Supermarket Energy Retrofit

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Abstract:
Supermarkets use nationally significant quantities of energy with an average store exceeding 600 kWh/m2 pa.

The reason is simple. The design of these stores is to maximise sales and minimise initial costs. Energy costs are insignificant compared to the huge turnover generated, often less than 0.4%. If any energy conservation measure (ECM) has even a slight negative impact on sales, the savings for the storeowner will be wiped out.

Can an existing supermarket be retrofitted to substantially reduce energy consumption and maintain or increase sales?

This is the challenge that confronted us with our first supermarket energy retrofit and yes it can be done. We have achieved 36% energy savings and total sales for the store have increased 6% over the same period.

Keywords:

Lighting, Refrigeration, Retail, Skylights, Retrofit

1. Introduction

A conventionally built supermarket has a combination of features that result in excessive energy consumption. There are open refrigerated displays adjacent to occupied heated aisles and very high lighting levels, often without natural lighting and a single-minded focus on increased sales.

From an engineering point of view, a supermarket is inherently inefficient and uncomfortable with compromised product temperature control. Where else do you find -25°C maintained next to a 20°C aisle with no barrier but an air curtain?

These same issues mean that the potential for savings in supermarkets is huge. The savings we achieved in this project are only the beginning. We achieved 36% energy savings in a store which even now has 90% of the medium temperature cabinets without any doors. If we could get doors on all of those cabinets, we estimate 50 to 60% savings are possible, along with increased customer comfort and improved product temperature control.

The main barrier to achieving this is the perception (from store management) that doors on cabinets will reduce sales. Placing a barrier between the customer and the product is considered bad practise.

The reality of the introduction of doors is much more complex than this simple rule. Yes, in some situations, with some products, the sales may reduce but in others there will be no effect or even a positive effect on sales. Whether the product is a staple or discretionary, how cold it is in the aisle, where the cabinet is located within the store and even global economic conditions will all affect sales and it is often difficult to isolate these factors.

To successfully add doors on refrigerated cabinets, we must think outside the engineering involved and ensure the marketing, promotion and product display is improved. Use stickers on doors to tell the customer what is being achieved, ensure the product is clearly displayed and well lit and try to co-ordinate promotional activity around door installation to offset any potential negative effects.

Most supermarkets are in single storey big box retail buildings with great potential for natural lighting, especially if there is no suspended ceiling. In spite of this the vast majority of stores do not have adequately designed or fully integrated natural lighting. The stores that do have skylights are normally inadequate to fully illuminate the store and most do not have an automated control system to switch off the lights, so they run regardless of light levels in the store.

In our experience, good skylight design combined with an automated dimming control system will achieve substantial energy savings and improve the store environment significantly during the day. This project also proved the viability of retrofitting skylights in an operational store with little or no disruption to business.

There are many energy saving initiatives that can be implemented in supermarkets but the big two are natural lighting and doors on fridges. They are not the easiest to implement but they must be implemented effectively if substantial savings are to be achieved in supermarkets.

2. Food Retail – National Significance in New Zealand & Australia

The supermarket sector is the largest application of non-domestic refrigeration and consumes the best part of 4% of all electricity consumed in Australia and New Zealand. The technology is complex, capital intensive and has long life spans. There is a slow uptake of energy efficient systems, products and practices (Ellis, 2009).

The energy use of supermarkets is nationally significant and long life span of equipment and buildings means a retrofit solution is needed to reduce this consumption in the medium term.

The aim of this project is to provide a working example of the energy efficiency measures that can be implemented in a typical operational supermarket.

2.1. Site Description

The Pak'n Save store is located in the CBD of Whanganui, a small provincial town in NZ with a population of 43,000. The district enjoys a temperate climate with 2,100 average sunshine hours per annum and about 882 mm of annual rainfall. Several frosts are experienced in winter and the latitude of the town is 39.93°S.

Climate data for Whanganui													
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Average high °C (°F)	22.4 (72.3)	22.7 (72.9)	21.3 (70.3)	18.8 (65.8)	16 (61)	13.8 (56.8)	13.2 (55.8)	13.8 (56.8)	15.3 (59.5)	17 (63)	18.8 (65.8)	20.7 (69.3)	17.8 (64.0)
Average low °C (°F)	14 (57)	14 (57)	12.9 (55.2)	10.6 (51.1)	8.5 (47.3)	6.5 (43.7)	5.6 (42.1)	6.2 (43.2)	8 (46)	9.6 (49.3)	10.9 (51.6)	12.8 (55.0)	10 (50)
Rainfall mm (inches)	62 (2.44)	65 (2.56)	68 (2.68)	71 (2.8)	81 (3.19)	82 (3.23)	88 (3.46)	70 (2.76)	72 (2.83)	81 (3.19)	74 (2.91)	70 (2.76)	882 (34.72)
Source: NIWA Climate Data													

Fig. 1. Whanganui Climate Data

The store was purpose built as a supermarket in 2005 and is 6,400m² in size.

The mezzanine level is divided between the admin and the back of house, which includes the staff café, locker room, toilets and main plant-room.

The back of house area (BOH) contains the freezer rooms, cool rooms, bakery, butchery, general storage for all departments and the loading dock.

All plant is electric apart from some of the ovens in the bakery and the domestic hot water boiler, which use natural gas.

Common plant equipment and distribution boards (DBs) are located on the admin mezzanine, ground floor and BOH mezzanine. The main incoming DB board and meter are located in the main plant-room on the BOH mezzanine. Before the project was implemented there was no sub-meters installed on site.

The main food hall area is air conditioned by a single zone AHU with small heat pump units supplying other areas.

