Taking a Sensible Choice of Sustainable Super Market Refrigeration Equipment

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Taking a Sensible Choice of Sustainable Supermarket Refrigeration Equipment

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ABSTRACT

Supermarkets play a significant role in modern urban living in developed and developing nations worldwide. Technology has made it possible to provide peoples’ daily needs such as food either fresh, preserved or cooked, at the hand reach in these supermarkets. This easy lifestyle however, comes with a burden to the environment and natural resources. There are growing concerns for the sustainability of modern lifestyle in connection to worldwide population growth, increasing impact of climate change due to human activities, predicted shortage of traditional energy sources and uncertainty in alternative energy resource, New generation supermarket equipments such as refrigeration, air conditioning, lighting and other processes must aim for effectively reducing such sustainability burden in their application, individually and integrally. This paper investigates sustainability targets for supermarkets and identifies some sensible choices amongst many of that are possible using emerging technologies.

1. INTRODUCTION

1.1 Sustainability

Although the sustainability concept was originated from preserving the natural environment, but it entered into the economic development arena referring to sustainable development (WCED, 1987) that “meets the needs of the present without compromising the ability of future generation to meet their needs”. It is also seen as a tool of equity between generations and equity within generations. Sustainability now also emphasizes the reduction of the economic gap within and amongst the developed, developing and under-developed societies. Human society is continuously facing challenges occurring due to natural or human made changes in our living space. Our living space is where we live now and where the future generations will live including the natural environment and resources and living style and cultures. Natural changes, those are outside the human control, such as natural change of the earth environment and the outer space of the solar system and beyond, remains beyond the discussion of this sustainability topic. But the changes occurred due to the fast evolution of technology in the past century have brought very reasonable question as to whether the current world order is really sustainable if the changes are continuing in the increasing order. Attenborough (2009) presented that if the population of the whole world is to live in the lifestyle of UK today, then the world could only sustain 2.5billion people whereas if that of Indian lifestyle, then it could only sustain 15billion people. Being sustainable means, continuously reducing any negative impacts due to human activities to a level that can sustain the expected future world population.

Amongst many sustainability connections in the current human living style, there are five broader connections of the greatest importance today for any particular human activity.

- Use: Effective and sustained affordability
- Environmental impact: Climate change, Pollution and contamination of air, water and land, and Biological or genetic alterations
- Depletion of non-renewable resources such as primary energy sources
- Immediate health and safety impact
- Time factor for all the above connections.

The time factor of any connection is important to be considered because measures today may change with time making the assessment wrong in the future.

1.2 Supermarket and Sustainability
The supermarket is a place where people predominantly self-serve their shopping needs of daily groceries in a “box shop”. Supermarkets require mechanical preservations such as chilling and freezing, which requires refrigeration equipments. Supermarkets offer cooked foods in hot displays. Products are served or displayed in self-serve display cabinets for customer’s easy access. Display cabinets are arranged and lit up in a way that highlight the products, promote freshness of the food products and enhances merchandising ability with an aim to improved sales. Supermarkets also have chilled and frozen enclosed rooms for storage within the same building. The building envelope is air conditioned round the year for comfortable indoor shopping as well as maintaining a temperature for which the chilled and frozen display cabinets can operate correctly to maintain correct product temperature for increased shelf life. Hot water is used for food processing and hygiene. Hot water is produced from electric or fuel boilers or occasionally heat recovered using heat pumps or direct exchangers from refrigeration plants. All these equipments require a huge amount of energy which is primarily taken from the electricity grid and some from primary fuels.

In US region, typical supermarkets consume about 400-800kWh/year energy per m² of gross floor area (EPA, 2008). In Germany energy intensity can be between 300-600kWh/year/m² of sales area (Rhiemeier, 2009) and in UK it varies from 850kWh/year/m² to 1500kWh/year/m² (S.A. Tassou, 2010). Depending upon the primary energy source, the range of emission factor can be between 0.5kg CO₂-e/kWh and 1.3kg CO₂-e/kWh. A 1500m² floor store may emit as high as 3,000,000kg CO₂-e/year due to energy use. Energy resources depletion corresponding to the energy use is obvious. Refrigerants used in refrigeration and air conditioning plants can leak into the atmosphere therefore contributing to direct emission impact. Leaking refrigerant also has buried energy intensity and indirect emission impacts resulted from their production process. Taking a conservative leakage rate of 15% per annum for supermarket refrigeration plant in Australia, this can contribute to direct CO₂-e emission up to 590,000kg/year with a typical charge of 1000kg of R404A refrigerant. R404A has a Global Warming Potential (GWP) of 3,900kg/kg.

