Reducing energy use in the cold storage industry – A case study

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ABSTRACT

For a typical cold store, after wages, electricity is the second largest operational cost. With the huge increases in electricity network and renewable energy charges (RECs) in recent times and the Carbon Tax from 1 July 2012, the cost of electricity is predicted to increase by around 30%. The days of cheap electricity are now history, and unfortunately, we can confidently look forward to ongoing increasing energy costs.

This paper details how, between 2009 and 2012, at one of the largest cold stores in Australia, energy efficiency was improved from 53.5kWh/m³ to 37.6kWh/m³ (1.5kWh/ft³ to 1.0kWh/ft³). Over this period the total storage capacity increased by 34.5% from 106,270 to 142,970 pallets but the total electricity consumption (kWh) did not change.

The major contributors to improving energy efficiency were:

1. Constructing the new buildings and refrigeration plants to high energy-efficiency standards
2. Energy-efficiency benchmarking of the existing facility
3. Improved monitoring and control of chamber temperatures
4. Improvements in door design to reduce infiltration
5. Retrofitting energy efficient LED (light-emitting diode) lights to replace HPS (high-pressure sodium) chamber lights
6. Retrofitting VFDs (variable frequency drives) to existing screw compressors, freezer and condenser fans
7. Over-sizing evaporative condensers.

Other measures implemented or tried but not discussed in this paper

- Power factor correction
- Voltage optimisation
- Rain water harvesting to substitute for potable condenser feed water.

1. INTRODUCTION

Oxford Cold Storage is a family-owned business, which since 1975, has provided temperature-controlled warehouse facilities to service food manufacturers and importers. The company occupies a 450m x 510m (or 23ha) site in Laverton North, Victoria (Figure 1). Oxford has grown to be the 21st largest public refrigerated warehouse worldwide. It provides blast freezing for cartons and carcasses; the facility handles and stores palletised frozen and chilled products at temperatures ranging from – 27°C to 18°C.

The energy used by the cold store varies with seasonal factors, throughput, occupancy and the volume of blast freezing.

Over three years – 2009/10 to 2011/12 – the total storage capacity increased by 34.5% from 106,270 to 142,970 pallets but the total electricity consumption (kWh) did not change.

Since the completion of the latest 18,000-pallet facility in 2010, the yearly average pallet holding changed little until the first half of 2012. For most of this period, 34% more space was refrigerated, but occupancy levels gradually dropped to bottom out at 86% during the second half of 2011.

Figure 1: Oxford Cold Storage, Laverton North Facility.

Weekly Average Pallet Holding and % Full Capacity					
	2009–10	2010–11	2011–12	June 11 to Dec 11	Jan 12 to June 12
Weekly Av Plts	113,765	121,324	125,064	119,985	130,143
% Capacity	96%	88%	94%	86%	94%

Figure 2: Pallet holding and occupancy.

During the first six months of 2012, pallets stored increased by 13% and the space utilisation increased to 94%. Over the same period, daily blast freezing increased by over 50%, hence the increased energy use in June 2012 to the June 2009 level.

The energy-efficiency improvements detailed in this paper enabled us to reduce the electricity use to the 2009 levels.

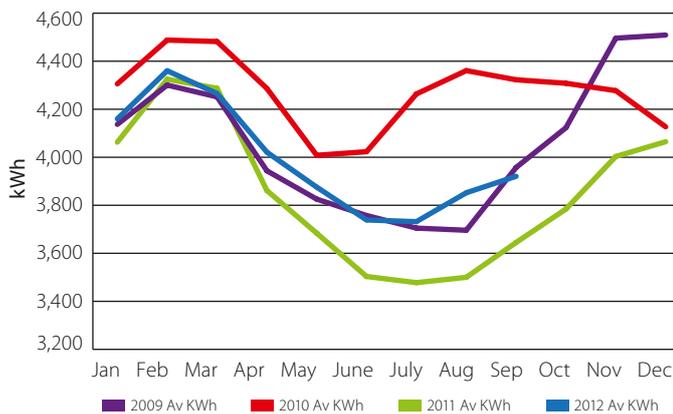## Hume Road Average Hourly kWh Electricity Use

Figure 3: Yearly electricity used kWh.

