Comparing Energy Efficiency in Supermarkets using CO_2 & R507

Date: July 15th, 2018

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1 Introduction

Ever since CFCs and HCFCs have been banned from use, the ozone layer has benefited from having a better regeneration capacity. It has improved so much that according to estimates, by mid-Century, the thickness of the ozone layer that shields us from the sun's harmful UV rays, will be similar to what it was back in the 1970s.

However, although CFC and HCFC replacements—known as HFCs or third-generation coolants—do not contain chloride, which destroys the ozone, despite their climate-friendly reputation, the fluoride contained within their molecule turns them into far more potent greenhouse gases, which in the end heat up the planet.

Industry's search for alternatives to these not-so-climate-friendly refrigerants has so far resulted in the widespread use of CO_2 or carbon dioxide (R-744). Carbon dioxide is naturally found in the environment as a byproduct of living beings' respiration, etc. It does not damage the ozone layer and has practically no effect on global warming.

The main advantage of this gas is that it is available in the quantity required and anywhere around the world. In terms of its suitability as an HFC replacement, because of carbon dioxide's physical and chemical properties, it is possible to reduce the size of equipment (smaller compressors, smaller piping diameters, etc.), even though working pressures are considerably greater (see Appendix 2).

This study will focus on comparing two stores that use R-507 with two stores that use R-744. The Tottus supermarket chain has agreed to include its Tottus Vitacura store (R-507) and its Tottus Alderete store (R-744) in this study. Both stores are located geographically close to one another, in Santiago's Vitacura District.

The Jumbo supermarket chain has also agreed to participate in this study with two stores: Jumbo El Llano (R-507) and Jumbo Valdivia (R-744).

2 Purpose of the Study

2.1 Purpose

The purpose of this study is to compare the energy efficiency of two refrigeration systems using two different coolants—R507 and R-744—and subsequently determine which of the two systems is more functionally efficient from an energy perspective.

To that end, gauges were installed at four stores belonging to two different supermarket chains (Tottus and Jumbo). The R-507 coolant will be used at Tottus' Vitacura store, while the R-744 coolant will be used at its Alderete location. As for the participating Jumbo stores, R-744 will be used at its Valdivia location, while R-507 will be used at the El Llano store in Santiago.

These stores were chosen to take part in this study from among all the other stores in both chains because they use refrigerants under comparison, and because they have monitoring systems that will allow for matching and standardizing study results. Moreover, in the case of Tottus, its two stores are located geographically close to one another, which facilitates the comparison since the exterior climate conditions are the same. Regarding Jumbo, as of the date of this study, its Valdivia store is the only store in the chain that uses R-744. It also happens to be the only Jumbo store in the entire city that is comparable in terms of installed cooling capacity, which is why Jumbo's El Llano store was the other one chose to take part in the study.

Data gathered will be used to calculate a System Coefficient of Performance (COPSI)[1] for each supermarket, which is understood as the Installed Cooling Capacity divided by the Electric Power Consumed (kW of Installed Refrigeration/kW of Electricity Consumed). This parameter will be basis for determining and comparing the efficiency of each system.

2.2 Parameters Measured

In order to meet the study's objective, a series of parameters will be measured and recorded. These will be used to calculate the operational properties of each central cooling system, as well as electric power consumption and system performance.

The following parameters must be taken into consideration and recorded, regardless of whether they are time variables or not:

[1] See definition of COPSI in Appendix 1 herein.

- Temperature on Sales Floor and Back Room (°C)
- Relative Humidity on Sales Floor and Back Room (%)
- Installed Cooling Capacity (kW)
- Total Accumulated Energy Consumed (kWh)

We will use the aforementioned parameters to calculate the COPSI by relating cooling and electric power capacity. Likewise, temperature and relative humidity on the sales floor, back rooms, reach-in and walk-in (lockers) coolers will be recorded in order to make cooler operating conditions as similar as possible.

2.3 Geographic Location

This study entails measuring the parameters set forth under item 2.b) at the following four supermarkets located in Chile.

- Tottus Vitacura: Av. Vitacura 9019, Vitacura, Metropolitan Region.
- Tottus Alderete: Miguel Comas 1798, Vitacura, Metropolitan Region.
- Jumbo El Llano: Llano Subercaseaux 3519, San Miguel, Metropolitan Region.
- Jumbo Valdivia: Errázuriz 999, Valdivia, Los Ríos Region.

3 Implementation

3.1 Equipment Used

There are several internationally recognized brands of refrigeration system operations and control equipment available on the Chilean market. The most widely used one in Chile is the Danish brand Danfoss, which is why it was chosen to supply the gauges used in this study.

The equipment listed below was used to measure energy, temperature and relative humidity:

- AK-SM880, central control system, is in charge of controlling the store's cooling system. It also has an internal memory for storing information from every sensor hooked up to its network. This information may be downloaded for analysis. For the study's purposes, the system was used to record electrical and environmental parameters (temperature and relative humidity).

Figure 3.1. AK-SM880 Central Control Installed at Tottus Alderete

- WattNode ModeBUS, WNC-3Y-480MB, uses coils to read the facilities' electrical parameters, such as voltages and currents, which are then interpreted by the central control to calculate energy, power, etc.

Figure 3.2. Picture of WattNode Gauge Installed at Tottus Alderete

- AK-CM 101, a humidity and temperature data communication module used to send temperature and relative humidity readings, taken from sensors connected to the gauge, to the central control system.

Figure 3.3. Referential Picture of a Danfoss Communication Module

Furthermore, each supermarket has its own refrigeration facilities called central refrigeration, and its capacity is determined by the power of the compressors available for operation. This power is calculated on the basis of cooling demand, which is, in turn, determined by the manufacturer-given capacity and technical specifications of each store's coolers/lockers, such as size, project type, rotation, etc.

3.2 Hardware Installation

Equipment listed under letter b) was installed in the machine room at each supermarket in order to provide quick and easy access to periodically check equipment and collect data.

Nuova Service's technicians installed this equipment in keeping with current Chilean standards governing high and low-power electric facilities.

Equipment was installed in October and November 2017, followed by the configuration of the AK-SM880 data collection devices for storing the parameters required for this study. As mentioned under section 2.b), the equipment has been configured to store the following data:

- Sales Floor Temperature and Relative Humidity
- Back Room Temperature and Relative Humidity
- Hourly Energy consumption

There was a 30-day calibration and adjustment period carried out in order to validate data reliability. The study also requested data interpretation support from Danfoss Chile for personnel in charge of certifying that the readings were correct and consistent.

4 Project Background Information

4.1 Temperature Data

The following is a map of Chile showing the geographic distribution of average high and low temperatures for major Chilean cities. Also shown are 2017 and first quarter 2018 average temperatures for the City of Santiago. Data were provided by the Chilean Meteorology Agency.

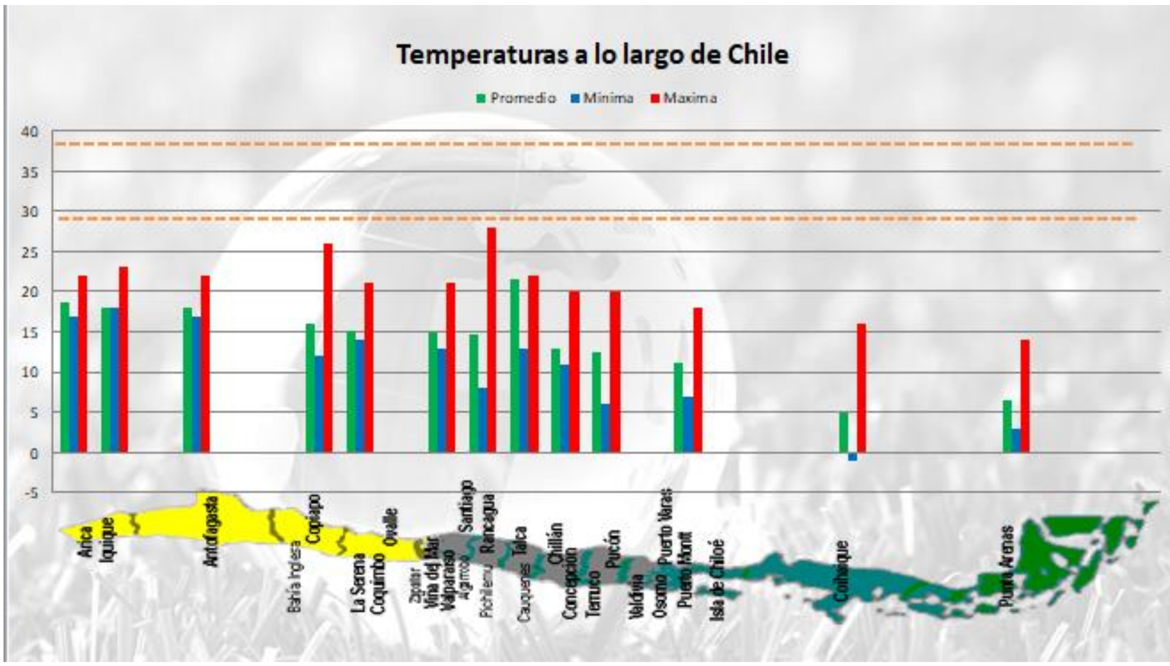


Figure 4.1 Temperature Distributions in Chile

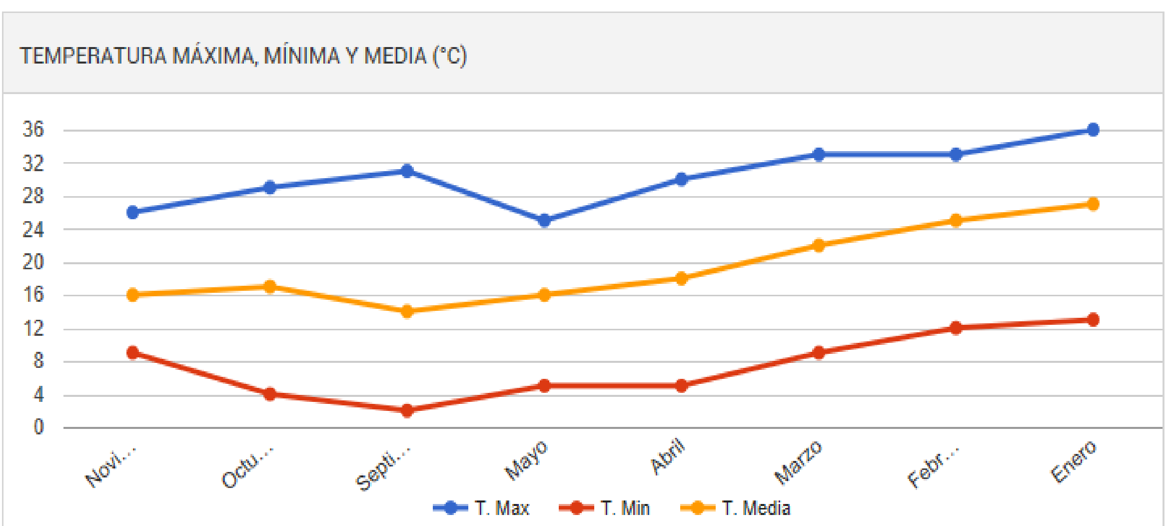


Figure 4.2. 2017 Average Temperatures in Santiago

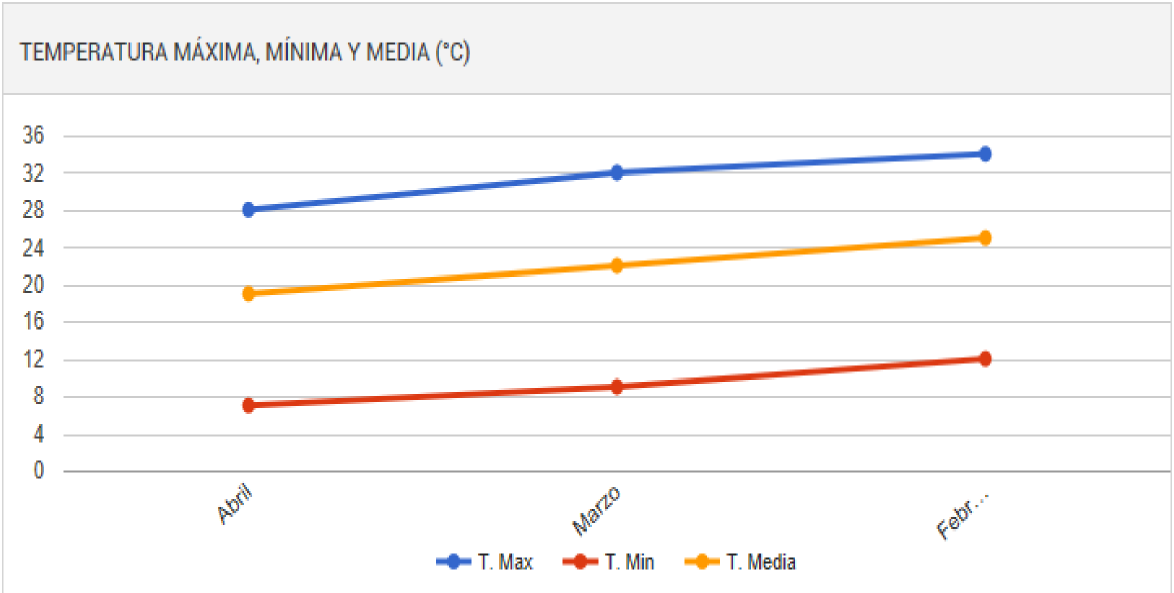


Figure 4.3. 2018 Average Temperatures in Santiago

4.2 Thermal Balance

Knowing the store's cooling demand is necessary to calculate the COPSI. This information is obtained from the project's thermal balance which is used to determine the capacity and quantity of compressors and the cooling system' overall capacity.