The store is occupied 23 hours a day 363 days a year and opening hours are from 7:00am to 10:00pm. The bakery runs between 3:00am and 12:00pm each day.

Customer numbers average around 23,000 per week.

3. Energy Consumption

3.1. Monthly Electricity Consumption

Figure 2 shows monthly electricity usage over a period of two and a half years from January 2010. The energy conservation measures (ECMs) implemented as part of this project took place between March and September of 2011 and reduced consumption considerably over this period.

The consumption figures from 2010 indicate the highest energy use is during the summer. This is due to increased refrigeration load with warmer ambient temperatures. Most of the store heating is recovered from the refrigeration system in the winter, which reduces demand in the colder months.

The post project energy consumption is much more consistent throughout the year without the high peak demands over the summer. This is because the natural lighting (skylights) provides increased savings during the longer summer days which offsets the increased refrigeration loads. Also the refrigeration ECMs reduced the load on the air cooled condenser racks and they can handle the peak summer loads with reduced head pressures.

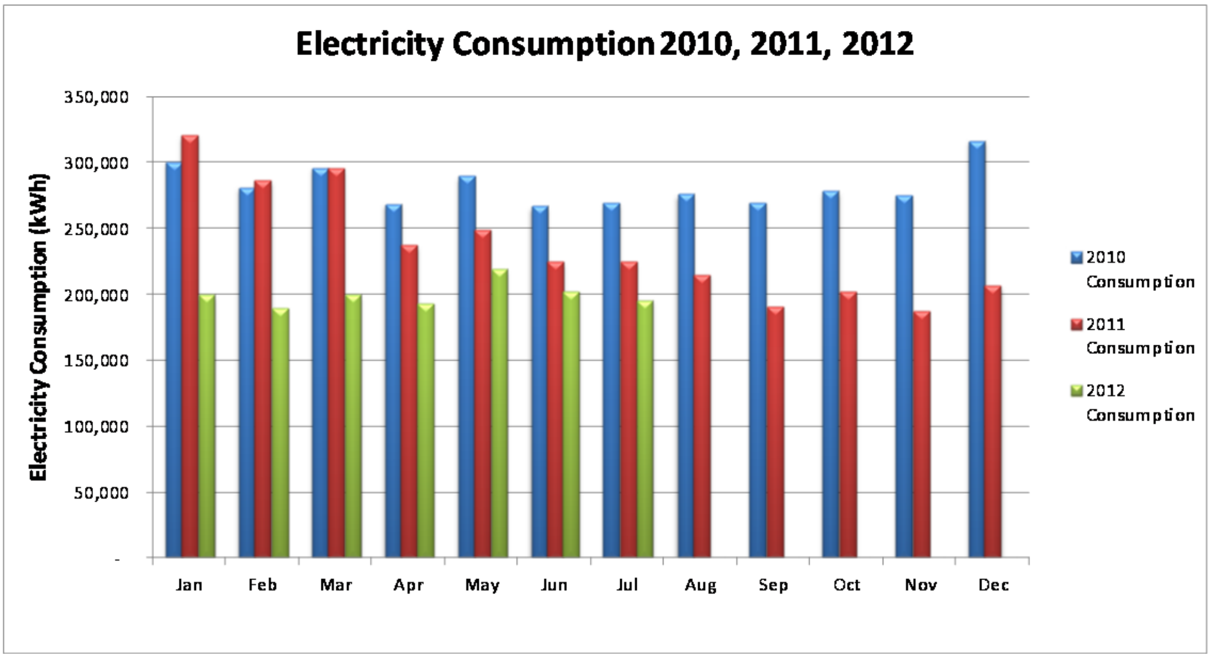

Fig. 2. Store Electricity Consumption (2010-2012)

The increase in energy consumption during May and June 2012 was due to a change in store operation. The night shelf stacking hours were increased and the staff were overriding the lights on all night. Analysis of the sub-meters showed the increase clearly and the lighting control was re-programmed to accommodate the operational changes and reduce energy consumption.

3.2. Daily Electricity Consumption

Figure 3 shows average daily electricity consumption profiles for each month in 2011. The change in these profiles over the year indicates the effect of the project on energy consumption.