More than a century ago, open market was a common place for selling fresh products and when used natural preservation methods. It only run in the daylight and goods were transported on carts. No air conditioned space and no refrigeration. This style can still be seen in some underdeveloped countries today. The contrast between the modern supermarket and the open market in relation to the energy and environmental impact is clear. The question is can we maintain the current lifestyle for infinite future? In supermarket context, we must make every effort to reduce any negative impacts of this service from birth, throughout the life and at the end of the life.

1.3 Making a Sensible Choice in Achieving Sustainability

In measuring how well the sustainability targets are achieved, consider all connections to the activity. They may have concurrent or contradicting inter-relationship. In a mathematical form, we can propose a sustainability index (SI) as below.

$$SI = f(U, E, R, S, t).$$  \hspace{1cm} (1)

Where $U$ is use, $E$ is Environment, $R$ is Resource, $S$ is for Safety and $t$ for time factor of all relevant connections. It can be simplified by leaving the time factor out of the equation but having $SI$ re-assessed at different time scale.

Optimizing sustainability means, maximizing $SI$ for corresponding changes in the connections. It is also important to understand that determining each of the connections have their own complexities and uncertainties. Without assessing the uncertainties, a decision taken today may become incorrect later. Impact of uncertainties can be determined by sensitivity analysis, which in the simplest form is to determine how much change in one independent element will affect the optimum function, which is sustainability index in this case. Thus,

$$\gamma_x(SI) = \frac{\delta(SI)}{\delta x}, \text{ where } \gamma \text{ is the sensitivity of SI to the variable } x.$$ \hspace{1cm} (2)

And $x$ are replaced with $U, E, R,$ or $S$.

2. SENSIBLE SUSTAINABILITY CHOICES FOR SUPERMARKET

Figure 1 presents the inter-relationship of different elements in the supermarket activities related to energy and climate.
It is obvious from Figure 1 that the energy interconnections between different activities, creates a complex energy optimization scenario. The refrigeration and air conditioning systems contain refrigerant gases which have direct climate impact through leakage. New and emerging technologies have the potential to reduce overall energy resource use and climate change impact. Some simple and common technologies are presented in Federal Environment Agency, Germany (2009) as individual options. Storewide net impacts of applying individual technologies can be significantly different than aggregate of all individual benefits. An integrated and time depended functional assessment is important.

2.1 **Integrated Approach of Choosing Sustainability Options for Supermarket.**

The integrated approach of assessing supermarket sustainability options involves considering all energy, resource and climate factor together so that impact of any factor is not hiding or contradicting to other. The optimum decision requires such collective method to be detailed as much as possible.

2.1.1 Energy: Referring to Figure 1, and applying energy balance of the supermarket equipment and processes for any finite time period, we derive the Equation (3) below,

\[ \sum E_i = E_a + E_d + E_r + E_p + E_l + E_x - E_g \]  

(3)

Where, 

- \( E_i \) is electrical energy consumed in the building by any element of activity, kWh. If any electrical energy is exported from the building, then that will be a negative figure.
- \( E_a \) = Energy consumed by all equipments associated to the air conditioning system
- \( E_d \) = Sum of direct electrical energy consumed by all display cabinets. Again, \( E_d = E_{dm} + E_{df} \).
- \( E_r \) = Sum of electrical energy consumed by all refrigeration plants. Again, \( E_r = E_{rm} + E_{rf} \).
- \( E_g \) = Electrical energy produced locally and exported to grid (if any).

Subscripts “m” and “f” refer to two typical refrigeration plants, one for an evaporating temperature, \( T_{em} \), higher than -15°C for chilling, and one for a low evaporating temperature, \( T_{el} \), between -25°C and -40°C for freezing respectively.

Direct electrical energy consumed by display cabinets can be broken into two types, outside and inside the cold area of the cabinet. So, \( E_{dm} = E_{dmi} + E_{dmo} \) and \( E_{df} = E_{dfi} + E_{dfo} \), where subscripts “i” and “o” refers to inside and outside respectively.