The table below illustrates a summary of the thermal balances at both Tottus stores. Appendix 2 provides a detailed view of each individual store's thermal balance.

	Current Vitacura	Original Vitacura	Alderete
Cooling Demand MT kW	118.4	134.6	162.2
Cooling Demand TB kW	12.1	12.4	44.6
Equivalent Cooling Demand TB kW	21.3	21.8	78.5
Total Cooling Demand kW	130.5	147.0	206.8
Total Equivalent Cooling Demand kW	**139.7**	**156.4**	**240.7**
Alderete v/s Vitacura Cooling Demand % Ratio	42.0%	35.0%	

Table 4.1. Summary of Thermal Balance at Each Tottus Store

	El Llano	Valdivia
Cooling Demand MT kW	306.8	287.6
Cooling Demand TB kW	69.8	92.7
Equivalent Cooling Demand TB kW	122.8	163.1
Total Cooling Demand kW		
Total Equivalent Cooling Demand kW	**429.6**	**450.7**
Valdivia v/s El Llano Cooling Demand % Ratio	4.7%	

Table 4.2. Summary of Thermal Balance at Each Tottus Store

It is worth noting that site visits were conducted to verify firsthand the equipment's current balance at the Alderete and Vitacura stores. In the case of the Vitacura store, there was a difference between the original thermal balance (Est. 2014), referred to as Original Vitacura, and the revised thermal balance (04/2018), referred to as Current Vitacura. The actual thermal balance is shown in blue. At the Alderete store, the thermal balance cooling demand and the store's actual TB cooling demand are the same and shown in red.

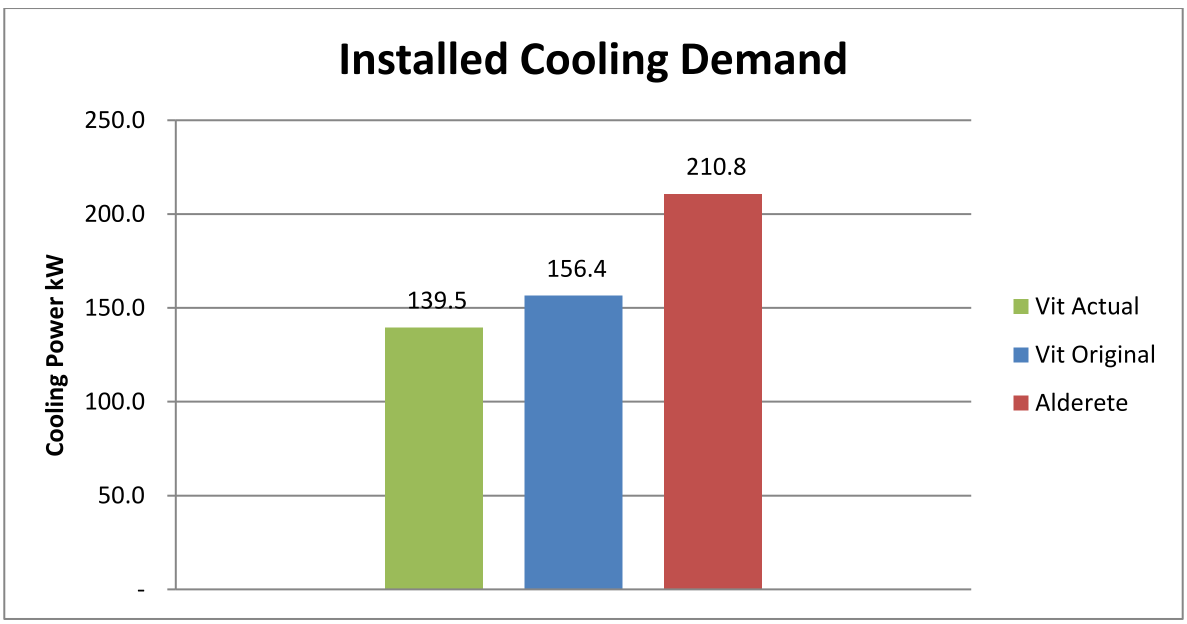


Figure 4.4. Tottus Stores Cooling Demand

Jumbo store thermal balances were also verified on site. The El Llano store's installed cooling capacity is at least 25% less than what was stated in the thermal balance. The corrected figure was used for calculations appearing herein.

Note: Subsequent verifications could result in changes to these figures.

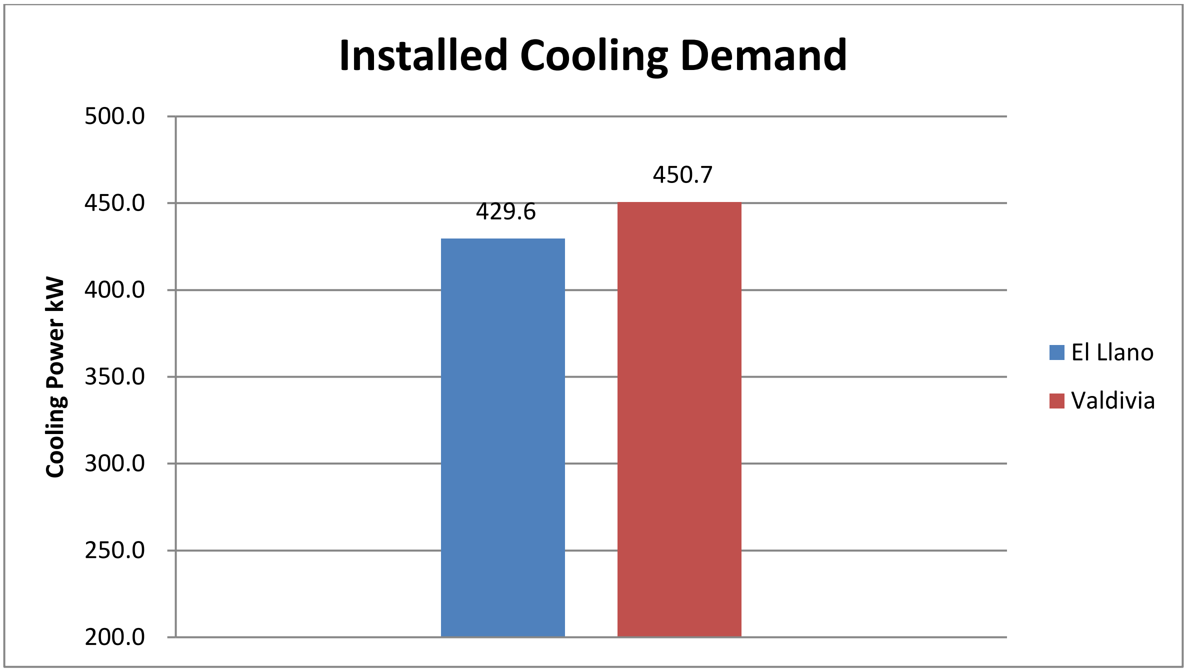


Figure 4.5. Tottus Stores Cooling Demand

5 Data Collection

Data used in this report were taken from the Tottus supermarket chain's AK-SM880 central control system database. Tottus store data were collected from January to April 2018, while Jumbo data were collected from April to July 2018.

Regarding data collection, it should be noted that the equipment listed in Chapter 3 herein, WattNode and AK-CM101, are not data storage devices. Their main purpose is to collect data and subsequently send it to the AK-SM880 central control device, which interprets the data and stores it on its internal memory. The data is later downloaded into a .csv file, which is generally used with a Microsoft Excel spreadsheet.

Table 5.1 shows an example of a data series collected by the WattNode AK-SM880 that measures electrical data, and from the AK-SM101 that receives temperature sensor data and transmits it to the central control system.

	Vitacura	Alderete	Vitacura	Alderete	Vitacura	Alderete	Vitacura	Alderete	Vitacura	Alderete
Name	Energia kWh Acumulados	Medidor 1 kWh Acumulados	Humedad Trastienda	Humedad Trastienda	Temperatura Trastiendas	Temperatura Trastienda	Humedad Sala de Ventas	Humedad Sala Ventas	Temperatura Sala Ventas	Temperatura Sala Ventas
Units	kWh	kWh	%		degc		%		degc	
Digital	0		0		0		0		0	
Horas	Energía Acum	ada	1 hr		1 hr		1 hr		1 hr	
00:00:00 am 01/03/18	79.6	68.9	33.5	35.7	20.5	17	31.6	35.1	20.44	17.11
01:00:00 am 01/03/18	66.2	68.3	35.1	37.7	20.22	16.67	32.8	36.9	20.44	17.11
02:00:00 am 01/03/18	58.5	62.6	35.7	39.7	19.94	16.39	32.8	36.9	20.44	17.11
03:00:00 am 01/03/18	63	63.2	38.5	40.5	19.39	16.11	34	36.9	20.17	16.56
04:00:00 am 01/03/18	61.6	67.8	39.7	39.9	19.11	15.56	35.4	35.5	19.89	16.56
05:00:00 am 01/03/18	60.4	62.1	40.5	40.5	18.83	15.28	35.4	35.5	19.61	16.56
06:00:00 am 01/03/18	55.8	63	40.5	42.5	18.56	15	36	36.9	19.33	16.28
07:00:00 am 01/03/18	57.2	62.4	41.1	42.5	18.56	15.56	36.6	36.7	19.33	17.11
08:00:00 am 01/03/18	54.3	60.8	40.5	39.9	18.83	16.39	36.6	33.3	19.33	18.78
09:00:00 am 01/03/18	65.1	72.9	36.5	34.1	20.22	17.22	33	30.9	19.89	18.5
10:00:00 am 01/03/18	81.1	85.3	31.5	31.5	22.17	18.61	33.8	30.3	19.61	19.06
11:00:00 am 01/03/18	80	83.3	30.1	30.5	23	19.17	32.8	30.3	19.89	19.61
12:00:00 pm 01/03/18	87.5	89	27.7	28.9	24.11	20.61	32	30.3	20.44	20.17
01:00:00 pm 01/03/18	92.1	92.3	26.5	28.5	24.39	21.22	31.4	30.3	21	20.72
02:00:00 pm 01/03/18	92.1	87.8	26.9	28.3	24.67	22.33	30.8	29.5	21.56	21.56
03:00:00 pm 01/03/18	95.9	98.5	26.9	25.1	24.94	23.44	30.2	28.9	22.11	21.28
04:00:00 pm 01/03/18	100.7	109.4	27.1	24.3	26.06	23.72	29.2	27.5	22.39	21.28

Table 5.1 Example of Data Collected by the AK-SM880 Central Control System

The following charts contain sales floor and back room temperature and relative humidity data from the stores under study. Data were recorded every two minutes on the dates listed. Data were extracted every 24 hours in order to create the charts below. Using more data would have hindered chart interpretation.