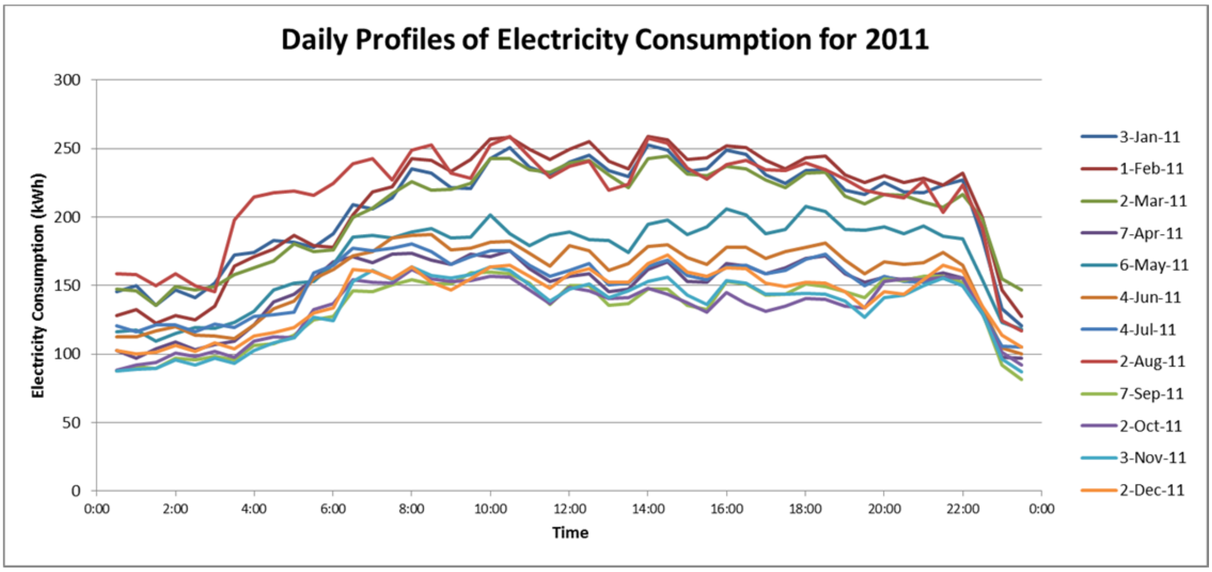

Fig. 3. Daily Electricity Consumption Profiles 2011

The initial increase in consumption for each day starts at approximately 3:30am with the arrival of the bakery staff. Consumption is then relatively consistent until about 6:30am as other staff arrive to begin their shifts. By 8:30am the store is at full load and runs consistently until 10:30pm when the store closes.

The energy savings generated by the project are very clear from these profiles. The peak consumption for the day has reduced by approximately 40% while the overnight base-load has reduced by around 33%. This again is because the savings made with natural lighting normally occur at peak load times during the day and the refrigeration load has been reduced.

3.3. Maximum Energy Demand

Figure 4 shows the peak monthly electricity demand for the store in 2011. Maximum demand is calculated on the amount of electricity (in kWh) consumed each half hour and the data is collected from the revenue meter on site.

As shown below, the electricity maximum demand for the site reduced considerably during 2011 due to the ECMs implemented. This has resulted in considerable savings on lines charges for the store owner, in addition to consumption savings.

The reduction in peak demand means further savings can be made by reducing the size of the on-site transformer. Currently the transformer is sized for 1000 kVA and we are now looking to reduce this to a 500 kVA unit.

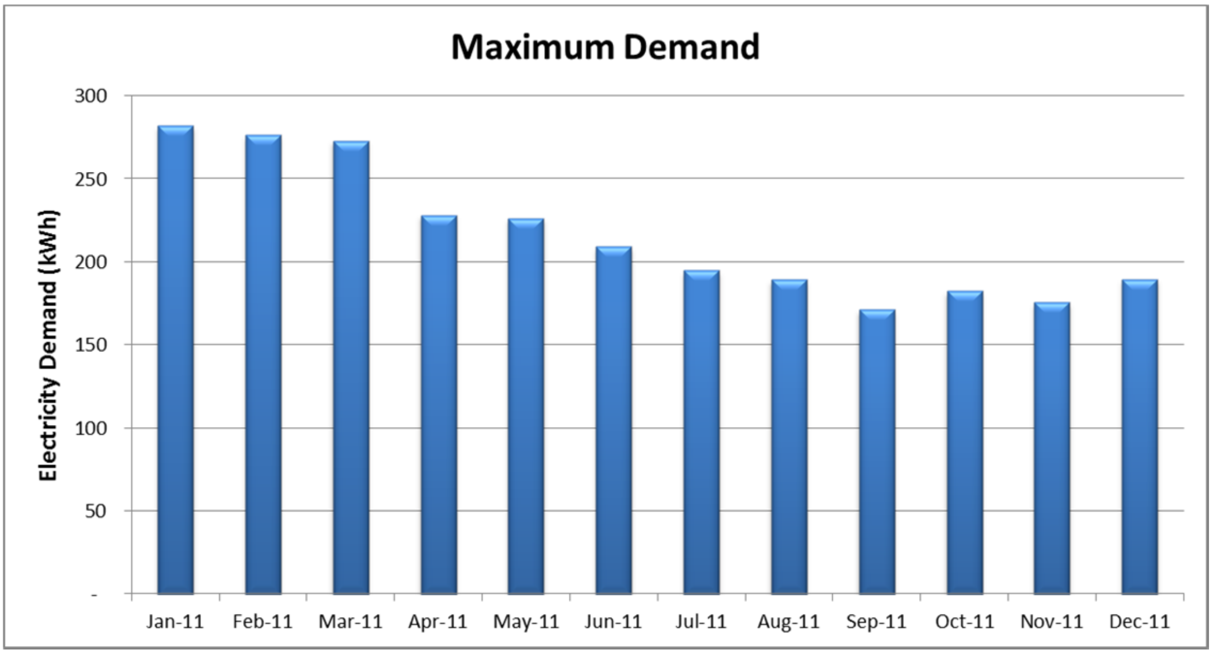

Fig. 4. Monthly Maximum ½ Hourly Electricity Demand 2011

4. Energy Balance

4.1. Pre-Project Energy Balance

Figure 5 shows the energy balance for the store before the project was implemented. The major loads are refrigeration, lighting and HVAC which use over 96% of the electricity consumption in the building.