\( E_p \) = Sum of direct electrical energy consumed by all processes including, water heating, cooking, hot displays, other energy activities that are occurring within the conditioned building.

\( E_l \) = Sum of direct electrical energy consumed by all lights within the store. It is assumed that full store-lighting energy is transferred into the conditioned store area, as \( Q_l = E_l \).

\( E_x \) = energy consumed by all refrigeration and air conditioning auxiliary components that does not enter into the refrigerated or air conditioned thermodynamic cycle, such as condenser fans.
Assume, $Q_a =$ air conditioning heat load, which is expanded in equation 4 below.

$$Q_a = Q_b + Q_p + Edmo + Edfo + El - Qrm - Qrf$$  \hspace{1cm} (4)

Where,

$Q_b =$ the heat energy exchange between the building and the environment including infiltration, radiation, conduction, shoppers etc. that would be considered as building heat load excluding the refrigeration and processes. This simplistic heat does not cover all aspects of building heat load estimates but considered enough to represent the energy modeling purpose.

$Qrm =$ the heat gain of all medium temperature display cabinets from the conditioned store

$Qrf =$ the heat gain of all freezer cabinets from the conditioned store

$Qp =$ the heat rejected into the store from the processes that consume electrical energy

Let us also define,

$Qpw =$ the heat wasted to the environment due to processes. Or $Qpw = Ep - Qp$

$Qcm =$ condenser heat rejection to the outdoor ambient from the medium temperature plant

$Qcf =$ condenser heat rejection to the outdoor ambient from the freezer plant

$Qca =$ condenser heat rejection to the outdoor ambient from the air conditioning plant

The energy performance of real refrigeration and air conditioning plants are defined in terms of system performance factor in compared to ideal Carnot cycle efficiency between the sink and source temperatures. Symbolically, performance factor, $F = \frac{E_{actual}}{E_{Carnot}}$. Higher the value of $F$, the poorer the performance is. Say,

$Fm =$ performance factor for medium temperature refrigeration plant,

$Ff =$ performance factor for freezer refrigeration plant,

$Fa =$ performance factor for air conditioning plant, thus,

$$Ea = Q_a \frac{Fm(Tca - Tea)}{Tea}$$  \hspace{1cm} (5a)

$$E_{rm} = Fm \frac{(Qrm + Edmi)(Tcm - Tem)}{Tem}$$  \hspace{1cm} (5b)

$$E_{rf} = Ff \frac{(Qrf + Edfi)(Tcf - Tef)}{Tef}$$  \hspace{1cm} (5c)

Where, $Tc$ and $Te$ are condensing and evaporating temperatures in Kelvin respectively. Subscripts are as usual. The heat rejected from the condensers can be expressed in the forms below.

$$Qca = Qa + Ea = Qa \left(1 + \frac{Fm(Tca - Tea)}{Tea}\right)$$  \hspace{1cm} (6a)

$$Qcm = (Qrm + Edmi) + E_{rm} = (Qrm + Edmi) \left(1 + \frac{Fm(Tcm - Tem)}{Tem}\right)$$  \hspace{1cm} (6b)

$$Qcf = (Qrf + Edfi) + E_{rf} = (Qrf + Edfi) \left(1 + \frac{Ff(Tcf - Tef)}{Tef}\right)$$  \hspace{1cm} (6c)

Energy that is exchanged due to drainage of cabinets’ defrost water should be included, but for simplicity it is ignored for the time being.

Inserting from previous equations,

$$\sum E_i = (Qb + Qp + Edmo + Edfo + El - Qrm - Qrf) \left(\frac{Fm(Tca - Tea)}{Tea}\right)$$
The Equation (7), shows a simple form of energy interlink between the key equipments in supermarkets that contribute to climate change and energy resource consumption. Optimization of energy means minimizing energy consumption with maximizing usability. All energy equations must be treated with time dependent variations, such as daily, seasonal, annual and life cycle changes. Therefore, total energy consumption for the life time of, \( N \), can be estimated by,

\[
\int_0^N \left( \frac{\partial (\sum E_k)}{\partial t} \right) dt
\]

Further on the time dependent analysis is kept out of the scope for this article.