Over the past three years electricity costs averaged 20% of earnings before interest, taxes, depreciation and amotisation (EBITDA). With increases in renewable energy charges (REC) and electricity network charges from January 1, 2012, together with the $23/tonne carbon tax from July 1, 2012, electricity costs are projected to increase up to 30% of EBITDA.

Electricity costs will continue its upward trend, and the further increases of 80–100% are expected by 2020. The predictions are based on projected increases in electricity generators' coal and gas purchase prices when current contracts expire and the ongoing switch to more gas and renewable generation. This coincides with rapidly increasing network charges due to high maintenance and upgrade costs of ageing electricity and gas-transmission infrastructure.

2. ENERGY EFFICIENCY IMPROVEMENTS

The cost of electricity equals the rate per kWh times the volume. The rate is mostly beyond our control but energy efficiency can substantially reduce the volume.

Figure 5 shows the increase in storage capacity in cubic-metres and Figure 6 the improvement achieved in energy efficiency MWh/m³ over the same period.

The energy-efficiency improvements were achieved by a combination of many small, inexpensive and some large costly changes to operating procedures, and by retrofitting new energy-efficient plant.

2.1. Energy-efficiency benchmarking of the existing facility

Before energy improvements can be made, it is necessary to establish where and how much electricity is used throughout a facility. A good place to start is to track and keep records of past electricity consumption data, not in dollar terms but in kilowatt-hours (kWh), and the maximum demand in kilowatts (kW).

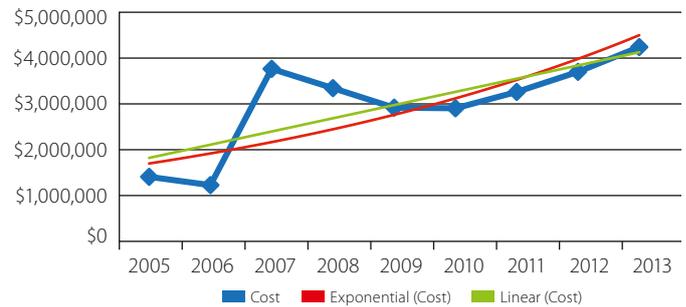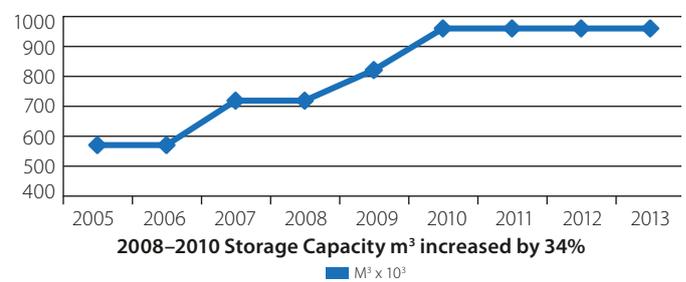## Yearly Total Electricity Cost $Aus

Figure 4: Yearly total electricity cost, Oxford's Hume Road facility.

Storage Capacity m³ x 1000

2008–2010 Storage Capacity m³ increased by 34%

Figure 5: Increase in storage capacity m³.

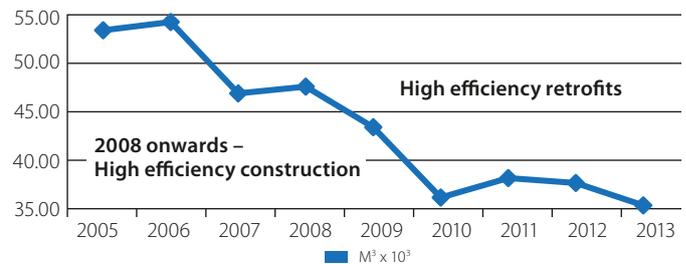## Yearly Energy Efficiency Electricity Used MWh/m³

Figure 6: Reduction in energy used MWh/m³.

The effectiveness of energy-efficiency measures can be measured against past records. To understand seasonal fluctuations it is necessary to track the volume of electricity used for the past two to three years.