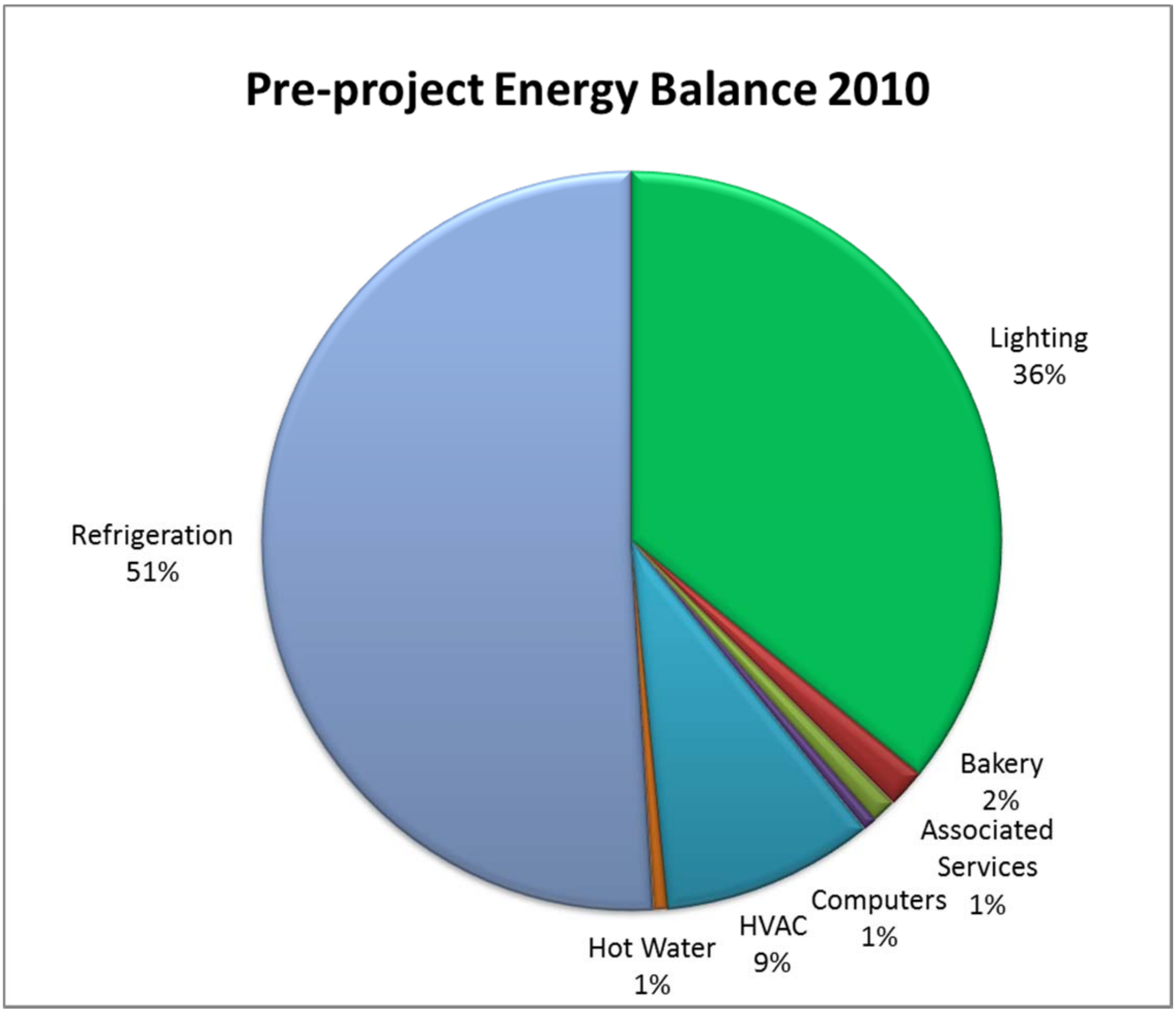

Fig. 5. Store Energy Balance (Electricity only)

We have not included the gas consumption for the store in the energy balance to maintain the focus on the significant energy savings achieved in electricity. The gas consumption (bakery ovens and domestic hot water) is included in calculations for the Energy Use Index (EUI) of the store.

4.2. Post-Project Energy Balance

The general proportions of the energy balance have remained reasonably stable during the project, although lighting has reduced from 36% to 33%. Significant savings were made in refrigeration, lighting and to a lesser extent HVAC but there is still more potential for refrigeration and lighting.