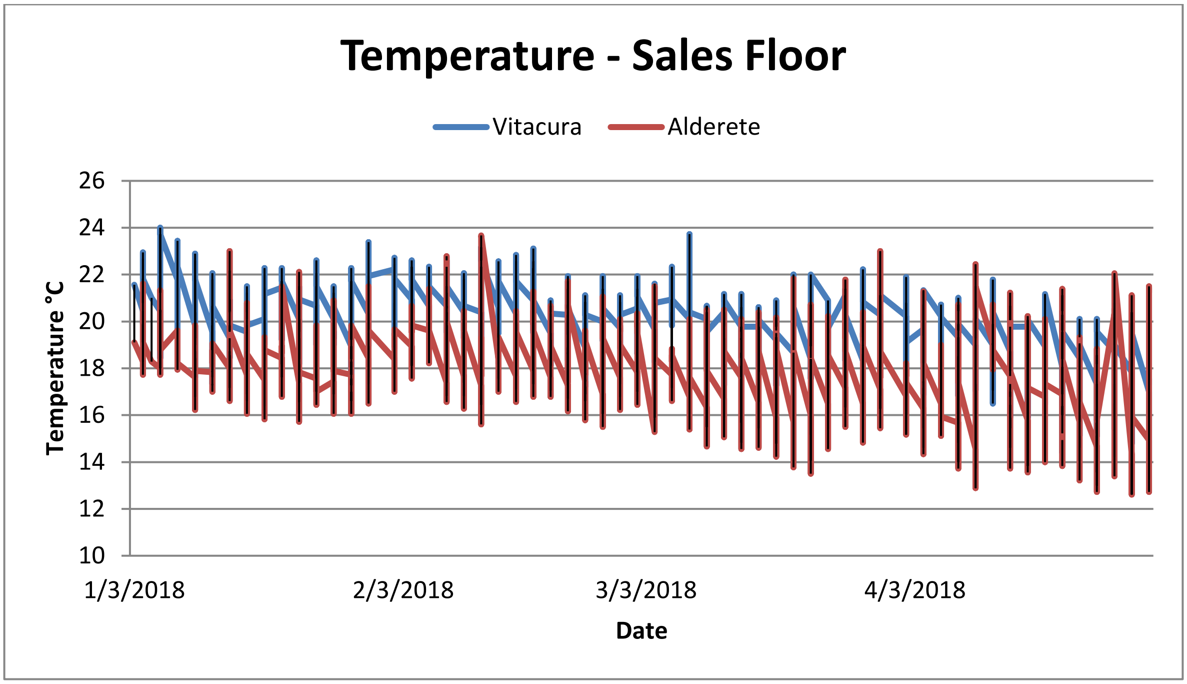


Figure 5.1. Tottus Stores' Sale Floor Temperatures

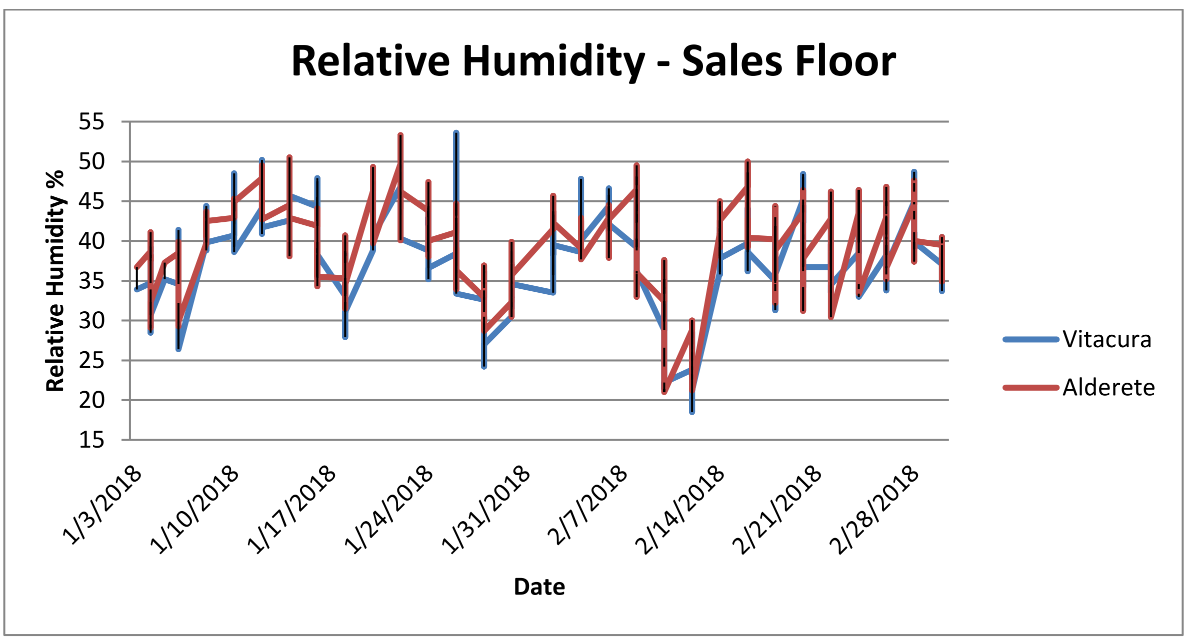


Figure 5.2. Tottus Stores' Sale Room Relative Humidity

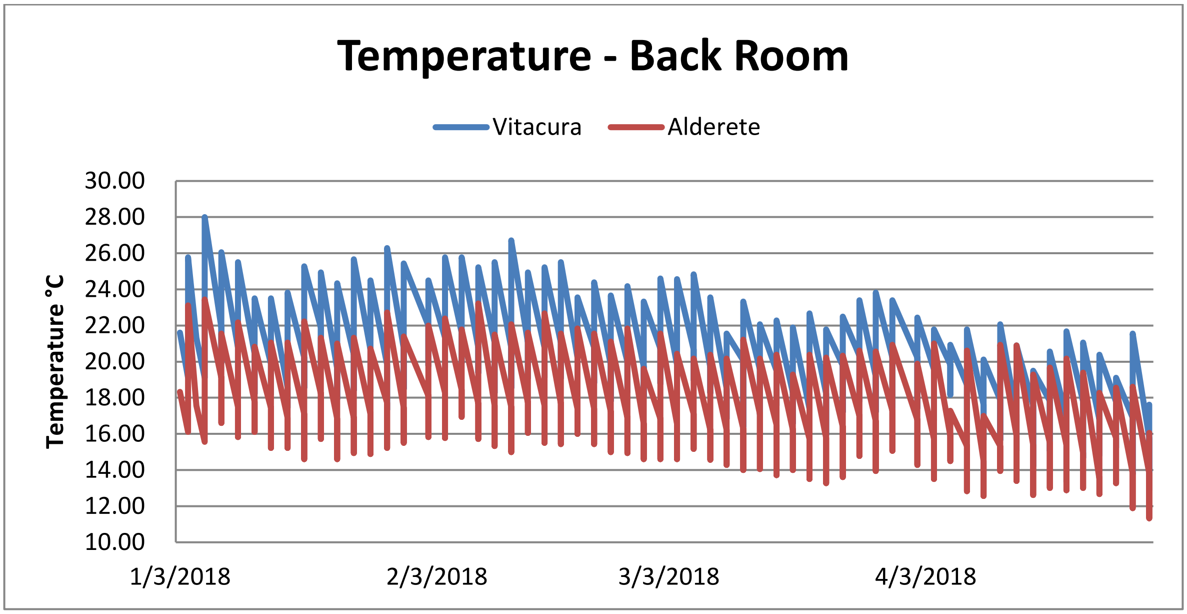


Figure 5.3. Tottus Stores' Back Room Temperatures

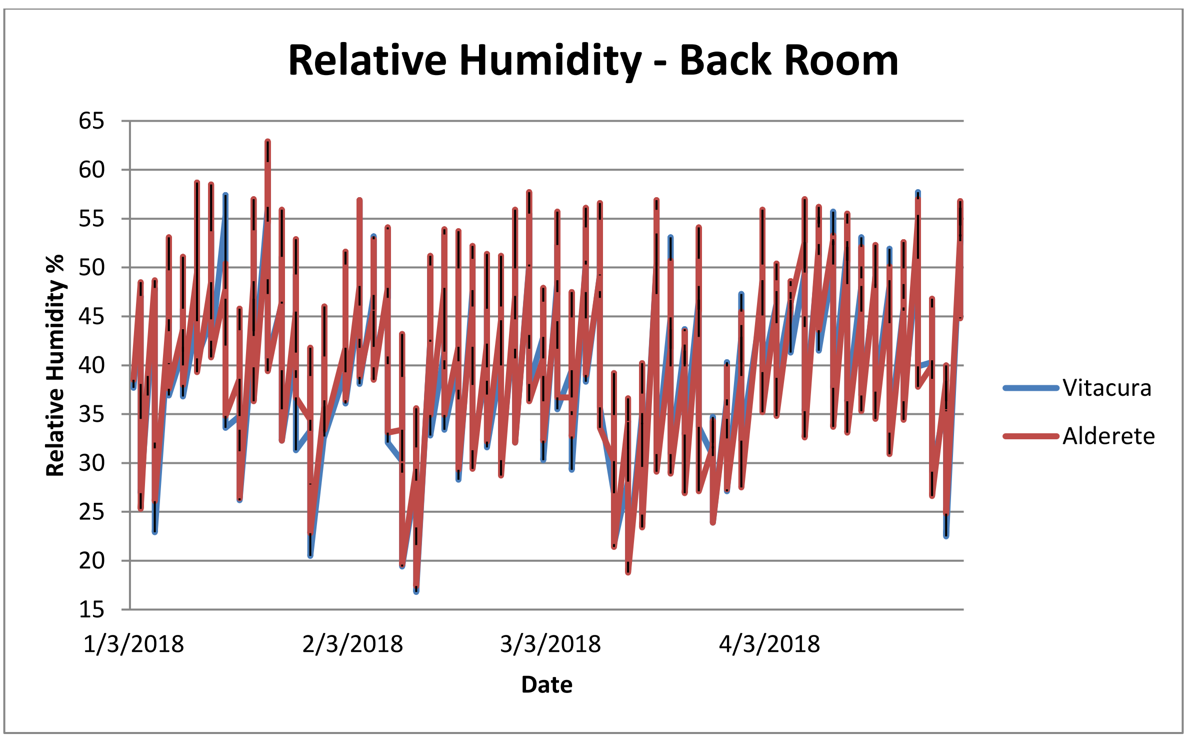


Figure 5.4. Tottus Stores' Back Room Relative Humidity

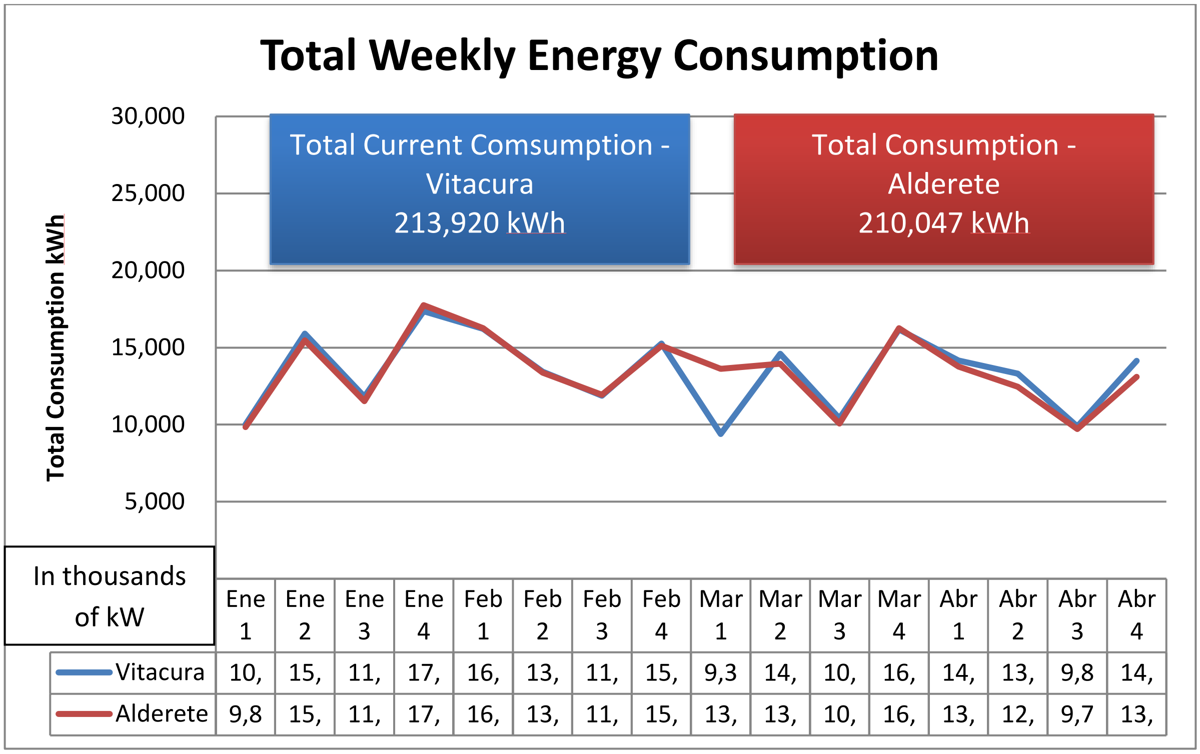


Figure 5.5. Tottus Stores' Total Energy Consumption. See Appendix 4 for details.