A SCADA system that reports by means of spreadsheets or graphs helps to establish the distributed power usage patterns and to analyse the effectiveness of investments in energy – efficiency retrofits.

The energy efficiencies of the buildings on site were benchmarked against each other and against the Energy Efficiency Benchmarking Survey (unofficial organisational survey) conducted by the Refrigerated Warehouse and Transport Association of Australia. Possible energy savings were prioritised and implemented on the basis of cost benefits and ease of implementation.

2.2. Improved monitoring and control of chamber temperatures and plant controls

It is essential that all thermometers and pressure transducers are regularly calibrated, and provide reliable, accurate readings. It is also important to track product movements and heat loads caused by freezing products and by reducing incoming product temperatures to chamber temperatures. Operational staff must ensure that the plant engineers are kept up to date with customers' storage temperature requirements.

Running a sub-zero chamber 1°C colder than required can increase the energy use by up to 3%. It is important to set room thermostat differentials to minimum, and to avoid large temperature fluctuations. Temperature fluctuations damage product quality and reduce shelf life. From experience, turning off chambers during the busiest times of the day and sub-cooling during periods with off-peak electricity, will not necessarily result in monetary savings and can increase the total kWh consumed, and possibly the maximum electrical demand.

2.3. Improvements in door design to reduce infiltration

At Oxford Cold Storage there are daily in excess of 800 truck movements. The trucks are loaded and unloaded through 90 dock levellers leading into refrigerated loading docks. Product movements from the loading docks to the chambers are with forklifts, reach trucks and pallet trucks through automated high-speed insulated doors. Additionally, in excess of 400,000 items are picked daily, causing many thousands of door openings every day. Due to the high number of door openings daily defrosts are required.

The largest heat load in a cold store is from infiltration of warm and humid outside air and leakage of refrigerated air to atmosphere. To improve energy efficiency it is essential to limit the number and size of the doors leading outside.

In an ideal world, all product receival and load-outs should take place in a refrigerated loading dock, and pallets should be transported into the storage areas via mechanical conveyors through port holes in the chamber walls. Pallet movements inside the chamber should be by automated cranes or forklifts.

Some of the measures implemented to limit infiltration of outside air and loss of refrigerated air in the newer buildings, and slowly retrofitted to the older ones, were:

* Airlocks on all personal access (PA) doors

* Interlocking inflatable airbag operation to dock doors

* Airlocks on forklift ramps

* Insulated finger-dock (enables unloading from the side inside an enclosed area) to unload tray trucks and taut liners

* Strict maintenance on door seals, door self-closers and air bags.

2.4. Energy-saving solid-state LED lights

In a typical cold store, lighting directly accounts for 10–12% of the total electricity consumption. Conventional globes make light by heat and this heat, which is 100% of the light's rated energy consumption, has to be removed by the refrigeration plant.

It is now possible, while maintaining the same level of illumination, to directly replace conventional 400W high-pressure sodium or metal halide high-bay flood lights with 120W to 150W LED lights. LED lights produce only a small amount of heat in the power supply and at the silicon chip's junction or contact point. The reduction in heat input into the chamber reduces the load on the refrigeration plant.

LED lights are claimed to produce minimum 80% of the original light output after 50,000 hours, can be switched on and off as required and reach full output immediately when energised. Manufacturers claim that LEDs have a service life in excess of 100,000 hours.

At Oxford Cold Storage we have installed in new chambers and retrofitted in existing chambers in excess of 1,700 LED lights as high-bay lights and internal and external flood lights. The failure rate is less than 1%, and all faults were easily rectified by replacing the power supplies with new ones supplied under the three-year warranty.

The 1,700 lights reduced our peak lighting load by 476kW, with a similar reduction in our maximum demand. The refrigeration heat load was decreased by 476kW, which we calculated at 238kW refrigeration motor load. Based on operating two, eight-hour shifts daily the estimated savings are:

(476+238)kW x (16x5x52)hrs =2,970,240kWh

At an average cost of electricity at 12.5 cents/kWh (including carbon tax and renewable energy charges).