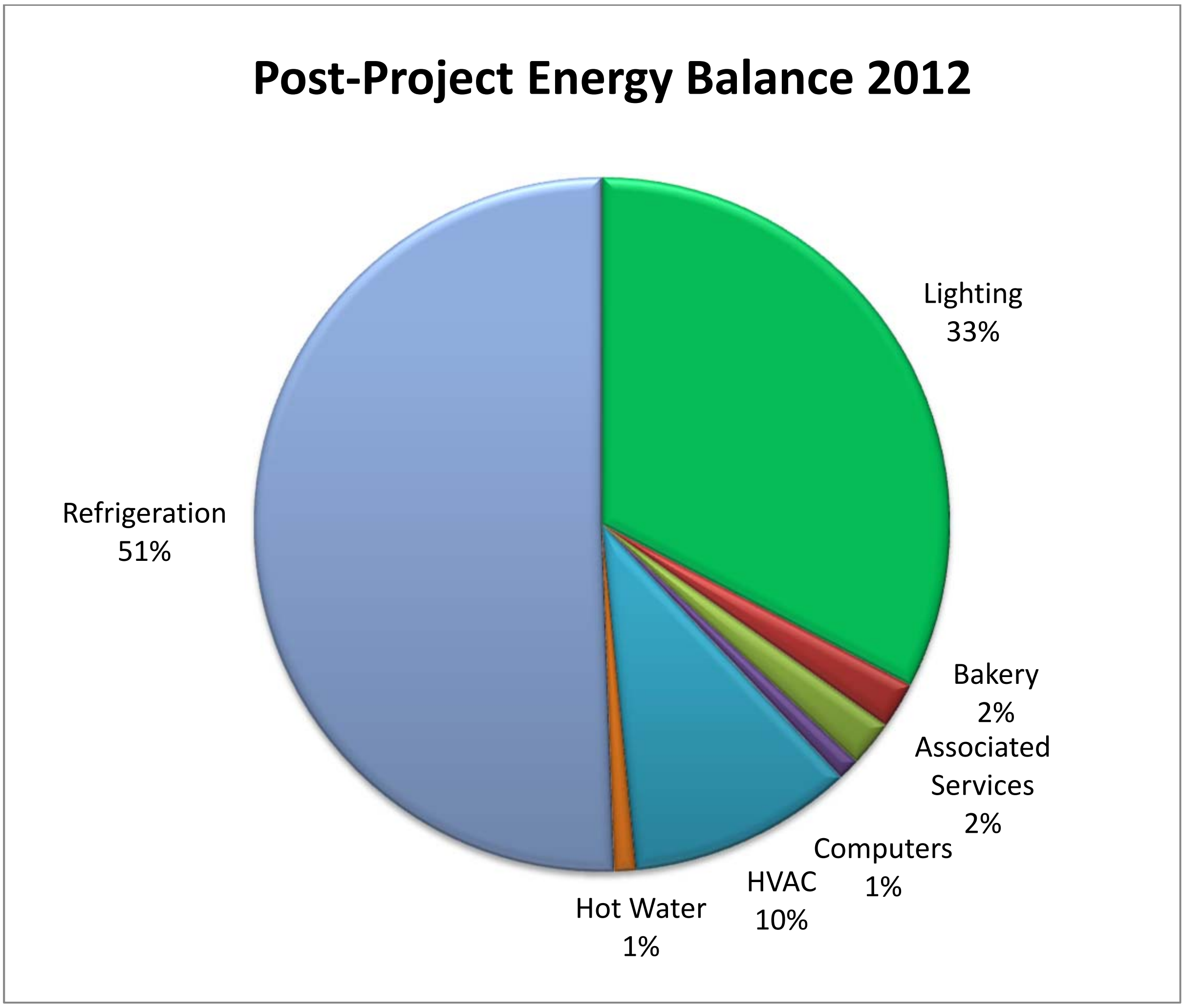

Fig. 6. Store Energy Balance (Electricity only)

5. Energy Benchmarks

5.1. Pre-Project Energy Benchmarks

The largest component of energy consumption for the store is refrigeration and special attention is needed to benchmark energy consumption in this area. The store contains cool rooms, freezer rooms and refrigerated displays served by a central refrigeration plant. The refrigerated displays are by far the largest load on the plant and the major focus for the retailer, so it makes sense to use them as an index for refrigeration energy use in the store.

We have developed an index or benchmark for the store that also enables comparisons with the Minimum Energy Performance Standards (MEPS) or High Energy Performance Standards developed by EECA (Energy Efficiency & Conservation Authority) here in New Zealand. EECA is a government agency working to improve energy efficiency and promote the use of renewable energy in New Zealand. http://www.eeca.govt.nz/

The MEPS and HEPS standards for Refrigerated Display Cabinets (RDCs) rate various types of displays based on the amount of energy used by 1 square meter of display in one day (24 hour period). We have used the same system to benchmark the refrigeration energy use in this store.

Table 1: Energy Index Table

	Building Area *(m^2)*	***Refrig. Display Area*** *(m^2)*	***Total Energy*** *(kWh/pa)*	***Refrig. Energy*** *(kWh/pa)*	***EUI*** *($kWh/m^2/pa$)*	***RDI*** *($kWh/m^2/day$)*
Pre-Project	6400	140	3,634,686	1,700,175	567.9	33.3
Post-Project	6400	144	2,651,970	1,228,941	414.4	23.4

The RDI has decreased by 30%, which is significant when you consider 90% of all the medium temperature cabinets are still without doors.

6. Lighting

6.1. Pre-Project Lighting

The lighting level in most areas was good and is often in excess of requirements. The entrance lobby is one area that was over lit, with levels of over 1100 Lux in recorded in some areas.

There was no use of natural daylight in the store, apart from the entrance lobby and car park ramp area. In each of these areas, the lighting did not reduce with increased daylight so no savings were achieved.

The main foodhall was lit with 400W metal halide fittings, which ran at 100% for 16 hours a day and were manually switched to 50% in the morning, when the bakery staff arrived. If staff switch the lights on and off as instructed, they will run the equivalent of 18 hours per day at 100%. In our experience, the only reliable way to ensure lights are switched off is to automate their operation. Staff cannot be relied upon to consistently switch equipment off at appropriate times together with their primary responsibilities.

The light levels recorded in the main aisles were between 580 and 840 Lux at 1m above floor level. The specified lighting level is 600 Lux. The variation in light level is due to variation in lamp age.

There was also significant lighting load within the refrigerated displays in the store. These are not counted with the official lighting load as they are considered part of the refrigeration plant. The cost to run these lights is increased because you pay for energy to run the lamp and for the refrigeration system to remove the heat produced by the lamp.

All of the refrigerated display lamps are fluorescent, which do not operate very well in the cold. This means an increased maintenance cost because the lamp life is reduced. Fluorescent lamps produce UV light which fades product and produces heat that can reduce product shelf life. We have observed many cases of over stacked shelves with product placed too close to the lights causing product overheating.

The lighting level recorded in these displays ranged from 500 to 2000 Lux.

There are many areas outside the main foodhall that are not occupied consistently and do not require lighting when unoccupied. Most are controlled with a manual wall switch. We have observed many lights still running when not needed and wasting energy.

The lighting in the covered car park is manually switched and often not needed. Often the occupancy in this car park is minimal.

6.2. Introduce Natural Lighting

A major focus of this project from the beginning was to add natural light into the store. The energy savings effects of this are obvious (the main foodhall lights switch off completely on bright days) but other softer benefits are also crucial.