2.1.2 Estimating energy resource depletion: The original source of conventional energy is fossil fuel, either in gas, oil or coal form. Taking coal as an example, the energy journey starts from mining. For this analysis we determine coal consumed at the power plant per kWh of energy delivered to the end user as,

\[
M_c = \frac{3.6}{H(\varepsilon\tau)}
\]

Where, \( M_c \) is the ton of coal required to produce 1kWh of electricity delivered to the end user, \( H \) is the heating value of the coal in kJ/kg. \( H \) for black coal is 24000-35000 kJ/kg, \( \varepsilon \) is the overall power plant efficiency. For typical coal power plants this can vary from 25% to 35%. Plant efficiency can change diurnally due to change in loads, thus the time of use at end user influence the resource consumption too. Peak plants, which cannot be operated at the optimum efficiency, then have less efficiency than a base plant which can run at its optimum operating condition throughout the running period, \( \tau \) is the transmission efficiency including all losses from plant to the user. It can vary with network operations. Australian typical network can have range 2% to 8%.

2.1.3 Climate Change Impact Assessment: Climate change impact from supermarket equipment is attributed primarily from emission of greenhouse gases through escape of refrigerant into the atmosphere and indirect emission from energy use. Life Cycle Climate Performance (LCCP) model (UNEP 1999) contains lifelong emission elements of any refrigerant. An alternative version of the LCCP model is adapted in EN378-1-2008 to estimate emission impacts, mainly for the operational life, called Total Equivalent Warming Potential (TEWI). Islam (2010) applied this to a system that has multiple components in the form below.

\[
TEWI = N \sum_j L_j GWP_j + \sum_j m_j (1 - \alpha) GWP_j + N \sum_k E_k \beta
\]

Where,
- \( N \) = Life of equipment, years
- \( GWP_j \) = Global Warming Potential (GWP) of refrigerant \( j \), kg of \( CO_2-e/kg \).
- \( m_j \) = Total mass charge for each refrigerant \( j \), kg.
- \( L_j \) = Leakage rate of refrigerant \( j \), kg/year, or
  \( L_j = m_j l_j \), where, \( l \) is the rate in fraction of the total mass charge per year.
- \( \alpha \) = Refrigerant recovery factor (0-1) as a fraction of total mass charge.
- \( E_k \) = Energy consumption for energy consuming component \( k \), kWh per year. For supermarket, this will be refrigeration plants and air conditioning plants.
- \( \beta \) = Emission factor for electrical energy use, kg \( CO_2-e \) per kWh.
The TEWI method has a critic that engineers are often attempting to reduce the refrigerant charge, \( m_t \) to combat total leakage figure used in the equation \( L_j = m_t l_j \) instead of reducing the leakage rates, \( l_j \). Although reducing charge has its own merit but leakage rate is the core problem of all direct emission. \textit{Whatever the charge is in a system, if there is no leak then there is no direct emission.} Small charge with a leaking system only means that the refilling has to occur more often for the same leak rate. So containment is far more sensible to work on to reduce climate impact of refrigerant use. When comparing two alternatives, this method offset the emission increase due energy use by reduction of direct emission producing a net reduction of TEWI, the decision penalizes the energy resource. When energy use increase is taken good for the entire life of the equipment, the sustainability is demised.

3. SUPERMARKET EQUIPMENT SCENARIOS IN INTEGRATED APPROACH.

3.1 Lowering Store Temperature and Humidity; Separate Walk-in Refrigerated Display Area

It is argued that if store air temperature and humidity is lowered, the refrigeration heat load is lower thus saves energy (Lindberg et al., 2007). This is true but it cannot be used universally. Particularly in buildings that require air cooling and de-humidification (air enthalpy reduction) and have relatively much higher cooling load than refrigeration free cooling \( Q_r \) the total energy spent for lower \( T_e \) of air conditioning plant may well offset the energy saved in refrigeration. It is sensible to prioritize on what gives the most benefit. Lowering the relative humidity in a store can reduce the use of anti-sweat heaters for cabinets that usually sweats without heating. However, it is more sensible to design new generation equipment that requires low or no surface heating, for most energy efficient humidity level.