* The annual electricity cost savings are estimated at **$371,280**.

* The annual savings in carbon is 4,039 tonnes CO_2-e (ref: Carbon Neutral for Victoria)

* Over the year, the saving in the monthly maximum demand charges are 476kW x $8.00/kW x 12months = **$45,696**

* Total annual savings = **$416,976**

The ROI (return on investment) on retrofitting the LED lights is under two years.

2.5. Variable frequency drives (VFD) on fans

A VFD allows most induction motors to operate at reduced speeds. Fans operate under predictable set of laws (fan laws) concerning speed, power and pressure. A change in speed (RPM) of any fan will predictably change the pressure rise and power necessary to operate it at the new RPM.

Although VFDs can produce energy savings on many different equipment loads, evaporator and condenser fans offer great potential savings. This is the result of the affinity laws, which govern the flow, pressure, and power requirements.

* The volume of the air flow is proportional to the fan speed

* Pressure of the air is proportional to the square of the fan speed

* Power used is proportional to the cube of the fan speed

Evaporator fans in a refrigerated warehouse are a good example of these laws, which offer nearly perfect cubic power reduction with speed. This means that a fan operating at 50% speed will ideally draw 12.5% shaft power. Although motor and drive efficiency might temper this ideal value to the about 15%,
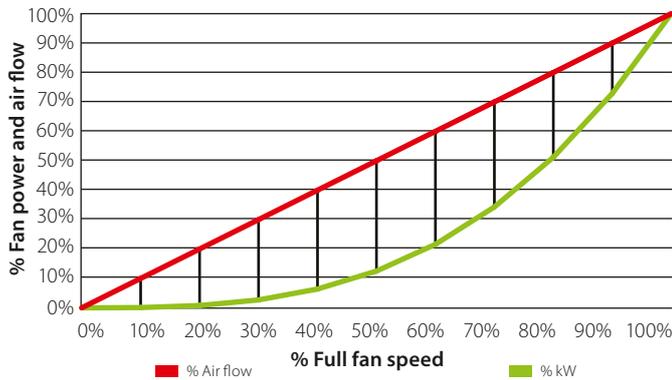
Effect of fan speed on power and air volume

Figure 7: **Effect of fan speed on power and volume.**

the power reduction is tremendous. And to top off the fan energy reduction, any savings in fan energy result in reduced room heat loads. Compressors unload and condenser fans operate less as a result, adding another 20–50% to the direct fan-energy savings.

The evaporator fan speeds are monitored in our SCADA (supervisory control and data aquision) system. When the chamber temperature is within 1°C of the desired temperature, the fans slow down until they stop after the set temperature is reached.

2.6. VFDs on condenser fans – The effect of high discharge pressure on energy efficiency

The energy used by refrigeration compressor drive motors increases when the compressor discharge pressure increases (Figure 8). Consequently, it is a good practice to run a refrigeration plant at the lowest possible discharge pressure. However, factors other than condenser capacity limit the theoretical minimum discharge pressure. These are the pressure differential required for expansion valves to feed evaporators and pressure vessels at full capacity and for hot gas defrost systems to operate at sufficiently high pressure.

Condensers are designed to enable the plant to operate at peak load conditions and the condenser capacity must be controlled to maintain the most efficient operating conditions. Condensers at Oxford Cold Storage are oversized by 30% to achieve lower discharge pressures in peak summer conditions. To maintain the most efficient plant discharge pressures, the use of VFDs on the condenser fans is preferable to using multi-speed fan motors or cycling fans on and off.

There are 14 large evaporative condensers at Oxford with 19 fans that have a total capacity of 288kW.

Turning off 50% of the fans for six months the annual power consumption will be

kWh = 8736/2 * (288 + 288/2) or 1,886,976kWh per year.

