Performance Assessment and Improvement of an Existing Air Conditioning System of a Supermarket: A Case Study on Bi-Lo Supermarket

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Abstract
Bi-Lo Supermarket in this study is located in sub-tropical coastal area in Queensland, Australia. The main objective of air conditioning in any building or supermarket is to provide comfort to the occupants and patrons of the conditioned space, an objective the air conditioning system at Bi Lo is struggling to achieve. The objectives of this case study are to identify the factors contributing to poor performance of air conditioning system at Bi-Lo and how to improve the economic life, air distribution throughout the store and system efficiency. Energy audit and performance calculation of the existing systems is performed. This study found that the premature aging of the system and consequent loss in economic life and poor performance are due to a combination of the coastal climate and poor maintenance of the system. Another contributing factor in the systems poor performance was due to uneven distribution of the conditioned air within the store. The cooling load required for the store is calculated using CAMEL, a heat load calculation program developed by Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH)), based on the local climatic data, Dailey people flow to store, building survey data, properties of building materials, etc. This study discussed and recommended that the appropriate performance and improved economic life of the Bi-Lo air conditioning system can be achieved through correct selection of air conditioning units (based on new cooling load calculation), duct redesign and applying correct installation techniques and maintenance of the system.

Keywords: Performance improvement, air conditioning systems, supermarket, design principles

1 Introduction

The expected economic life of packaged air conditioning units is 10-15 years [1]. The 8 year old system in operation at Bi-Lo is in poor condition and in need of an upgrade. Identifying the thermal comfort zone for supermarket applications is necessary to ensure the right internal conditions are chosen for the calculation of cooling loads and ensuring the accurate selection of air conditioning plant. The correct selection of plant is vital to providing comfort for the majority of the general public. Energy audit is essential to identify the factors that affect cooling loads which is the basis for determining the performance of required system.

Energy audit and assessment of building thermal performance have been widely published in the literature. In large commercial buildings energy consumption is a complex function of climatic condition, building usage, system characteristics and type of Heating, Ventilation and Air-conditioning (HVAC) equipment used. Dry bulb temperature and wet bulb temperature of outside air can explain most of the variations of energy consumption on a monthly time scale. Ambient temperature as the single independent variable eliminates the statistical problem due to multicollinearity [2]. Lam, *et al.* [3] investigated the electricity use characteristics of air conditioned office buildings through site survey and energy audits to obtain a breakdown of the energy use. Regression techniques can be used to correlate the monthly electricity use with the design, climate variables and the energy use implications. Pless and Torcellini [4] evaluated the annual energy performance of an academic building with an aim to design high performance buildings and to realize significant site energy savings, source energy savings and energy cost savings. A partial commissioning and energy audit were performed on a recently constructed building and different component and energy systems were inspected to evaluate the performance of the in built energy management systems by Moujaes, *et al.* [5]. Case study analysis by Gallachoir, *et al.* [6] showed the usability of simple performance indicator and metrics to enhance the understanding of energy trends and to assess building energy performance. Their work depicted that in absence of detailed data at end user level, significant progress can be made in accessing energy performance and informing energy policy decision. To identify the energy conservation opportunities and know details on the existing technologies, energy audit has to be carried out.

The correct air conditioning system cannot be designed and installed without knowing accurate cooling load. A comparison of performance of the required system with the existing system is necessary to be able to assess the performance of the existing systems and to determine whether the system is adequate. The comparison will also aid in identifying areas of economic improvement that can be addressed during the redesign to make the system more efficient. This study investigates and audits the performance of existing system and reports on the reasons for poor performance and consequent losses in economic life of the existing system. Improved economic life and system performance can be achieved through appropriate design and selection of air conditioning units, redesigning ducting and applying correct installation techniques. These issues are discussed.

2 Existing System

The existing Air Conditioning system at Bi-Lo consists of Five (5) Carrier Apac Packaged Roof top Units and ductwork,

- Four (4) S51 (51kW) units and
- One (1) S46 (46kW) Unit.

This system is controlled by an on/off switch and temperature adjustment located in the Manager's office. There are staff present in the store 18hrs/day and the system is run 24hrs/day to maintain space conditions for after hours staff and to prevent stock from perishing, particularly the fresh produce. Each packaged unit has its own supply and return air duct. The duct work consists of a supply and return air dropper from the base of the unit through the roof into a square plenum mounted to the underside of the roof. Supply air is distributed via side blow registers in each side of the plenum while return air is drawn through ceiling mount return air grilles in the base of the plenum and duct work through the centre of the plenum where it is mixed with outside air before being re-circulated via the cooling coil and supply air duct.

