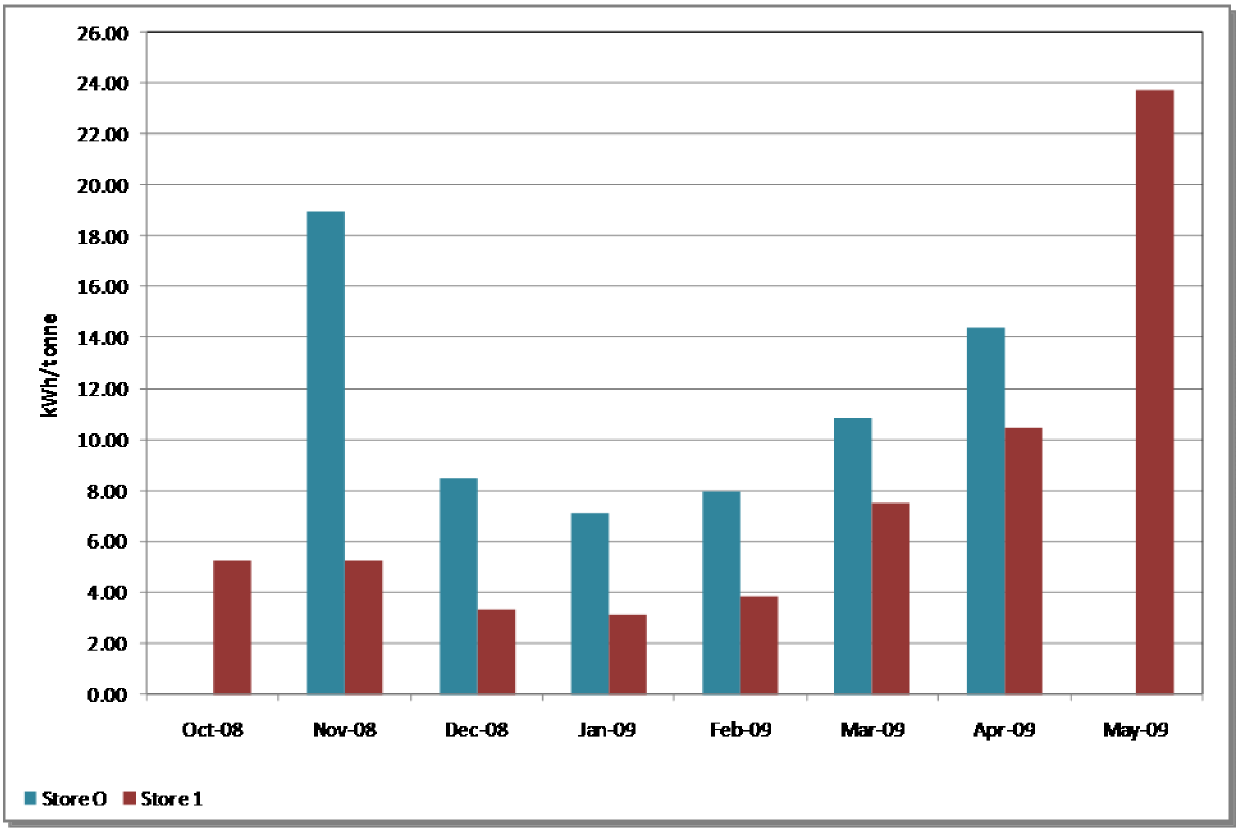


FIGURE A11 - PERFORMANCE FOR STORE O (BLUE) AND STORE 1 (RED) IN 2008/2009

Later loading of a store generally results in less energy being used to pull down the temperature of the crop as it is cooler. As such it might be expected that Store O would use less energy during November than Store 1 did in October. This was not the case. Store O had, in fact, much greater energy consumption than Store 1.

Although the store was loaded later, the crop was much wetter and took significantly more fan hours to dry effectively. To counter continuing disease risk, the store also needed more fan use throughout the storage months.

9.2.9.2. Conclusions

The condition of the crop entering the store has a big affect on the store energy consumption. What is gained in availability of ambient cooling and a cooler crop can easily be lost through a greater requirement for drying.