Effect of increasing discharge pressure on enegy use and compressor efficiency (Ref.1)
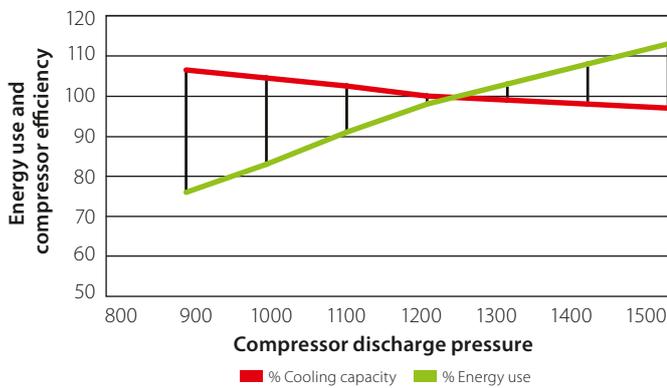

Figure 8: Effect of discharge pressure on energy use. Reference 1: Ecolibrium august 2005.

Operating all fans at 50% speed for six months the annual power consumption will be

kWh = 8736/2 * (288 + 288*0.125) or 1,415,232kWh per year.

Annual savings 471,744kWh which at 12.5cents/kWh will save $58,968 per year.

Further savings can be made by operating the fans for most of the year at lower speeds – an average 20% reduction in fan speed will halve the annual power consumption.

The energy used by the condenser fans to achieve lower discharge pressures should alway be offset against any energy savings by compressor motors operating with lower discharge presures.

2.7. Variable speed drives on screw compressor motors (Ref.3)

The refrigeration load on the refrigeration plant varies with the heat load from the chambers and with seasonal weather. Compressors are sized for maximum refrigeration load, and the capacity is varied to maintain the required suction pressure. The standard capacity control fitted to screw compressors changes the position of a mechanical slide valve to modulate the volumetric displacement of the compressor.

The refrigeration capacity of a compressor is proportional to the swept volume. The volumetric displacement of the compressor can also be varied by changing the rotational speed. VFDs control the motor speed, resulting in proportionate changes in motor kW and the refrigeration capacity (Figure 9). Most screw compressors can't be run at less than 50% of the full motor speed. Further reductions below 50% in capacity require mechanical unloading.

The theoretical savings (based on technical information supplied by Mycom) that can be achieved by retrofitting VFDs to screw compressor drive motors depend on the degree of unloading (Figures 9 and 10). With multiple compressor installations a good practice is to run the lead compressor fully loaded to use a VFD on the lag compressor to maintain suction.

Screw Compressor Part Load Power
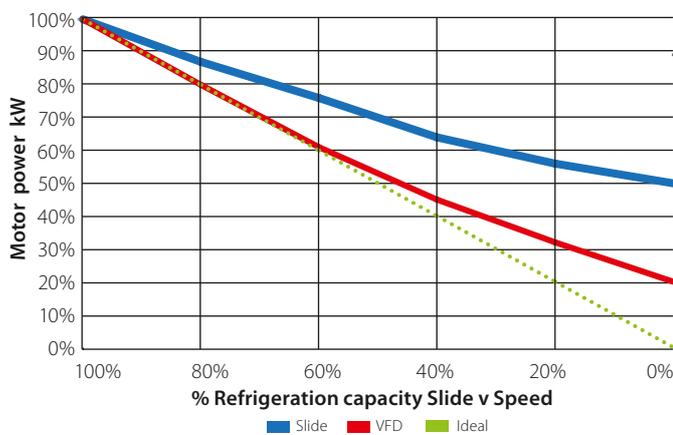Economised @-28 C to +24 Energy Savings RED

Figure 9: Screw compressor energy savingspart-load power slide valve vs VFD control.

Estimated annual savings using VFD on 560kw screw compressor

CAPACITY	SLIDE	VFD	IDEAL	SAVING	COMP.FL kW	ANNUAL @ 12.5c/ kWh
100%	100%	100%	100%	0%	0	$0
80%	87%	80%	80%	7%	39	$42,806
60%	76%	61%	60%	15%	84	$91,728
40%	64%	45%	40%	19%	106	$116,189
20%	56%	32%	20%	24%	134	N/A
0%	50%	20%	0%	30%	168	N/A

Figure 10: Screw compressor estimated annual electricity savings at part-load conditions.