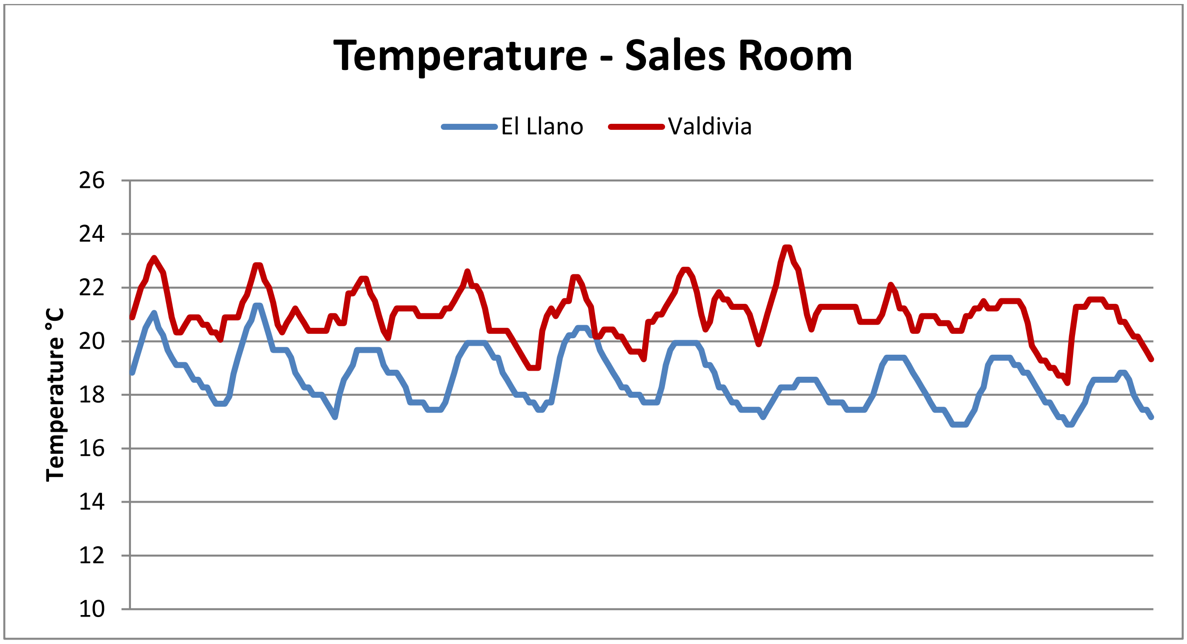


Figure 5.6. Jumbo Stores' Sales Floor Temperatures

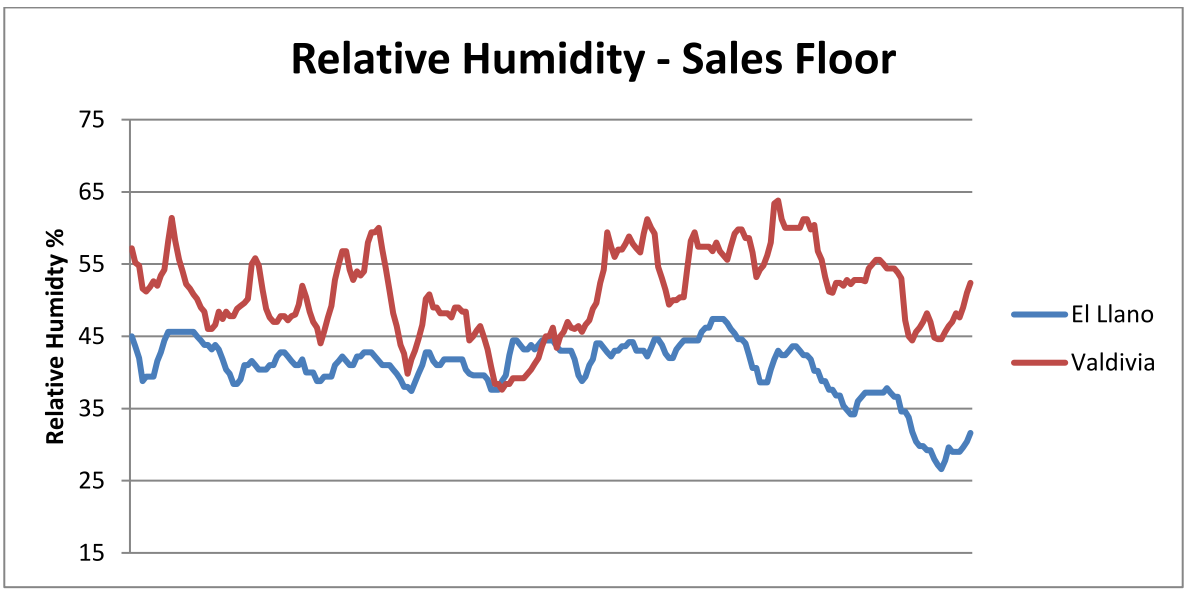


Figure 5.7. Jumbo Stores' Sales Floor Relative Humidity

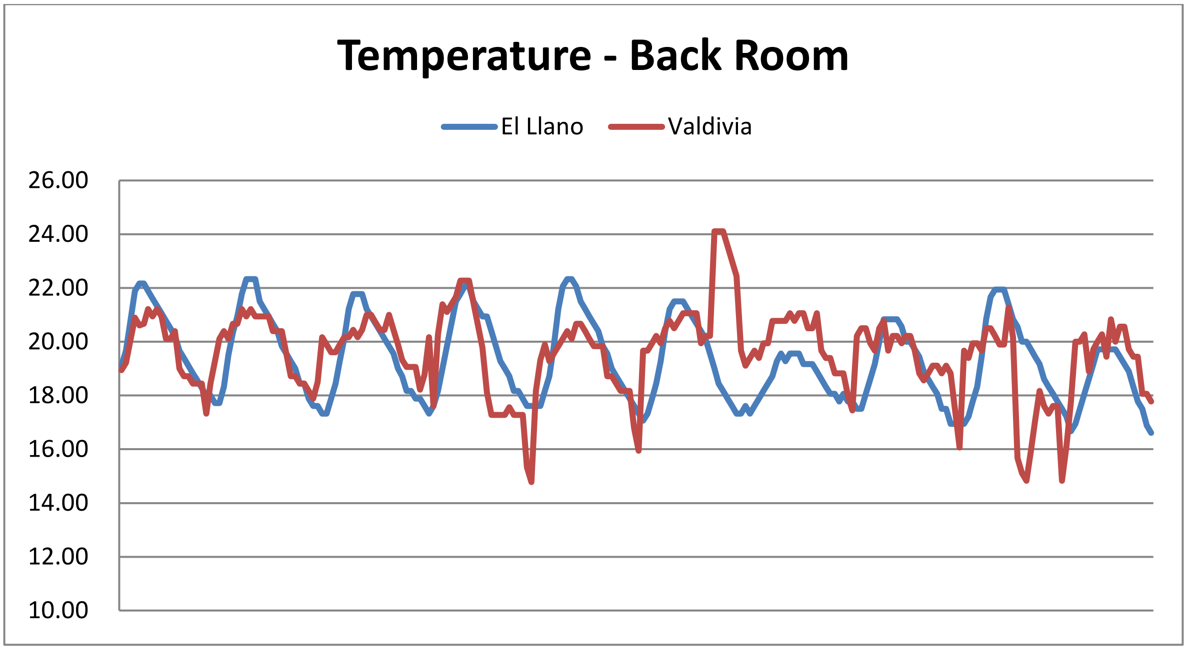


Figure 5.8. Jumbo Stores' Back Room Temperatures

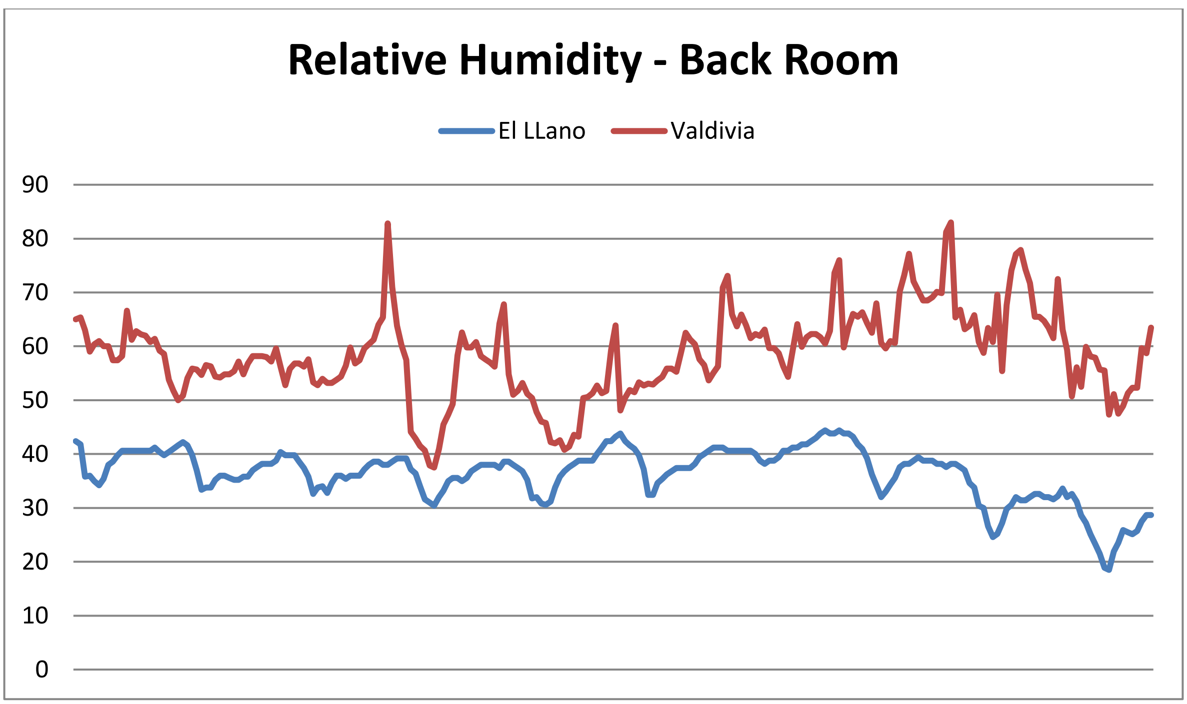
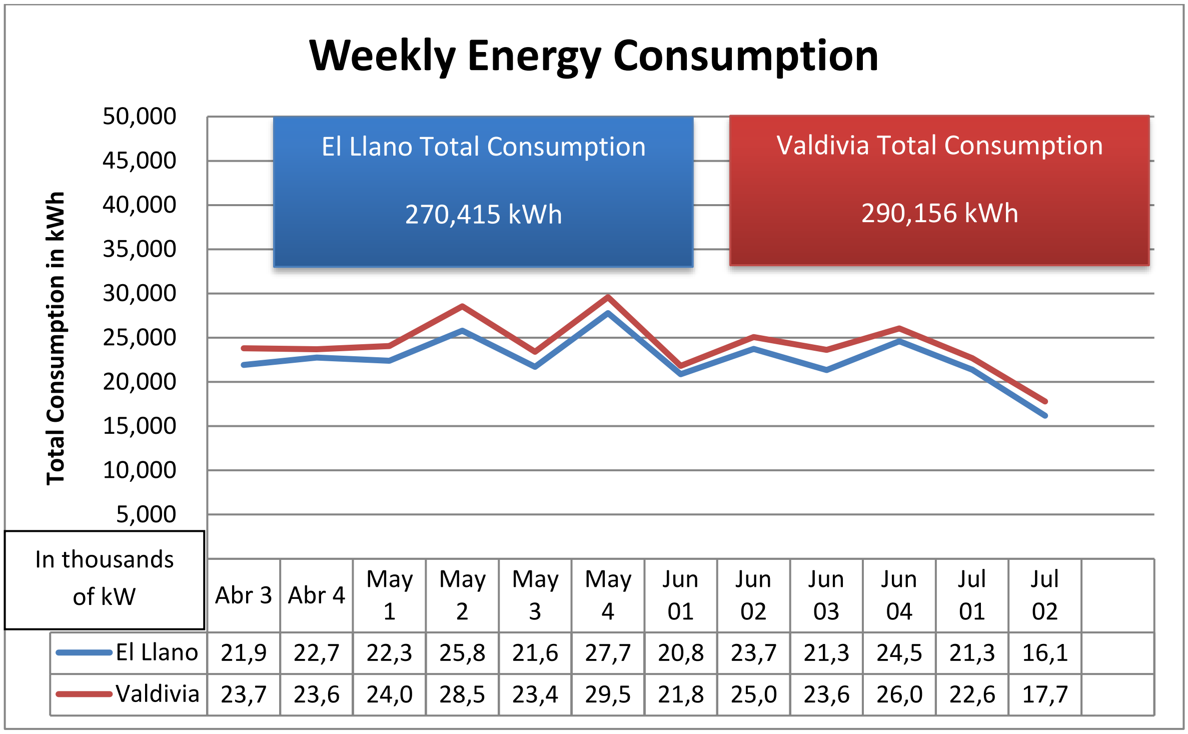