The main objective for a comfort air conditioning system is to provide comfort to occupants and patrons of the conditioned space. To achieve this objective, factors that influence the bodies' ability to dissipate heat need to be identified. There are four (4) environmental factors that influence the body's ability to dissipate heat. These include air temperature, temperature of the surrounding surfaces, humidity and air Velocity. These factors interact with the amount and type of clothing and the activity level of the occupants to affect their comfort level. Comfort air conditioning systems control these four environmental factors to provide comfortable conditions with in the conditioned space. If the occupants within the conditioned space are wearing appropriate clothing the following range should be acceptable.

Space Temperature: 20 - 26°C
Relative humidity: 50-60%
Dew point temperature: 2 - 17°C
Average air velocity: Up to 0.25m/s [7].

For supermarket applications, the conditioned space temperatures should be generally within the following scale:

- Space temperature 23°C ± 1°C
- Relative Humidity of 50% ± 5%

3 System Performance

The existing system at Bi Lo is eight (8) years old and in poor condition. The air conditioning units have not reached their expected economic life of 10-15 years or the duct work their expected economic life of 20-30 years [1]. To check the system performance space temperature and humidity readings were taken at various locations throughout the store. Two sets of readings were taken, one during the winter months and one during the summer months. Winter readings were obtained in September with ambient conditions of 25.5°C and Relative Humidity (RH) of 45.9%. In store conditions ranged from 17.6°C to 20.2°C and RH from 33% to 49%. These readings were all outside the design conditions for the store of 23°C and 50% RH and outside the acceptable range in conditions of ± 1°C and ± 5% RH. With ambient conditions of 25.5°C and RH of 45.9% the air conditioning compressors would not have been working and the indoor conditions could be attributed to the cold air from the cold Isle open case refrigerators being circulated throughout the store. Summer readings were obtained in January and showed indoor conditions to range from 21.5°C to 24.2°C and 42 to 55% RH with ambient conditions of 36°C and 62% RH. The summer store temperature readings are generally within the desired temperature range while the humidity readings exceed the desired max RH. Even though store temperature and humidity readings are generally within the desired range the temperature still fluctuates 3 degrees and humidity can vary by up to 10% across the store. This variation in conditions creates discomfort for patrons.

The variation in store conditions could be attributed to the existing duct design not being efficient in distributing air about the store. With the return air grille being in the base of the plenum not all of the supply air is distributed through out the store instead a percentage of the supply air is being drawn directly back into the return air grille. The remaining percentage of air is directed along the ceiling and not towards the trading floor where it is required. Replacing the existing air conditioning units and improving the existing air distribution through duct redesign would greatly improve the efficiency and effectiveness of the Bi-Lo air conditioning system.

The air conditioning units condensing coils are salt encrusted and corroded greatly, reducing heat transfer from the coils and is affecting the performance of the units. Rusting outside air ducts are reducing control of the supply of fresh air to the system. Filter access panels are rusted and hard to open and close, making routine maintenance difficult, if at all possible, and present a water leak hazard to the store in wet weather. The design of the existing duct work within the store is not efficient in circulating cooled air throughout the store and is creating a variation in temperature and humidity conditions across the trading floor. These conditions make it uncomfortable for staff and patrons.

4 Cooling Load Calculation for a (new) Required System

An air conditioning load calculation comprises of indoor and outdoor loads. Outdoor loads include:

- Suns rays entering windows
- Suns rays striking the walls and roof
- Air temperature outside the conditioned space
- Outdoor air required for ventilation

Internal loads include:

- People, Lights, Appliances
- Cash registers
- Any other sources of heat

To aid in the cooling load calculation a survey of the space to be conditioned must be made. The completeness and accuracy of the building survey will dictate the accuracy of the load calculation. The following physical aspects were considered when calculating the cooling load for Bi Lo:

- Orientation of the building. Location of the space to be air conditioned with respect to compass bearing and nearby structures
- Use of space, Physical dimensions of the space – length, width and height
- Ceiling height
- Construction materials
- Windows, Doors
- People, Lighting, Appliances
- Ventilation, Thermal storage
- Continuous or intermittent operation.