3. CASE STUDY

3.1. Energy Savings over 12 months following retrofitting with VFDs

During May and June 2011, variable frequency drives were fitted to compressor drive motors at Oxford's Building 11 complex, which has a total capacity of 73,200 pallets. Building 11 represents 50% of the facility's floor area and 51.6% of the total storage capacity.

The centrally located, two-stage liquid recirculation ammonia refrigeration plant operates with four screw compressors:

High-stage: Frick RWB 1-177 driven by 225kW electric motor and Mycom 250VLD driven by 465kW electric motor

Low-stage: 2 x Mycom 320VSD driven by 220kW electric motors

VFDs were fitted to the 465kW high-stage and one of the 220kW low-stage screw compressors, and these machines were operated as lag compressors, allowing the other compressors to operate fully loaded.

The cost of the retrofit was $132,146 as shown in Figure 10.

Installation	$42,000
VFDs	$76,665
Replace 220kW motor	$9,681
Bearing change 460kW motor	$3,800
	$132,146

Figure 10: Cost of Retrofitting VFDs to Screw Compressor Drive Motors.

Saving kWh	123
Electricity cost $/kWh	$0.12
Savings 8736 hours kWh	1,076,712
Savings 8736 hours $	$129,205

Figure 11: Savings by retrofitting VFDs to screw compressor drive motors
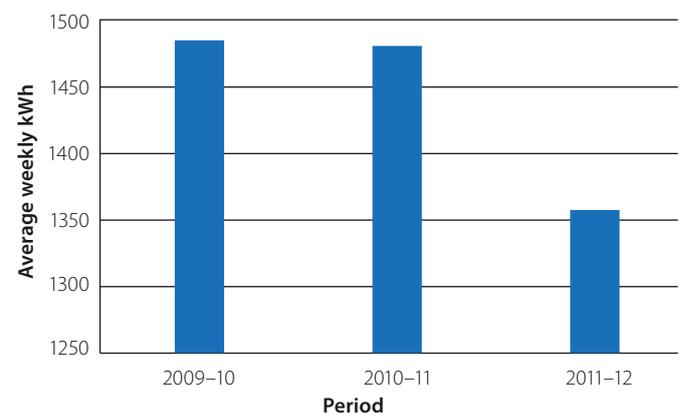

Figure 12: Average weekly electricity consumption Building 11 complex

The average reduction in electricity use for the last year, July 1, 2011 to June 30, 2012 was 123kW per hour (Figures 11 and 12). The electricity savings over 12 months were $129,205 and the return on investment was one year.

4. CONCLUSION

By 2020 it is predicted that electricity prices will rise by 80–100%. Energy efficiency in temperatuture-controlled warehouses will not only be good for the environment but will result in substantial monetary savings. Some of the things facility operators can do are:

· Audit energy-saving opportunities

· Build in efficiency in every part of the building

· Establish best-practice maintenance systems

· Install metering to measure and verify energy savings

· Lighting accounts for 10% of electricity use
  – Creates heat
  – Replace high-energy-use discharge lamps with solid-state lighting – LEDs

- Use variable frequency drives on:
  - Fans
  - Condenser fans
  - Screw compressors
  - Pumps

5. MY ADVICE

- Understand your business now and in the immediate future
- Don't make assumptions – get the facts
- Focus on quick wins
- Capital-intensive projects – look at funding options and the expected life of the project
- Management must take ownership of energy-efficiency initiatives, and drive and monitor progress of all projects
- Ensure that consultants and engineers employed or contracted to oversee energy efficiency are suitably qualified in a specialised industry. ∎

6. REFERENCES

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   By: Abdelhak Dhaibi, Danfoss, Denmark

About the author

Gabor Hilton has over 45 years' experience as an engineer and manager in the cold storage industry. He originally qualified as an electrical engineer in 1964, and was cold store manager at Polar Cold Storage Company from 1966 to 1974.

Hilton was co-founder of Oxford Cold Storage Company in 1975, and was a founding member of the Refrigerated Warehouse and Transport Association of Australia's (RWTA) energy efficiency subcommittee.

He is life member, director and Victorian state representative of the RWTA.