Figure 5.9. Jumbo Stores' Back Room Relative Humidity



In thousands of kW	Abr 3	Abr 4	May 1	May 2	May 3	May 4	Jun 01	Jun 02	Jun 03	Jun 04	Jul 01	Jul 02	
El Llano	21,9	22,7	22,3	25,8	21,6	27,7	20,8	23,7	21,3	24,5	21,3	16,1	
Valdivia	23,7	23,6	24,0	28,5	23,4	29,5	21,8	25,0	23,6	26,0	22,6	17,7	

Figure 5.10. Jumbo Stores' Total Energy Consumption. See Appendix 4 for details.

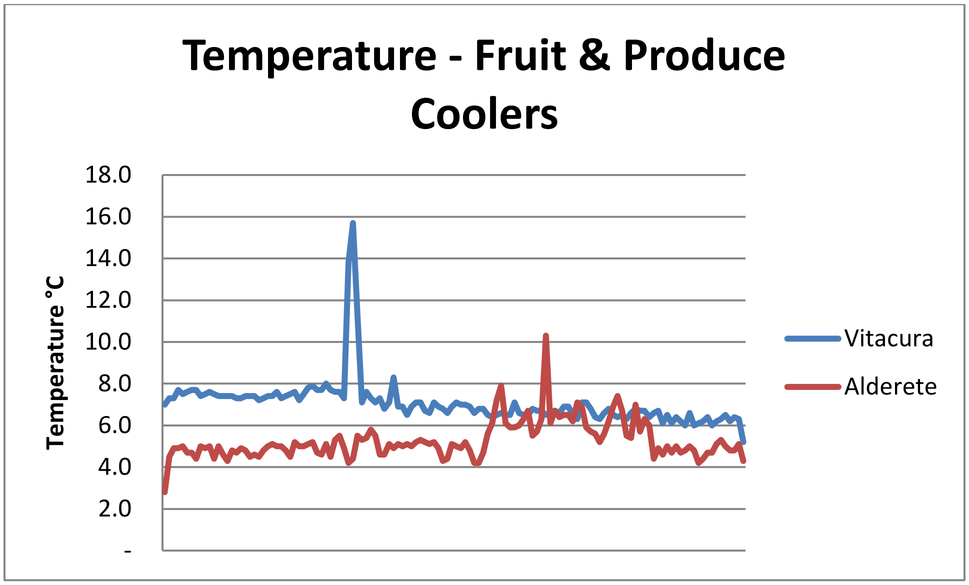


Figure 5.11 Tottus Fruit & Produce Coolers

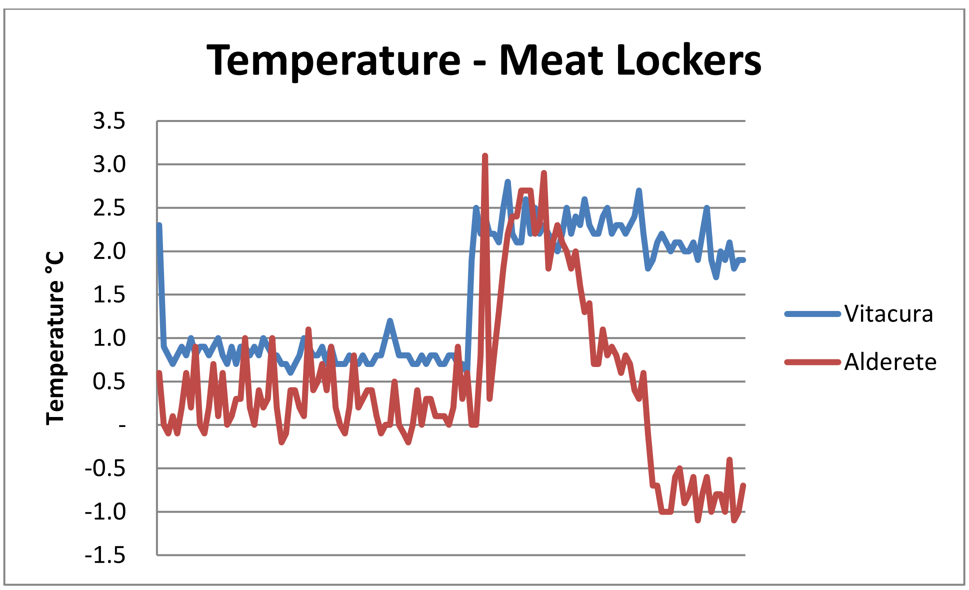


Figure 5.12 Tottus Meat Lockers

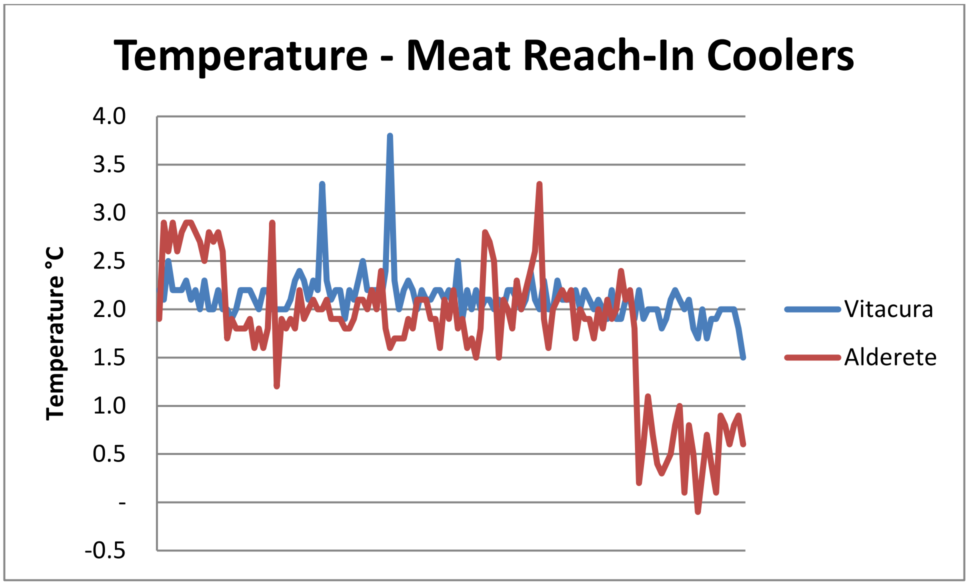


Figure 5.13 Tottus Meat Reach-In Coolers

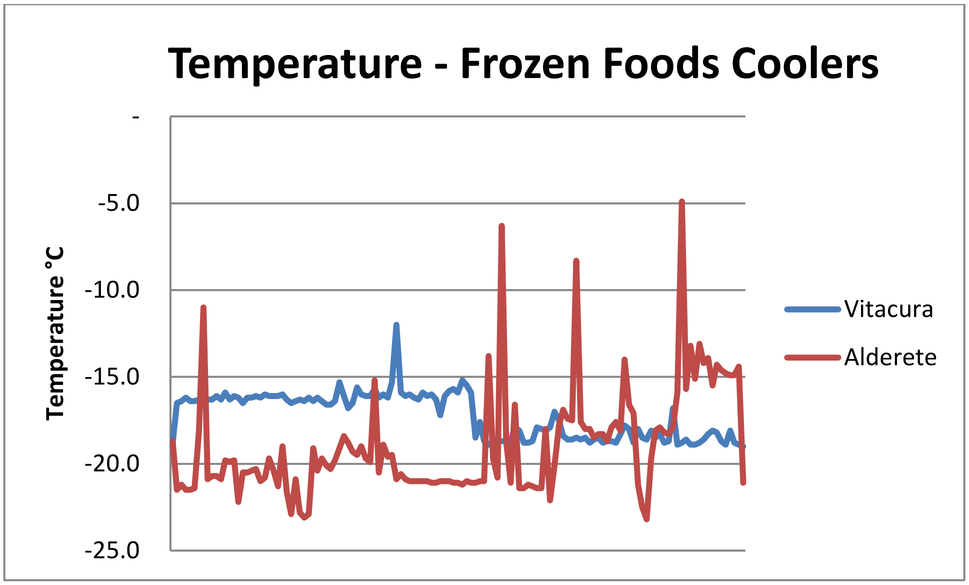


Figure 5.14 Tottus Frozen Foods Cooler

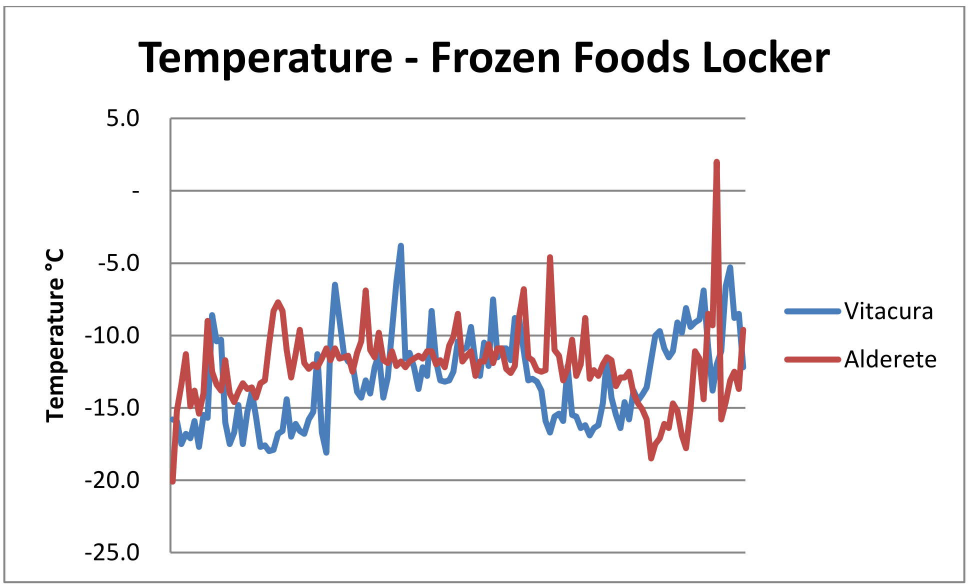


Figure 5.15 Tottus Frozen Foods Locker

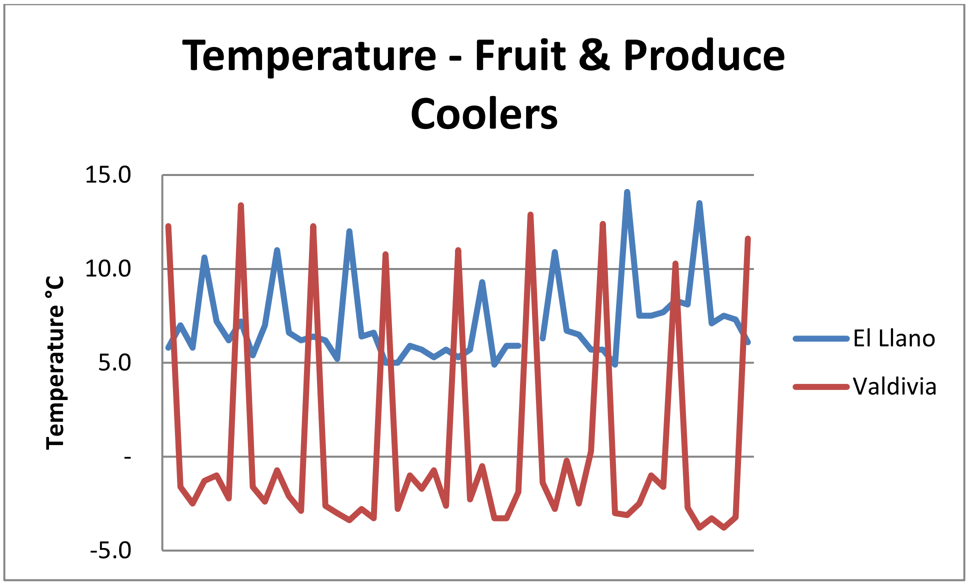


Figure 5.16 Jumbo Fruit & Produce Coolers

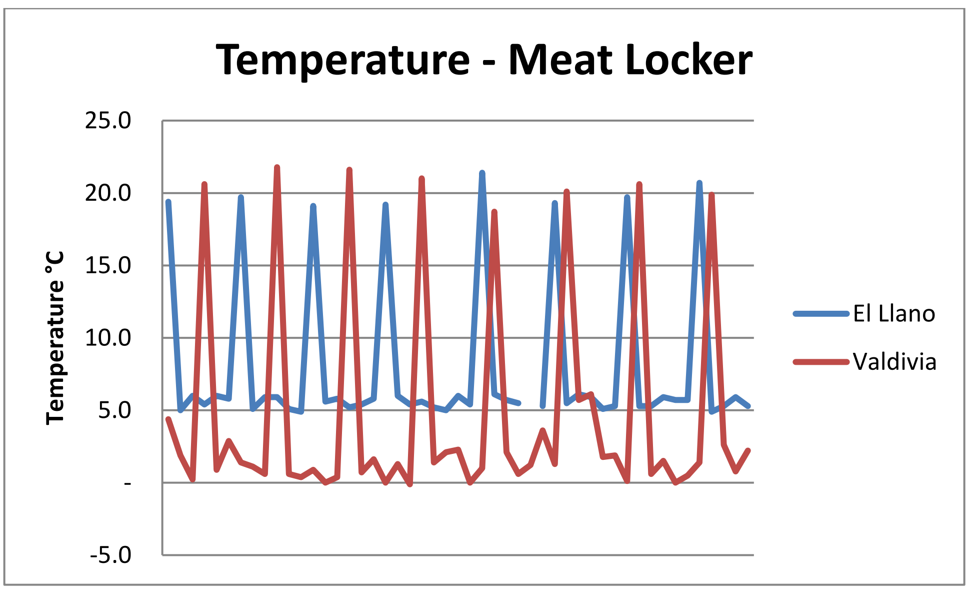


Figure 5.17 Jumbo Meat Locker

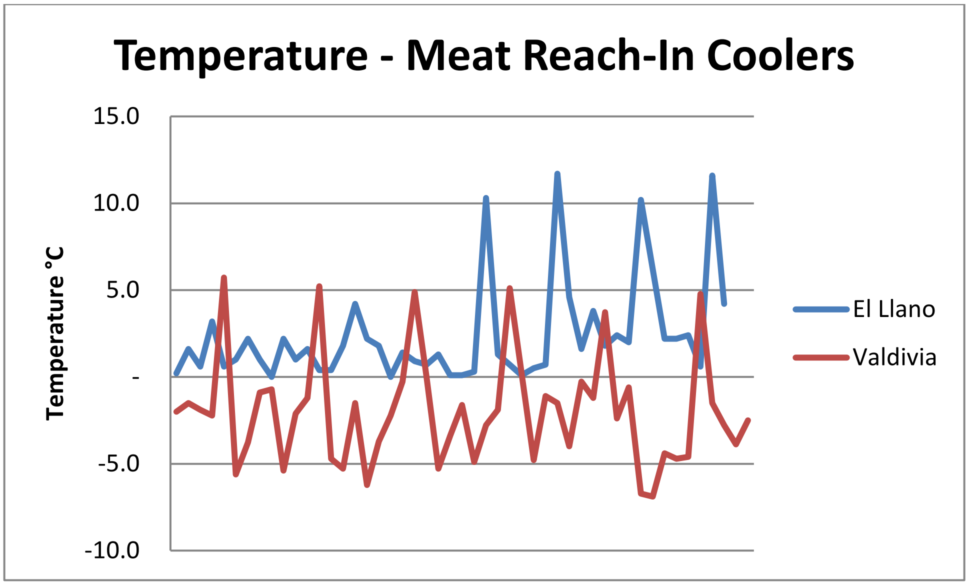


Figure 5.18 Jumbo Meat Reach-In Coolers

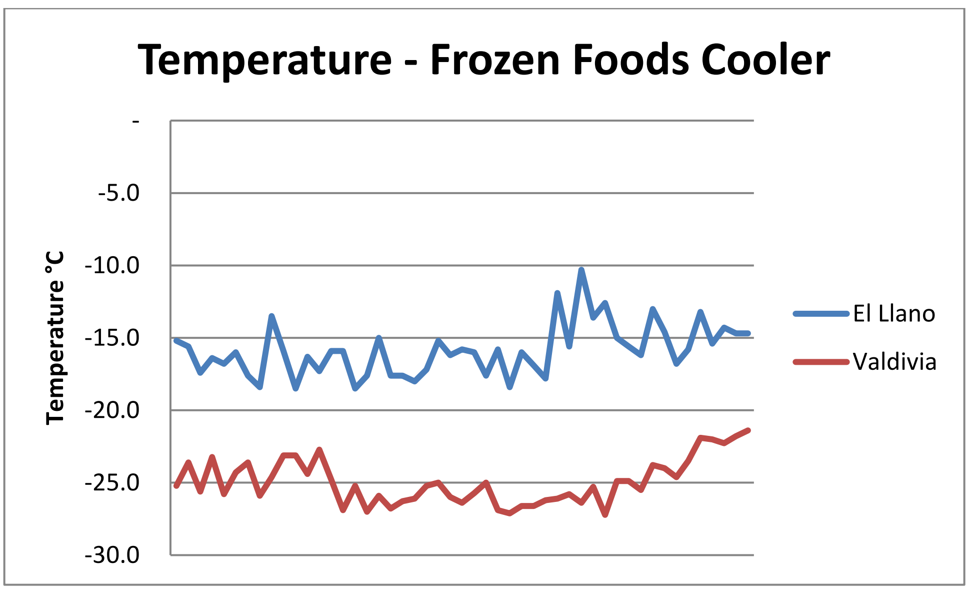


Figure 5.19 Jumbo Frozen Foods Cooler

6 Data Analysis & Results

Section	Vitacura	Alderete	Factor
(A) T Reach-In Coolers MT °C	3.7	2.9	+2%
(B) T Cooler BT °C	-17.23	-18.97	+3%
(C) T Sales Floor °C	19.65	17.98	-1.5%
(D) T Back Room °C	20.21	17.51	+4%

Alderete v/s Vitacura Equivalent Total Effect on Energy Consumption (+2.5%)

Table 5.1 Tottus Equalization Factors

Section	El Llano	Valdivia	Factor
(A) T Reach-In Coolers MT °C	5.5	0.9	+10%
(B) T Cooler TB °C	-15.9	-24.9	+18%
(C) T Sales Floor °C	18.6	21.0	4%
(D) T Back Room °C	19.3	19.6	+0%
(E) Sales Relative Humidity (%)	41	51	5%

Valdivia v/s El Llano Equivalent Total Effect on Energy Consumption (21%)

Table 5.2 Jumbo Equalization Factors