The skylight installation without doubt had the biggest impact on customers and staff of any measure we introduced. The increased natural light had a feel good factor and common sense logic that did not need to be explained to customers. In essence, the skylights bring the natural world into the store. For a retailer trying to promote their credentials as environmentally friendly, nothing is a better fit than saving the global environment by improving the store environment.

The process of retrofitting skylights also increased the awareness of customers and staff to the improvements. The install took around six weeks and we began at one side of the store and worked our way across. As most customers are in the store at least once a week they could see the transformation as it progressed and noticed the difference between artificial and natural light.

A white paper prepared for the California Energy commission provides in-depth analysis of effects of daylight on retail sales. Their study of 73 California stores revealed benefits to sales, staff retention and showed that even customers who didn't notice the skylights, judged the store to be "cleaner" and "more spacious" (Heschong, 2003).

The following images illustrate the transformative effect skylights had in the store.

Fig. 7. Before & after skylight installation (note: lights are off in skylight photo)

6.3. Efficient Lighting Replacements

A variety of luminaires were replaced with more efficient options as part of this project. The major items are listed as follows:

- **Replace Main Foodhall Metal Halides with Dimmable Hi-Bay T5 Fluorescents**

  The original 400W (450W with Ballast) Hi-bays were replaced with T5 (4 x 54W) hi-bays which produce more light, better colour rendition, significant energy savings and are easily dimmed when daylight is available. The replacement fittings are 250W (Max.) and use considerably less when dimmed.

- **Replace Underground Car Park Lighting**

  The original twin 58W T8 Fluorescent fittings in the carpark were replaced with high efficiency twin 28W T5 luminaires with daylight control (in naturally lit areas) and occupancy control. When the car park is empty of people, the fluorescent lamps switch off and are replaced by small LEDs to provide minimal lighting. As soon as movement is sensed the fluorescents switch back on.

- **Replace Refrigeration Lighting**

  All of the fluorescent lighting in the refrigerated display cabinets, cool rooms and freezer rooms was replaced with LED tube fittings. The LEDs work well in the cold and offer significant savings for energy consumption, maintenance and improved light levels.

6.4. Improve Lighting Control

The existing lighting control in the store was a combination of individual time-clocks, daylight sensors and manual controls. Many of the time-clocks were overridden or incorrectly set up and often manually controlled items were simply left running 24/7.

As part of the project we installed a fully programmable lighting control system to replace the existing time-clocks and provide flexible and fully integrated dimming control of the main foodhall lighting.

The hi-bay fluorescents are dimmed in separate zones to provide consistent light levels in all areas regardless of the natural light available through the skylights. In addition, the lamps dim outside store opening hours while staff stack shelves, to achieve further savings.

The key to achieving savings in the retail areas is seamless control. If banks of light are switched or the dimming control is too rapid, the occupants notice the change and attention is drawn to the lighting operation. The light levels in the store can change quite quickly on days with wind and scattered cloud (common in NZ) so a compromise must be struck between speed of operation and gradual dimming control. In our experience, accurate dimming control is crucial to provide a useable solution with skylights.

7. Refrigeration

7.1. Pre-Project Refrigeration

The system is well maintained with very comprehensive controls but many of the display cabinets are inefficient.

Condenser heat is used to pre-heat the domestic hot water (DHW) and provide all the space heating in the main retail area, even on the coldest days of the year.

The lead compressor on the low and medium temp racks did not have variable frequency drives (VFDs).

Fig. 8. An infrared image showing cold aisle conditions for customers

Many of the aisles with open displays are noticeably cold. This is not only uncomfortable for shoppers, but indicates inefficient operation. This has been observed even when displays were not over stacked and seems to be inherent with the open vertical display cabinets.

7.2. Post-Retrofit Refrigeration

The open refrigerated display cabinets represent a large part of the refrigeration load. The obvious answer is to use glass door displays instead of open refrigerated displays but it may be difficult to convince the store management.

Fig. 9. Double glazed doors were retrofitted onto the beer and wine cases

A glass door display is always going to separate the cold and warm air better than an open display and should be used when possible.

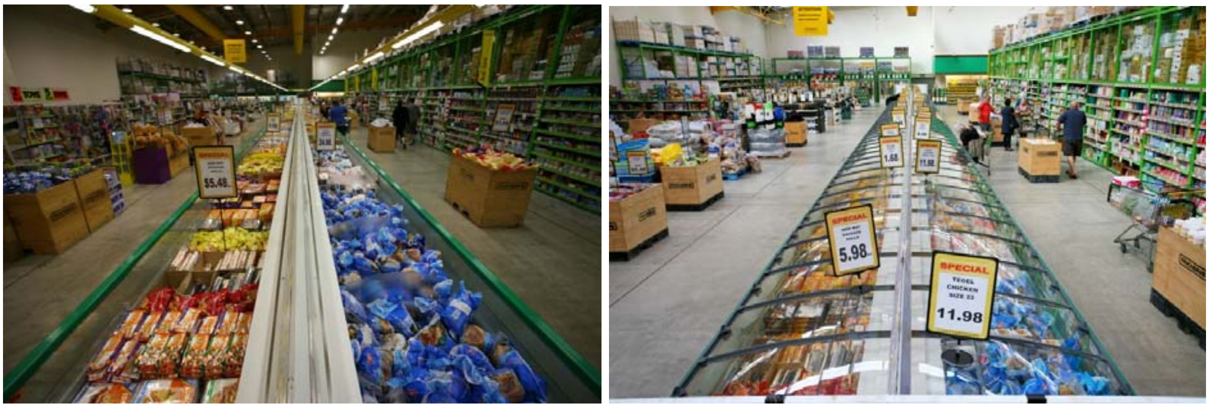

Fig. 10. Lids and EC Fans were retrofitted into existing chest freezer cases

An effort must be made to stop displays being over stocked. This is quite common and causes increased losses from the refrigerated cabinets and often increased product temperatures. Staff education and small changes to cabinet design can make all the difference.