The following are the results of the building survey conducted at Bi Lo. *Orientation of the Building*: The Bi Lo store lies north south in the western side of Keppel Bay Plaza. The eastern side is the entry, and opens to the shopping centre while the western side of the store is the storage, offices and plant rooms. A recent upgrade of the store has seen the back of house offices air conditioning improved. As these areas have been upgraded they have been excluded from the cooling load calculation. *Use of Space*: The space to be air conditioned is zoned as a supermarket. *Physical Dimensions*: The store has a floor area of 1815m^2. *Ceiling Height*: The ceiling height of the store is 4.5m. *Construction Materials*: The walls and roof of Bi Lo are constructed of 150mm sandwich panel and the floor is concrete. *Windows*: There are no windows in the store to affect cooling loads. *Doors*: The front of the store is open to the rest of the shopping centre. There is minimal temperature difference between the shopping centre and the trading floor area to be air conditioned. There is also a large double door from the storage area in the back of house to the trading floor for staff access and stocking of shelves which will allow some infiltration of unconditioned air into the store. *People*: From store data Bi Lo can have up to 2900 people pass through the store each day not including rostered staff. Figure 1 shows the customer and staff traffic throughout the day.

Lighting: The lighting of Bi Lo is provided by exposed suspended double flourescent tubes. *Appliances*: Bi Lo utilises a variety of different appliances that all contribute to the cooling load both positively and negatively. Appliances include bakery ovens and donut and chicken hoods. Freezers, open case refrigerators and cash registers. The bakery and deli areas have been excluded from the cooling load calculation as these areas are served by their own air conditioning system and do not contribute to the trading floor cooling load. As a general rule of thumb, widely accepted across the refrigeration industry, open case refrigerators supply approximately 15% of the total cooling required for the store. This 15% is subtracted from the final cooling load calculation. *Ventilation*: 10L/s of outside air has been allowed per person for ventilation purposes as per the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) Technical Handbook [8]. *Thermal*

Storage: Thermal storage factors for building materials have been taken from tables in the AIRAH Air Conditioning Load Estimation manual [1]. *Continuous or Intermittent Operation*: Bi-Lo requires constant 24hr operation. Staff occupies the store 18hrs per day and conditions in store need to remain constant to prevent the spoiling of stock.

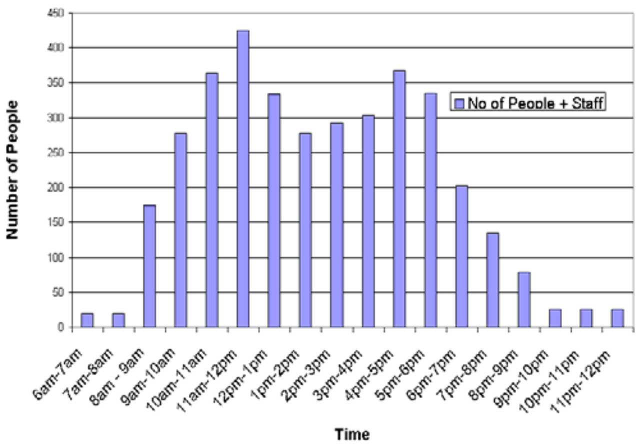

Figure 1: Dailey customer and staff traffic in Bi-Lo

For the air conditioning system to achieve the identified thermal comfort zone of 23°C ± 1°C and Relative Humidity of 50% ± 5% outdoor design conditions need to be determined utilising climate data from the Bureau of Metrology for outdoor conditions of 28.5°C Dry Bulb, 23.3°C Wet Bulb, 20.5°C Dew Point and 63% Relative Humidity. This data is the mean 3pm dry and wet bulb conditions in December. Figure 2 and 3 show the space temperature profile and variation of RH throughout the year respectively. Gladstone data was selected as there is no near local data available and as Gladstone is the closest coastal town its conditions would be similar to this location.

Computer calculations were performed using CAMEL a heat load calculation program developed by AIRAH. CAMEL is the HVAC industry standard program for the calculation of heating and cooling loads. The CAMEL program returned a grand total heat of 304.1kW. Calculations were checked using a check value for supermarkets of 160W/m^2 [1]. The calculation found a value of 167W/m^2 which verifies the calculation of cooling load. Additional load calculations were performed using CAMEL for different ceiling heights to illustrate the effect of reducing the ceiling height will have on the cooling load for the supermarket. The CAMEL program automatically analyses and makes assumptions on the data entered. While the data entered must still be quite accurate, less experience is required to perform this calculation.