Nota 1: The working conditions of the Valdivia refrigeration equipment caused significant differences in the equalization of sales floor working conditions, which on average amounted to 21%. This was calculated by taking the relative weight of the average and low cooling demand of reach-in coolers, and by estimating the greatest consumption or work that the cooling equipment must put out in order to keep a constant temperature when ambient temperatures and relative humidity are higher on the sales floor. The latter resulted in an additional variable, which we call "Adjusted Electric Power."

Note 2: Estimating performance on the basis of the temperature at which the cooler operates has a linear relationship with the performance of CO_2 compressors at various evaporation temperatures.

The table below is used to calculate COPSI, which will be determined weekly. Actual power was determined on the basis of the electricity consumed during the period.

It is worth pointing out that the equivalent cooling power (shown in Table 4.1 below) and electric power (illustrated in Table 5.2 below) are used to calculate COPSI.

	Vitacura TEP kW	Vit Original COP	Current Vitacura TEP	COP Vit Actual	Alderete Power kW	Adjusted Electric Power kW	Alderete COP
Jan 1	83.39	1.88	83.39	1.68	82.08	80.03	3.01
Jan 2	82.79	1.89	82.79	1.69	80.53	78.51	3.07
Jan 3	82.07	1.91	82.07	1.70	79.98	77.98	3.09
Jan 4	80.36	1.95	80.36	1.74	82.19	80.13	3.00
Feb 1	84.49	1.85	84.49	1.65	84.73	82.61	2.91
Feb 2	79.99	1.96	79.99	1.75	79.61	77.62	3.10
Feb 3	82.47	1.90	82.47	1.69	82.97	80.89	2.98
Feb 4	79.45	1.97	79.45	1.76	78.70	76.73	3.14
Mar 1	80.26	1.95	80.26	1.74	80.76	78.74	3.06
Mar 2	75.98	2.06	75.98	1.84	72.71	70.89	3.40
Mar 3	72.19	2.17	72.19	1.94	69.95	68.20	3.53
Mar 4	74.86	2.09	74.86	1.87	75.25	73.37	3.28
Apr 1	73.80	2.12	73.80	1.89	71.66	69.87	3.45
Apr 2	69.36	2.26	69.36	2.01	64.87	63.24	3.81
Apr 3	68.69	2.28	68.69	2.03	67.46	65.77	3.66
Apr 4	65.41	2.39	65.41	2.14	60.67	59.16	4.07

Table 5.2 Tottus COPSI Calculation

Data collected have been illustrated in the graphs below to facilitate data viewing and comparison. Shown below are working conditions at the Vitacura stores, i.e., the project's original conditions and actual or real installation.

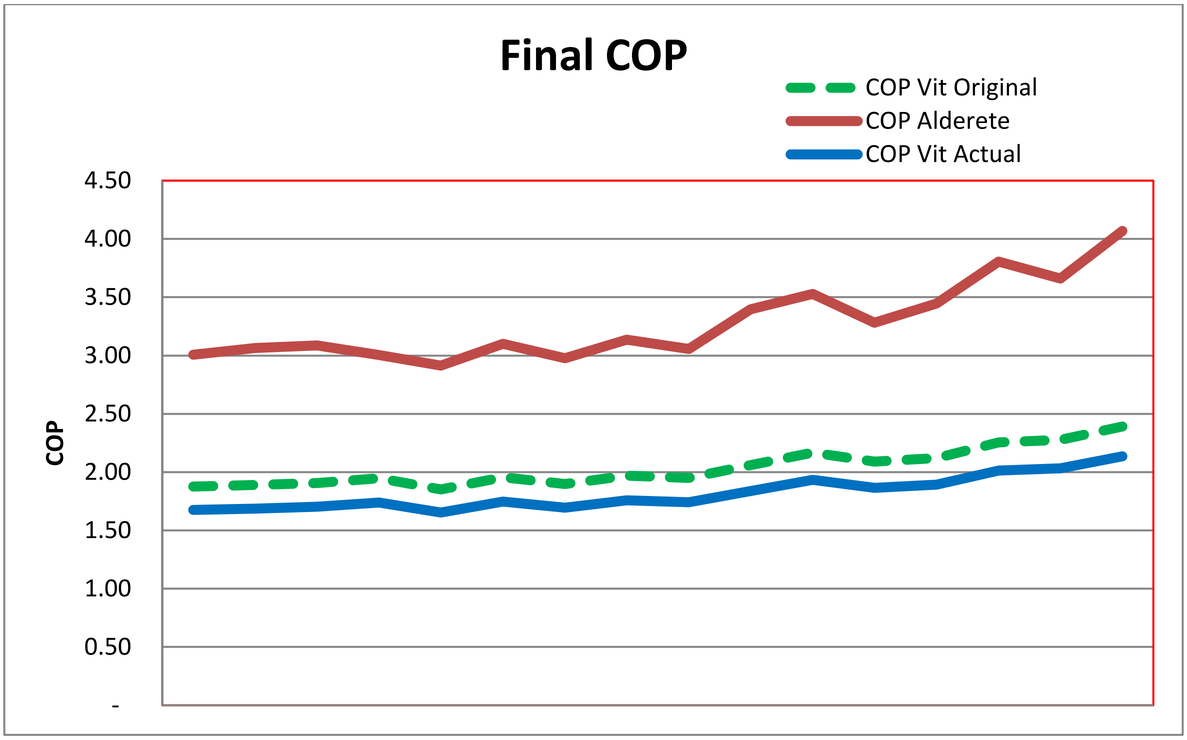


Figure 5.6. Graph of COPSI for Each Tottus Store.