We installed VFDs on the lead compressors of the low temp and medium temp racks to provide more accurate capacity and suction pressure control.

All of the condenser fans were replaced with electronically commutated (EC) fans with integrated speed control. Instead of switching on/off fans to control head pressure, all the fans ramp up and down together on to a single speed. This means fan energy is saved and the head pressure of the system is better controlled.

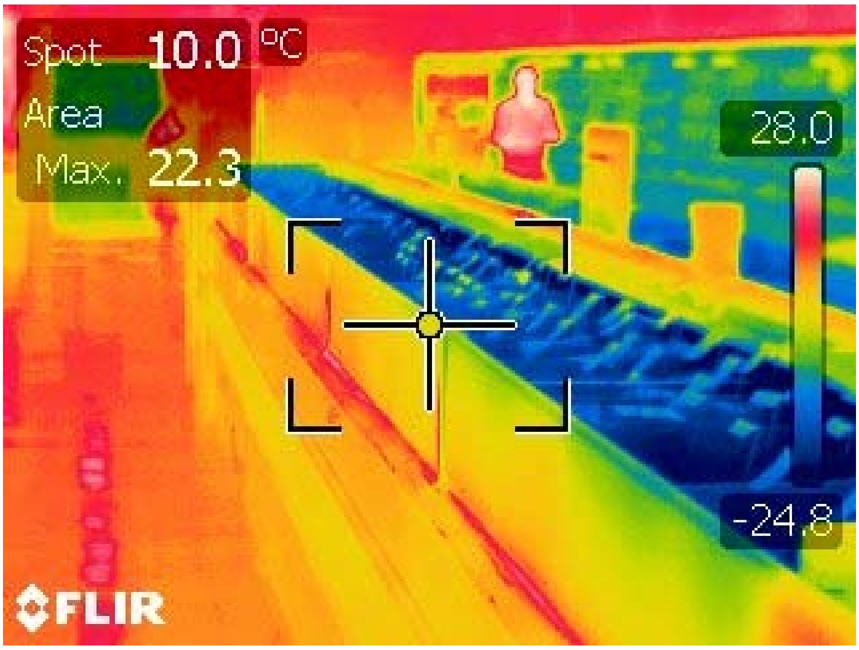

Fig. 11. The aisle is noticeably warmer next to tough freezer because less cold air escapes

Sliding glass lids were retrofitted onto the existing chest freezers and the evaporator fans were replaced with EC units with reduced airflow. This achieved significant energy savings and reduced maintenance requirements.

8. HVAC System

The Heating, Ventilation and Air Conditioning (HVAC) load for this building was 9% of the electricity used in the building. This is comparatively low for a supermarket (can be as high as 30%) and is mainly due to heat recovery from the refrigeration system providing the majority of space heating.

8.1. Pre-Retrofit HVAC

A building of this size and insulation levels would normally display a relatively consistent cooling load in Whanganui's climate, but from our site observations it is clear that the main retail area is heating much of the year.

The reason is simple. Most of that increased heating load is caused by cool air escaping from the refrigerated displays.

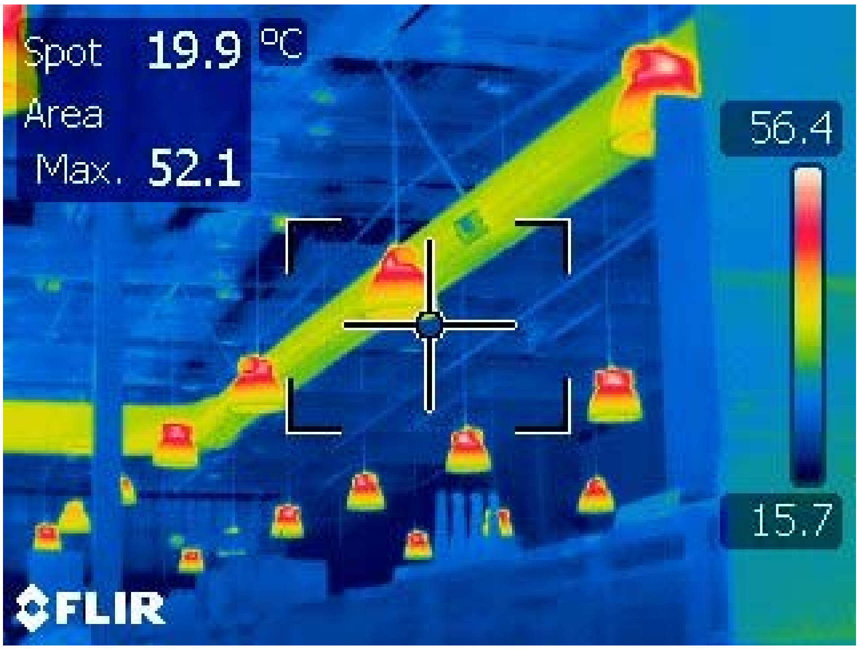

Fig. 12. The AC system supplying warm air to heat the building

The heat taken from the refrigeration system is recycled back into the building through the heat recovery coils in the main AHU, so the cost of heating is greatly reduced.

The main AHU provides cooling with a direct expansion coil, supplied by a bank of three compressors, which operate to cool the supply air into the store. The AHU did not have an economizer or a C02 sensor.