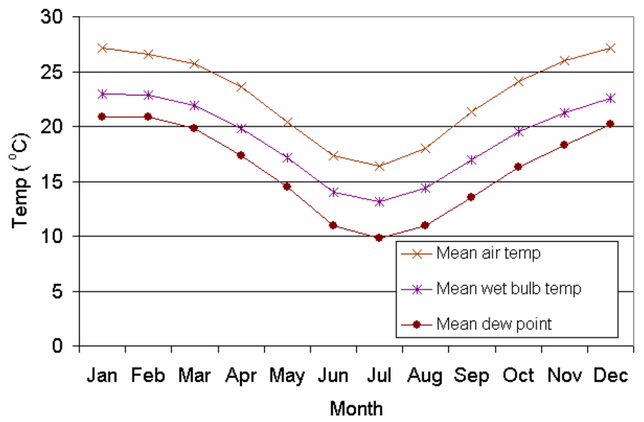

Figure 2: Space temperature profile throughout the year

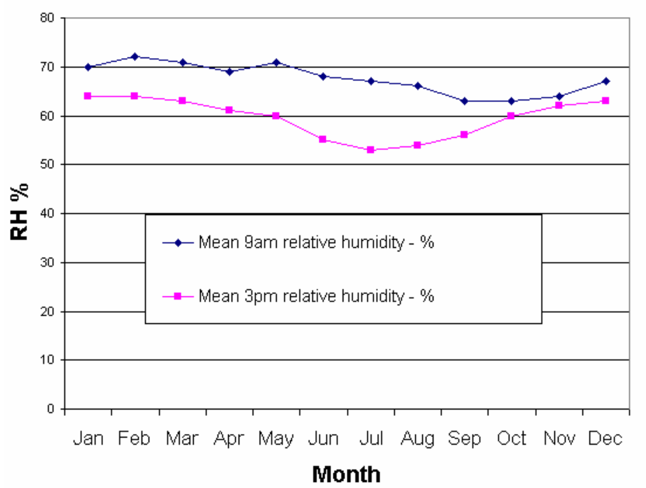

Figure 3: Variation of humidity throughout the year

Figure 4 shows the calculated cooling load profiles for the whole year using the local climatic data, customer traffic into the store, building survey data, building material properties, etc. The highest peak cooling demand of the supermarket is about 284 kW in both January and February, occurrence period 3-4 pm whereas lowest peak cooling demand is about 166 kW in both June and July. Cooling load demand increases sharply during 9 am to 12 pm, while a fall is recorded between 12 pm to 2 pm, then, increases again to peak at 4 pm and since then decreases slowly for the rest of the working hours.

5 Discussion and Recommendation

5.1 Air Conditioning Unit Selection

The air conditioning units should be selected using the peak cooling load data from the CAMEL cooling load calculation for a ceiling height of 3.5m. The Peak cooling load occurs at 3pm-4pm in January. This calculation was selected as lowering the ceiling height reduces the cooling load required and ductwork can be "hidden" from public view. The Carrier APAC Unit Selection Guide can be used in conjunction with the cooling load calculation to select units that most closely matched the required performance characteristics

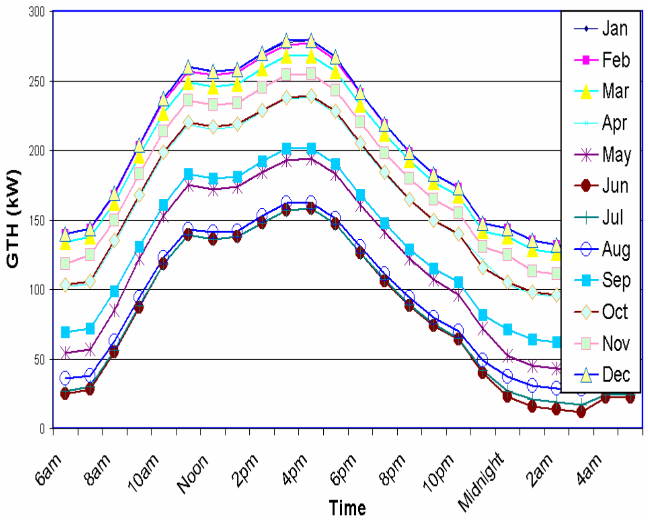

Figure 4: Calculated cooling load profiles

Choosing the correct units for the air conditioning system involved subtracting 15% (the amount of cooling supplied by the open case refrigeration) from the CAMEL figures and comparing these figures to the manufacturers data for a variety of unitary packaged units. Packaged units were selected as they have lower purchase and installation costs and when properly sized and controlled they also provide lower operation costs. The disadvantages are that specific sizing of components is limited because they are mass produced in particular capacities. The Central Queensland climate also makes it quite hard to select "off the shelf" units as this climate has very high latent heat component compared to the sensible heat during the spring months. In selecting the correct packaged units there was two choices: replace the existing units with updated models of the existing units, or replace the existing units with 2 larger units. The option of replacing the existing units with updated models was selected as with the 5 units there is a combined 10 stages of cooling available as opposed to the 8 stages available if replacing with 2 units. Having multiple units with 2 stages of cooling each rather than 2 units with 4 stages of cooling will cope better with periods of low sensible and high latent loads