	El Llano Power	El Llano COP	Adjusted Electric Power kW	Valdivia COP
Apr 3	140.48	3.06	120.51	3.74
Apr 4	135.38	3.17	111.39	4.05
May 1	133.30	3.22	113.14	3.98
May 2	133.74	3.21	116.81	3.86
May 3	129.14	3.33	110.07	4.10
May 4	128.62	3.34	108.20	4.17
June 01	124.15	3.46	102.64	4.39

June 02	123.60	3.48	103.21	4.37
June 03	127.07	3.38	111.15	4.06
June 04	128.07	3.35	107.24	4.20
July 01	127.18	3.38	106.64	4.23

Table 5.3 Jumbo COPSI Calculations

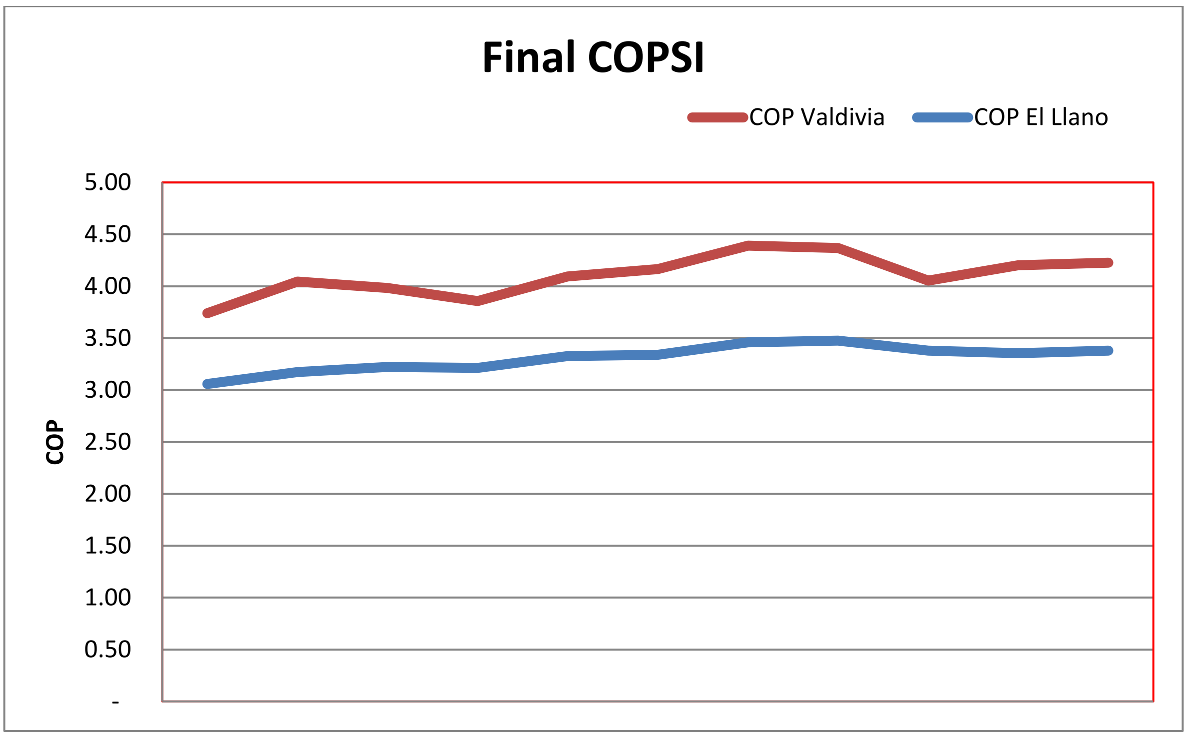


Figure 5.7. Graph of COPSI for Each Jumbo Store

7 Conclusions

Total energy consumption at the Vitacura store was 213,920 kWh during the period studied. Total energy consumption at the Alderete store was 210,047 kWh during the same period (January to April 2018)—a difference of 3,873 kWh—nearly 2% more at the Alderete store. This represents 42% more total equivalent cooling than what is currently installed at the Vitacura store.

In the case of Jumbo stores, total consumption was 270,415 kWh at El Llano and 290,156 kWh at Jumbo Valdivia (April to July 2018), nearly 5% more than at the El Llano store.

The COPSI or average efficiency at the Alderete store is 3.3 and 1.8 at the Vitacura store, which means that the **adiabatic CO_2 transcritical refrigeration system is 44% more efficient** than the R-507 refrigeration solution. Approximately 10% to 15% of these better results are due to adiabatic cooling which in the Santiago climate is equivalent to parallel compression. These data correspond to the January-to-April 2018 period; however, if we single out the month of April, the average COPSI at the Alderete store was 3.7 and 2.0 at the Vitacura store.

At Jumbo stores, the average COPSI at El Llano was 3.3** and 4.1** at the Valdivia store, which points to 20% better performance for the CO_2 system. Data correspond to the April-to-July 2018 period; however, if we single out the month of April, the average COPSI at the Valdivia store was 3.9 and 3.1 at El Llano.

Changes in the COPSI resulting from changes in ambient temperature confirm that in both types of refrigeration systems the COPSI improves at lower ambient temperatures. However, as the temperature drops, the CO_2 system COPSI improved much more than the R-507 system COPSI.

During fall and winter months, the CO_2 system performance should increase proportionally more than the R-507 system's efficiency. In the case of Tottus stores, the Alderete store's COPSI **(CO_2)** increased 23% from January to April while the Vitacura store's COPSI **(R-507)** increased 19%. Regarding Jumbo stores, the Valdivia store's COPSI **(CO_2)** increased 9% from April to July while the El Llano store's COPSI **(R-507)** increased 8%.

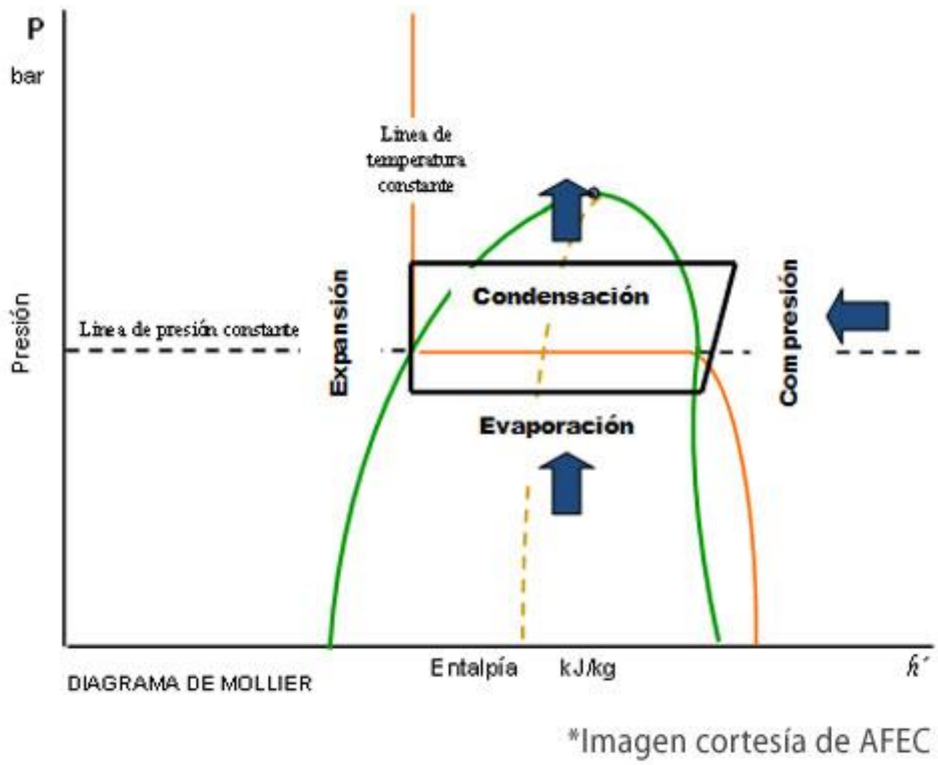
A plausible hypothesis is that the CO_2 transcritical system with adiabatic cooling is significantly more efficient than the traditional R-507 system. Also bear in mind that Chile's climate is particularly suited to these new technologies.

** These values could undergo changes in the future.

APPENDIX

Appendix 1

The Mollier refrigerant gas diagram below shows how this gas behaves during the various stages of the cycle and shows the energy and thermal output during each stage of the machine's operating cycle.



As shown in Figure 1, when operating in the heating mode, i.e., using the heat pump, the energy coming from the exterior corresponds to electric power, W, generated by the compressor, and the free contribution of air from the outside, QE. (An air source heat pump).

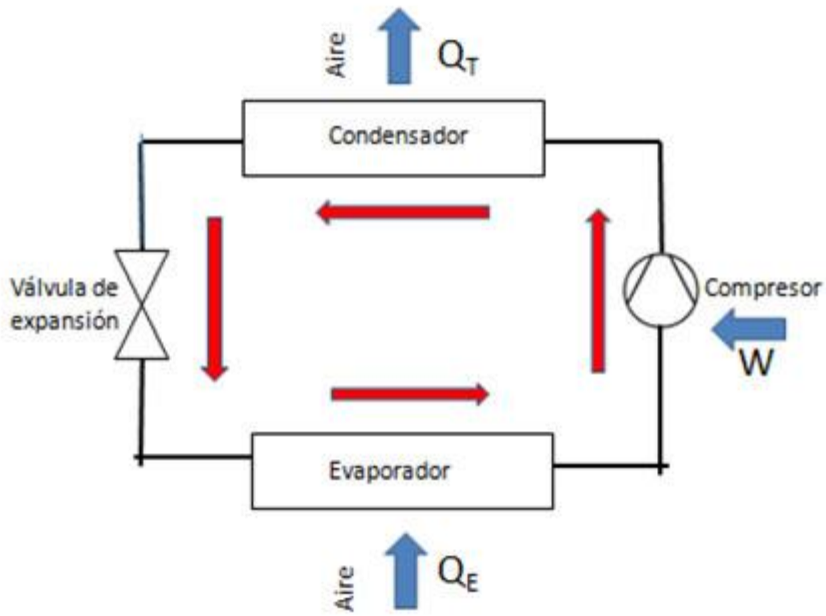


Figura 1.

Energy generated by the QT equipment is, as a result and in simplified terms—meaning that the previously mentioned losses are not taken into consideration—the sum of both contributions.

Therefore, performance η = QT/W where (QT = QE + W), is obviously greater than one.

Similarly, performance can also be determined in the cooling mode, although, logically, when inverting the cycle (reversible equipment), the condensation and evaporation pressures would be different and, therefore, so would performance. In any case, it would still be greater than the unit.

The four concepts defined below are used to measure performance: EER and SEER in cooling mode, and COP and SCOP in heating mode. Where:

EER (energy efficiency factor in cooling mode) is defined as the ratio between cooling power and electric power absorbed under specific temperature conditions with the unit operating at full capacity.

SEER (seasonal energy efficiency factor) is defined as the seasonal energy efficiency of a unit, calculated for the annual cooling demand, determined by specific climate conditions given under standard UNE-EN 14825:2014.