Separating the refrigerated display area from the mass shopping area that have separate temperature zone can be more sensible than mixing all shopping zones in one conditioned space. Lindberg (2007) discussed the comfort and energy impact of shopper in such shops where shoppers can enter in chilled area for a brief amount of time. It is perceived that shoppers may feel uncomfortable if the refrigerated area is much colder than the other area when they move between the zones. It can be argued that to be sustainable, the way we live can and eventually must change, so accepting the change and adapting to it is a sensible choice. Supermarket owners may also argue that if a shop is less comfortable than the other, it may affect the sale of the former. Sustainability is a socially sensible collaborative effort and over time adaptation will come through other ways such as impact on price due to not being efficient.

3.2 Use of Self-contained (integral) Refrigeration Unit for Display

Self-contained display units are also used in supermarket within the conditioned space for the ease of mobility and re-arrangement for changing merchandising needs and removal from the service when not required. They add heat load to the building cooling system in warmer climate and counted towards \( Q_p \) of the Equation (7). In colder climates where building heating is required predominantly, they reduce heating load. The net heat delivered by the self-contained units is equivalent direct electric heating.

3.3 Self-contained Units with Defrost Water Dissipater Using Electric Heating

Some self-contained units come fitted with defrost water dissipater. The defrost water is collected in a tray and boiled off using electric heaters. This feature avoids connecting to a plumbing point for draining defrosted water. These are highly un-sustainable equipment. For a typical vertical multideck open chilled milk cabinet of 2.0m high and 1.25m wide, and having a total display area (\( TDA \), as per AS1731-2003) of 2.09m², tested in climate class 3 (25°C and 60% RH), the defrost water amount is about 26L/day which when boiled off requires about 22kWh/day of electric energy. The cabinet would require a total 47kWh/day of electric energy including refrigeration. All this energy must be cooled down from the conditioned space by the air conditioner in warmer climate. If we take a typical air conditioning system COP of 2.5, this equates to a store level energy consumption of 66kWh/day (or 31.7kWh/day/m² display). Alternatively water can be pumped to a nearest drain point run either in the ceiling or under the floor. This drain system would use only 26kWh/day (vs 47kWh/day) for refrigeration or 36.4kWh/day (vs 66kWh/day) (or 17.4kWh/day/m² display) store level energy. This means about 81.5% more energy with electric dissipater compared to a pumped system which is thus a sensible choice.

3.4 Refrigeration Equipment Heat Gain from Store, \( Q_r \)
The value $Q_r$, must be reduced to as low as possible, to reduce $E_r$. However, there is a perception that refrigeration heat load also provides free cooling so it is not too bad in warm climates. It is arguable that refrigeration $Te$ is much lower than air conditioning $Te$ therefore, this free cooling is expensive. In low climate period, this cooling basically augments to the heating energy bill. Chen et al. (2007) thus attempted natural free cooling from outdoor air for display cabinets for cold climates.

### 3.5 Open Multideck Display Cabinets

Open multideck refrigerated display cabinets are the most energy intensive refrigeration equipment in supermarket. This can contributes approximately 50%-60% of supermarket refrigeration load. Typically an air-curtain is used to reduce heat ingress and keeping the products cool. Yet, the total heat gain through the air curtain contributes 70% to 80% of the total heat load (Faramarzi, 1999). Some multideck cabinets have lights fitted under the shelf to enhance merchandising. The typical total energy intensity of a lit shelf cabinet, when measured as per AS1731-2003, can be 30% to 40% higher than an unlit shelf cabinet serving same temperature class.

The angle of shelves can increase energy intensity by 15% compared to horizontal shelf in vertical cabinets. This is due to increased turbulence in the air curtain induced by the angled shelf. However, it is found that for shorter cabinets (less than 1.4m), called semi-vertical cabinets, with angled shelf set in parallel to the diagonal and low turbulent air curtain reduces heat ingress significantly. Total energy intensity of semi vertical cabinets can be around 20% based on per m² display area (or 49% based on occupied floor area) lower than corresponding 2.0m high cabinet. From merchandising point of view, semi vertical cabinets, being lower in height, are also desired to give an open view of the shopping floor. Experience also suggests that a properly designed horizontal air curtain cabinet with products laid on tub style display reduces the heat ingress significantly. Some new generation open horizontal display cabinets (remote type) have energy intensity as low as 3.3kWh/m²/day which is 75% based on display area (or 88% based on occupied floor area) lower than a 2.0m high cabinet.