5.2 Duct Design

Air conditioning problems at Bi Lo seem to stem more from poor duct design and hence poor air circulation with-in the store rather than poor unit selection. The existing duct work and side blow registers combined with the return air duct in such close proximity to the registers can not effectively distribute air through out the store. The side blow registers are loosing approximately 1/3 of the air supply directly to the return air plenum while the other 2/3 are delivered close to the ceiling and not to the trading floor as required. The duct work has been redesigned to remove the plenum arrangement that exists to insulated hard duct runs and supply registers that will direct the air down into the trading floor area and separate return air ducting. Having the return air grilles away from the supply air registers also aids the air distribution by drawing the supplied air through the store before being drawn into the return air duct. The duct work has been sized utilising the velocity reduction method. A duct velocity of 5m/s and grille face velocities of 5m/s for supply air and 2.5m/s for return air have been selected to keep air and duct noise to a minimum. The filter plenum has been changed to an external roof top box containing deep bed filters to improve air filtration and accessibility for ease of servicing. All external ductwork should also be painted to provide extra corrosion resistance and prolong duct life.

5.3 Areas of Economic Improvement

The existing system has not lasted for its expected economic life. Generally packaged units should last 10 to 15years and ductwork and fittings should last 20-30 years. The installation is in a coastal environment so the life expectancy of the plant would be lower than the expectancy of an inland system however the Bi Lo installation is only eight years old and in need of replacement. This is due to the harsh coastal conditions and a lack of necessary preventative maintenance. The Painting of all external ductwork at installation will provide better corrosion resistance and the implementation and close monitoring of a preventative maintenance program in addition to the regular service schedule would greatly increase the economic life of the Air conditioning Plant. Units are required to run 24hrs and while the cooling load has been reduced by dropping the ceiling height, the revised cooling load is greater than when the store was originally built and therefore any reduction in running costs by reducing the cooling load has been lost in the extra cooling capacity required.

5.4 Load Management and Control Techniques

The Air conditioning plant at Bi Lo is required to run 24hrs per day. Due to the construction and orientation of the building and its operation requirements there is not a lot that can be done to relieve cooling and/or electrical loads. The only option for reducing the cooling load on the air conditioning system is to reduce the volume of air that is required to be cooled. This has been achieved by reducing the ceiling height to 3.5m. This has reduced the cooling load by almost 15kW as indicated by CAMEL heat loads. As the store had no existing ceiling there was not an air gap between the roof and the store. The 3.5m ceiling has created a 1m air gap and also hides the AC duct work and fire services piping from view. There are no other building modifications that could be made to help reduce the cooling load any further. The operation of the units and location of the temperature control and on/off switches located in the managers office will remain the same, however regulating space temperature has been improved by better placement of temperature sensors in the return air duct away from the supply air. This allows more accurate sensing of the store temperature and more efficient running of the air conditioning units.

5.5 Costing

A full air conditioning system comprising of 1x PO46 and 4x PO55 Carrier APAC packaged unit's insulated ductwork, supply and return air registers and controls will cost approximately $150 000 to implement [9]. The system provides more controlled and efficient cooling of the store through unit selection, temperature sensor location and duct layout. The painting of external ductwork and selection of units with treated coils will ensure an improved economic life expectancy. Unfortunately any savings in operation over the old system due to improved efficiency will have been lost to running the larger capacity units required.

6 Conclusions

Replacing Bi Los' existing air conditioning system will be a costly exercise, an expense that most likely will not be returned. The new system will provide more efficient and controlled cooling of the store through the improved duct design and placement of supply and return air grilles and temperature sensors. The upgrade required extra air conditioning capacity over the old system and any saving in operation costs through improvements to the systems efficiency may have been lost in this extra capacity. The new system however will have a longer economic life than the existing system through the painting of external duct work and ensuring preventative maintenance is performed during the regular service of the system. Substantial operational savings could made utilizing other combinations of Air conditioning plant and controls such as a built up air handler and Direct Digital controls however these systems are very expensive to purchase and set up and not easily 'retro fitted' to buildings that did not originally have this style of system. The proposed system is possibly the best compromise between installation and operation cost available.

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