COP (coefficient of performance in heating mode) is defined as the ratio of useful heating generated and electric power absorbed under specific temperature conditions with the unit operating at full capacity.

SCOP (seasonal coefficient of performance) is defined as the seasonal efficiency of a unit calculated for the annual reference heating demand.

All definitions hereinabove are used to determine values that are based on laboratory calculations or measurements under reference conditions, which rarely occur under real operating conditions.

Moreover, there are considerable differences between performance values when seasonal ones are used (SEER and SCOP) since, by definition, in both cases, performance assessments are based on an annual reference demand; i.e., the goal is to bring theoretical operations closer to real operations instead of measuring or calculating single points.

In this regard, SEER and SCOP values are more realistic and, in fact, under current UE Regulations they have come to replace older EER and COP values for air-conditioning systems. **(Previous text source: https://www.caloryfrio.com/calefaccion/bomba-de-calor/definiciones-cop-y-eer.html)**

According to its definition, COP is calculated as a ratio of cooling power and electric power absorbed at specific temperature conditions and full operating capacity.

The goal is to evaluate the efficiency of each of the abovementioned systems, understood as: the **System's COP**, hereinafter referred to as **COPSI**, which is the relationship between the total cooling power expressed in the thermal balance and the electric power required to keep the refrigeration systems operating within temperature standards stipulated by the user over time plus the electric power of all components making up the refrigeration system.

In this specific case, a refrigeration system shall be understood as consisting of all of the components: coolers, lockers, backroom, central refrigeration system, condensers units, gas cooler and/or condensers, lighting, and cooler and locker defrosters, etc., that are fed from the general electric power panel(s) powering and cooling the food refrigeration system.

The same criteria will be applied to all four supermarkets participating in the study. Bear in mind that the electric power that will be measured will not be meeting the total cooling demand at all times. Instead, it will be meeting the specific demand required by the system to keep the system's temperature within the range stipulated by the owner as optimal.

$$COPSI = \frac{Thermal\ Balance\ Cooling\ Demand\ (kW)}{General\ Cooling\ System\ Electric\ Power\ Panel\ Consumption\ (kW)}$$

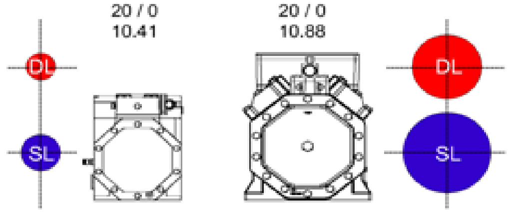
Appendix 2

The following properties of R744 make it a relatively safe and useful coolant.

- CO_2 is chemically stable and inexpensive to produce.
- Odorless, non-toxic, and naturally found in the environment.
- Heavier than air (will be installed in the lowest level).
- Compatible with most materials (non-corrosive).
- High-density vapor (700% compared to R134a at -10° C) with a high evaporation enthalpy (125% of R134a at -10° C) with a vapor velocity and liquid phase gradient lower than HFC. More thermal energy is needed to evaporate liquid CO_2 (liquid release)
- Low viscosity in liquid and gas (slight pressure loss).
- High heat transfer ratios and high thermal conductivity.
- Operates at an evaporation temperature of 2°K, greater than HFC.
- Works with small extension valve in the gas cooler and plate heat exchanger (PHE).
- CO_2 has a high volumetric refrigeration capacity (six times greater than R404A), which works well in smaller compressors, components and piping.

Comparison at subcritical conditions

	2HC-3.2K versus	4TCS-8.2 (Booster Applic.)
Displacement [m³/h]:	6.51	41.33
Refrigerant:	R744	R22
SST [°C]	-35	-35
SDT [°C]	-5	-5
SH / SC [K]	20 / 0	20 / 0
CAP [kW]	10.41	10.88



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Appendix 3

Details of Tottus stores' thermal balance calculations.

REQUERIMIENTO FRIGORIFICO Media Temperatura Central (°t evaporacion -10°C						
		Tottus Alderete			Tottus Vitacura P Hurtado	
Tipo	Uso	Modulacion	Req Termico [Watt]	Temp Aire	Modulacion	Req Termico [Watt]
Mural	Frutas y Verduras	1 x 375	4486	4 / 6		
Mural	Frutas y Verduras	1 x 375	4486	4 / 6	2x3750	8972
Mural	Frutas y Verduras	1 x 375	4486	4 / 6		
Mural	Frutas y Verduras	1 x 250	3102	4 / 6	2x2500	6204.48
Mural	Lacteos	1x2500	3370	2/4	1x2500	3370
Mural	Lacteos	1x3750	5055	2/4	2x3750	10110
Mural	Lacteos	1x3750	5055	2/4	4x3750	10110
Mural	Lacteos	1x3750	5055	2/4		
Mural	Lacteos	1x3750	5055	2/4		
Mural	Lacteos	1x3750	5055	2/4		
Mural	Lacteos	1x3750	5055	2/4		
Mural	Carnes	1x3750	5810	2/4	2x2500	11620
Mural	Carnes	1x2500	3870	0 / 2		
Vitrina	Carnes	1x3750	1690	0 / 2	2x2500	3380
Vitrina	Pescaderia	1x1250	675	0 / 2		
Vitrina	Pescaderia	1x1250	675	0 / 2		
Vitrina	Pescaderia	1x2500	1130	0 / 2		
Vitrina	Fiambres-Quesos	1x3750	1690	0 / 2	1x3750	1690
Vitrina	Fiambres-Quesos	1x2500	1130	0 / 2	1x2500	1130
Mural	Pasteleria	1x3750	5050	2/4		
SemiMural	Pasteleria					
cabeceras	Pasteleria					
Vitrina	Pasteleria					
Mural C/P	Bebidas Cervezas y Espuman	1x3750	2980	2/4	8x3750	23840
Mural C/P	Bebidas Cervezas y Espuman	1x3750	2980	2/4		
Mural C/P	Bebidas Cervezas y Espuman	1x3750	2980	2/4		
Mural C/P	Bebidas Cervezas y Espuman	1x2500	2006	2/4		
SemiMural	Espumantes	1x3750	3940	0 / 2		
Mural	Fiambres-Quesos	1xCab	2530	2/4	2x1850	5060
Mural	Fiambres-Quesos	1x3750	5053	2/4	1x2500	5053
Mural	Fiambres-Quesos	1x3750	5053	2/4	2x3750	10106
Mural	Fiambres-Quesos	1x3750	5053	2/4		5053
Mural	Fiambres-Quesos	1xCab	2530	2/4		
SemiMural	Fiambres-Quesos	1xCab	1920	0 / 2		
SemiMural	Fiambres-Quesos	1x3750	3835	0 / 2		
SemiMural	Fiambres-Quesos	1x3750	3835	0 / 2	1x3750	3835
SemiMural	Fiambres-Quesos	1xCab	1920	0 / 2	2xcab	3840
SemiMural	Platos Preparados	1xCab	1810	0 / 2	2xcab	
SemiMural	Platos Preparados	1x3750	2555	0 / 2	1x2500	2006
SemiMural	Platos Preparados	1x3750	2555	0 / 2	1x1250	1003
SemiMural	Platos Preparados	1xCab	1920	0 / 2	1x2500	2006

Nuova Service

Isla	Carnes	1xCab	530	-1 / 5		
Isla	Carnes	1x3750	2000	-1 / 5		
Isla	Carnes	1x3750	2000	-1 / 5		
Isla	Carnes	1xCab	530	-1 / 5		
		Total	132,495			118,388

Camaras y Trastiendas

Tipo	Descripcion	Requerimiento Frigorifica (Watt)	Potencia TOTAL	Modelo	Cantidad Evaporadores	
Camara	Carnes	3290	3290	GACC CX 031.1	1	
Camara	Pescaderia	1250	1250	GACC CX 031.1	1	
Camara	Frutas-Verduras	4270	4270	GACC CX 031.1	1	
Camara	Consolidados	3150	9450	GACC CX 031.1	3	
Trastienda	Carnes-Pollos	3360	3360	GACC CX 031.1	1	
Trastienda	Pescaderia	2320	2320	GASC CX 031.1	1	
Trastienda	Fiambres-Quesos	2200	2200	GASC CX 031.1	1	
Trastiendas	Adobo Pollos	1260	1260	GASC CX 031.1	1	
Sala	Corte	-			-	
Sala	Servidores	2320	2320	GASC CX 031.1	1	
		Total	29,720			
						118,388
	Total Requerimieto Media Te		162,215		118,388	

REQUERIMIENTO FRIGORIFICO Baja Temperatura Central (°t evaporacion -35°C - °t condensacion +45°C)

Muebles

Tipo	Uso	Largo	Requerimiento Termico[Watt]	Temperatura aire rango	Largo	Requerimiento Termico[Watt]
Cooler	Frutas y Verduras	1 x 5 puertas	3120	-18 / -24		
Cooler	Congelados	1 x 4 puertas	2490	-18 /- 24	1x4P	2490
Cooler	Pescaderia	1 x 4 puertas	2490	-18 / -24		
Cooler	Carnes	1 x 4 puertas	2490	-18 /- 24		
		Total	10,590			

Camaras y Trastiendas

Tipo	Descripcion	Requerimiento Frigorifica (Watt)	Requerimiento Frigorifica (Watt)	Modelo COOLTEC	Cantidad Evaporadores	
Camara	Pan	2,730	2,730	GACC CX 031.1	1	2,730
Camara	Congelados	6,830	6,830	GACC CX 031.1	1	6,830
		Total	9,560			

Total Requerimieto Baja Temperatura (W)		27,620	REAL	12,050
Total Requerimieto Baja Temperatura Equivalente (W)		48,611		21,208
Total Requerimieto Frigorifico Equivalente (W)		210,826		139,596

Valdivia Thermal Balance

SECTOR	PFRIG	TN1	tn2	BT1
	WATS	WATTS	WATTS	WATTS
CAMRAS Y TRAST	3,604	3,604.00	0.00	
MUEBLES TN	134,665	73,225	61,440	
MUEBLES BT	41,621			41,621
CAMARAS BT	4,605			4,605
		76,829	61,440	46,226
BT	**46,226**			
TN	**138,269**			

SECTOR	PFRIG	TN3	TN4	BT2
	WATS	WATS	WATS	WATS
CAMRAS Y TRAST	126,317	70,296	56,021	
MUEBLES TN	11,997	0.00	11,997	
MUEBLES BT	28,315			28,315
CAMARAS BT	14,564			14,564
		70,296	68,018	42,879
BT	**42,879**			
TN	**138,314**			

Appendix 4

Detailed electric power data for Figure 5.5, COPSI Calculation

Week	Hours	Energy Accumulated (kWh)	Power (kW)	Energy Accumulated	Power
Jan 1	120	10,006	83.39	9,850	82.08
Jan 2	192	15,895	82.79	15,461	80.53
Jan 3	144	11,818	82.07	11,517	79.98
Jan 4	216	17,357	80.36	17,752	82.19
Feb 1	192	16,223	84.49	16,268	84.73
Feb 2	168	13,438	79.99	13,374	79.61
Feb 3	144	11,876	82.47	11,947	82.97
Feb 4	192	15,254	79.45	15,110	78.70
Mar 1	117	9,391	80.26	9,449	80.76
Mar 2	192	14,589	75.98	13,960	72.71
Mar 3	144	10,396	72.19	10,072	69.95
Mar 4	216	16,170	74.86	16,255	75.25
Apr 1	192	14,169	73.80	13,758	71.66
Apr 2	192	13,317	69.36	12,454	64.87
Apr 3	144	9,892	68.69	9,714	67.46
Apr 4	216	14,130	65.41	13,106	60.67

Table A4.1 Tottus Stores

Week	Hours	Energy Accumulated (kWh)	Power (kW)	Energy Accumulated (kWh)	Power (kW) Valdivia)
Apr 03	156	21,914	140	23,797	153
Apr 04	168	22,744	135	23,687	141
May 01	168	22,394	133	24,061	143
May 02	193	25,813	134	28,537	148
May 03	168	21,696	129	23,407	139
May 04	216	27,782	129	29,584	137
June 01	168	20,857	124	21,828	130
June 02	192	23,731	124	25,084	131
June 03	168	21,348	127	23,637	141
June 04	192	24,589	128	26,062	136
July 01	168	21,366	127	22,679	135

Table A4.1 Jumbo Stores