Table 1 summarizes a comparison of energy intensity of cabinets of different profiles of open chilled cabinets which have the same use. It is sensible to say that use horizontal tub display instead of multidecks is a better sustainable choice. Additional products can be stored in closed cool room nearest to the display area for easy loading and unloading. The least usability of the top shelves on 2.0m cabinets make it less unsustainable.

#### Table 1: Energy intensity comparison of different style of cabinet for similar function

<table>
<thead>
<tr>
<th>Type</th>
<th>Vertical 2.0m lit</th>
<th>Semi-vertical 1.2m lit</th>
<th>Horizontal 0.9m high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length 3.75m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp Class: 3M1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$TEC$</td>
<td>86.85 kWh/day</td>
<td>44.71 kWh/day</td>
<td>19.41 kWh/day</td>
</tr>
<tr>
<td>$TDA$</td>
<td>6.527 m²</td>
<td>4.268 m²</td>
<td>5.918 m²</td>
</tr>
<tr>
<td>$TEC/TDA$</td>
<td>13.31 KWh/d/m²</td>
<td>10.47KWh/d/m²</td>
<td>3.28 KWh/d/m²</td>
</tr>
<tr>
<td>$FP$</td>
<td>3.70 m²</td>
<td>3.70 m²</td>
<td>6.87 m²</td>
</tr>
<tr>
<td>$TEC/FP$</td>
<td>23.48 KWh/d/m²</td>
<td>12.09 KWh/d/m²</td>
<td>2.78 KWh/d/m²</td>
</tr>
</tbody>
</table>

$TEC = \text{Total Energy Consumption}$ & $TDA = \text{Total Display Area (AS1731-2003)}$ & $FP = \text{Foot Print, m}^2$

In the past, dual air curtain technology has been used in open multideck cabinets to reduce product temperature but found costing additional energy due to increased heat ingress. Recent symmetric rear peak flow dual air curtain found reduced heat ingress by about 20% in a 2.0m high open multideck unit-shelf cabinet compared to the same cabinet with single curtain. The external curtain is re-circulated around the outer boundary of the cabinet. The Figure 2 depicts the air velocity contour of the symmetric flow dual air curtain.
Use of doors in the new generation of open multideck display cabinets became an industry good practice recently. It has been reported by Faramarzi et.al (2002) that 70% energy ingress reduction is possible and there has not been any loss of sale by applying doors in a trial supermarket in USA. Lindberg et al. (2010) found a 60% energy savings in real store in Sweden. Austral Refrigeration Pty Ltd has retro-fitted doors in a supermarket store in NSW, Australia in 2010 and it was found that 80% reduction of total energy for the entire line of cabinet was achieved compared to the baseline open cabinet. These cabinets were optimized for internal air flow and minimized door heating.

Adding doors on open cabinet also help in reducing cold isle or cold feet. The isle temperature was increased by about 3°C to 4°C. In many stores, cold isles are reduced by mechanical extraction or forced warm air circulation which put additional energy to the store and can degrade the cabinet temperature and energy performance.

3.6 Retrofitting Energy Efficient Component in Display Cabinets
Recently, supermarkets’ energy efficiency projects retrofitted individual components such as replacing less efficient fan motors with Electronically Commutated Motors (ECM), fitting night covers, applying efficient lighting and anti-sweat heater control. In relation to fan motor change in open cabinets, serious consideration must be taken so that the air flow pattern and air velocity are not altered to a point that increases air turbulence or infiltration. This may increase refrigeration energy consumption significantly, offsetting direct benefits of the change.

3.7 Cascade Refrigeration System
In the recent times, cascade systems with two refrigerant circuits with two different fluids separated by a heat exchanger are used in supermarket refrigeration. The loss of energy efficiency due to the temperature drop at the cascade heat exchanger can cost energy by 20% more than typical single fluid system.

3.8 Secondary or Indirect Refrigeration System
Indirect refrigeration is a method where a single phase fluid is cooled down by a refrigeration plant and the cool fluid is circulated throughout the supermarket stores. Indirect refrigeration have additional energy consumption for pumping, line heat gain, and lower evaporating temperature plant due to temperature drop at the inter-fluid heat exchanger. Two Australian supermarket trials have proven that energy increase between 8% and 15% is possible. Some latest systems used primary ammonia plant and optimized defrosting to make energy neutral or negative.