An economizer allows the AHU to supply 100% outside air into the space when required and permits outside air to reduce to zero if combined with a CO2 sensor in the return air duct. Presently the AHU cannot vary the amount of outside air or return air supplied into the space, which can cause increased heating or cooling loads at different times and limits the free cooling available.

8.2. Post-Retrofit HVAC

We installed an economizer on the main AHU to provide energy savings in the summer months and a return air CO2 sensor to optimize the ventilation requirement of the store. The cooling season for the store was quite narrow but installation of skylights and efficient gains in the refrigerated displays means the economizer is used more often.

9. Measurement and Verification

9.1. Sub-metering

We installed nine sub-meters as part of this project:

- Low Temp Refrigeration
- Medium Temp Refrigeration
- HVAC
- Main Foodhall Lighting
- Bakery
- Admin HVAC
- Admin Lighting
- Basement Car Park
- Gas (time of use pulse collected from revenue meter)

These meters have been invaluable for savings verification and analysis. Without these meters we would still be guessing about the actual savings made for each particular ECM implemented.

All of the meter data is available online for the store management and staff to view. This provides motivation for on-site staff and valuable feedback on energy implications of operational changes introduced.

9.2. Savings Verification

All the savings in this project have been verified using Metrix software to IPMVP standards.

10. Project Energy Conservation Measures (ECMs)

Table 2 shows a full list of the ECMs implemented to achieve savings in the store.

Table 2: ECM Table

ECM	*Description*
ECM 1	Skylights & T5 Hi-bays (Dimmed)
ECM 3 & 4	Replace Refrigerated Display Fluorescents with LEDs
ECM 5	Install Economiser & C02 sensors on Main AHU
ECM 7	Daylight Control Entrance Lobby
ECM 8	Daylight Control Car Park Ramp
ECM 9	Fit Night Curtains on Remaining Open Freezer Displays
ECM 10	Replace Open Freezer Displays with Glass Door Freezer Unit
ECM 12	Install LED/T5 Fluorescent Car Park Lighting
ECM 14	Install VSDs on Lead Rack Compressors for Suction Press. Control
ECM 15	Insulate DHW Tank & Ring Main
ECM 16	Replace Freezer Room Fluorescents with LEDs
ECM 17	Replace Chiller Room Fluorescent with LEDs
ECM 18	Reduce Admin Outside Air Fan Volume Flow
ECM 19	Fit Permanent Glass Lids & EC Fans on Trough Freezers
ECM 20	Butchery Prep Area Refrig. to Shutdown Overnight
ECM 21	Produce Prep Area Refrig. to Shutdown Overnight/Permanently
ECM 22	Replace Trough Freezer Honey Cones
ECM 23	Replace Bakery Canopy Lamps with LEDs
ECM 24	Replace Med Temp Refrigerated Display Fans with EC Fans
ECM 25	Install Glass Doors on Liquor Cases
ECM 26	Upgrade Refrigeration Control System
ECM 27	Refrigeration Tune up
ECM 28	Daylight Loading Dock & BOH Store
ECM 29	On-going Three Year Measurement & Verification Plan
ECM 30	Replace Condenser Fans with speed controlled EC Fans
ECM 31	Provide Metering & Sub-metering

11. Conclusion

The major focus of this project was always to achieve substantial energy savings without any negative impact on sales. The surprising result was some of the ECMs we implemented produced positive results in both arenas.

Natural lighting has been the largest of these. Increased light levels in the store resulted in a better shopping environment and serves as a promotional vehicle for the store owner to show sustainability. Everyone can understand that turning lights off saves energy and even sub-conscientiously we all feel better in natural light.

To achieve great natural lighting, the skylight design must be assessed thoroughly but there are a few simple rules that are crucial:

1. 10-15% of the roof area needs to be skylight (12-13% is ideal for our latitude/climate)
2. Try to reduce the width of individual skylights to 600mm or below. More narrow skylights is better to achieve even light levels and avoid hotspots
3. Use skylight materials with UV filtration. Some materials have infrared red filters to reduce heat gain inside the store which is also ideal
4. Install dimmable lighting with automatic control to maintain minimum light levels
5. Ensure the light from the skylight is diffuse. Direct sunlight is to be avoided
6. Always double (or triple glaze) to maximize insulation levels and avoid condensation

Refrigeration is the largest single energy consumer in most supermarkets and has very high potential for savings. The most efficient stores would have doors on every refrigerated cabinet but it would be difficult to convince even the most progressive store owner to do that so it is essential to prioritize.

The impact of doors on savings on savings generated is influenced by a couple of factors in our experience:

1. The colder the cabinet, the bigger the savings (start with low temp as a priority).
2. The worse cabinet (biggest load) on each rack (med or low temp) will achieve the greatest savings
3. Always include commissioning time for the refrigeration engineers to re-tune the system after door installation. The load to a particular cabinet could reduce 30-40% and often the system will require re-adjustment to optimize savings and operation

The sales impact of doors are influenced by the following factors

1. Product type. Doors will have little or no effect on sales of staple products like milk.
2. Promotional cabinets (designed to encourage unplanned purchases) will often suffer more sales impact from door or lid installation.
3. Try to incorporate improved lighting with the door installation. Installation of doors on vertical cabinets provides a perfect position to light product without overheating product (use LED lamps).

The potential for energy reduction in supermarkets is huge. We have achieved 36% energy savings in this store while the total sales increased by 6%, proving that energy efficiency can promote sales. There are still many ECMs we would like to introduce and think 50% savings is possible with further improvement to the customer experience.

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