3.9 Refrigerant Choice and Leakage Rate
Recently low GWP refrigerants are targeted to replace high GWP HFC and HCFC refrigerants due to their direct emission impact. Although it is essential that low GWP refrigerants are used for sustainability, but million tons of existing high GWP refrigerant are already in use. Therefore, the effort of leakage reduction from existing systems is extremely essential and sensible. It is also argues that due to embodied energy and emission from production, transportation and end use of any fluid, low or high GWP, leakage reduction must be prioritized. In Europe the leakage rate is claimed to be around 5% and targeted to reduce even more. According to supermarket maintenance data, the average leakage rate could vary from 15%pa to 20%pa in Australia. Rhimeier, et al. (2009) has presented possible leakage rates from different components used in supermarket refrigeration in Germany.

Islam (2010) has investigated few possible refrigeration system alternatives by statistical simulation method to determine optimum TEWI for uncertainties in refrigerant leakage and energy use data. R404A direct expansion system scenario has the highest sensitivity to leak rate because of highest GWP value. However at leak rate nearly less than 4.5%pa, this system is better choice than a CO2 cascade plant with R134a high stage system with liquid recirculation of medium temperature cabinets and low temperature direct expansion system judging on mean TEWI values. Applying doors on open multideck cabinet exceeds any of commonly used systems using CO2 as refrigeration at any leak rate. For any particular leakage rate the TEWI estimate becomes very sensitive to accuracy of energy estimate above approximately 4% for five scenarios studied. Higher the uncertainty of energy estimates, the more the technology selection based on TEWI becomes unreliable.

3.10 Cutting the Refrigeration Load and Store Operating Hours
The large supermarket stores have long runs of freezer, open multideck and deli cabinets. A long run of cabinets provides a kind of storage of foods; creates a wide view of product line and offers a less density shopping comfort. Keeping the sustainability in mind, it is obviously a sensible choice to review and reduce the total cabinet line length which would give reasonable usefulness. The refrigeration cabinet line length also has relation to expected shopper traffic and subsequently to trading hours. Longer trading hour may mean lesser traffic but it also has negative energy impact. A compromise between the trading hours and refrigeration line length is a good sustainable consideration.

3.11 Working with Reducing Op, the Store Heat Generation Due to Processes
Amongst the key elements of processes, the heat that has escaped into the conditioned space from the hot food display, in-store ovens, water heating and use of other electrical equipment, can be significant. Recently “grab and go” hot food cabinets are made with open top. This practice is very unsustainable. Table 3 below demonstrates the difference in store level total energy consumption from an open self-serve type and a closed type hot food cabinet situated in a conditioned space. A nominal COP of 2.5 was assumed for the air conditioning system.

<table>
<thead>
<tr>
<th>Enclosed hot food cabinet 1836mm</th>
<th>Self serve gravity air open hot food cabinet 1575mm</th>
<th>Self serve open forced air hot food cabinet 1836mm</th>
</tr>
</thead>
</table>

Table 3: Hot Food Cabinet Energy Consumption Comparison (maintaining 60°C)
When such open hot food cabinets are placed beside an open chilled cabinet, the operation of each equipment counteract the other leading to significant increase of store level energy use. Thus, the new generation sustainable hot display cabinets must be enclosed. Similarly for other essential processes, it is desirable to minimize heat escape into the conditioned space, recover the waste heat \((Q_{pw})\) and install energy efficient equipment.

### 3.12 Lighting- Dealing with \(E_l\)

Lighting is one of the major contributors to store energy consumption (15%-25% of total store energy, taking from various sources). In some areas of supermarket stores, it has been found to have 1000-1500lux compared to 500-700lux that should be enough for safety and display. Additional beam lighting over the chilled display often counters the energy performance and product quality of the display cabinets. New technologies such as the use of T5 lights with electronic ballast and LED lights are becoming more popular. However, reducing the level of lighting and designing building structure to bring natural sunlight during the day is going to add another step towards the next generation store sustainability.

### 3.13 Targeting Lowest Evaporating Temperature Refrigeration Device for Review

Looking at the integrated energy Equation (7) and its dependence to evaporating temperature, \(T_e\), of the refrigeration plant one would determine that lowest evaporating temperature of the entire group of the cabinets served by that rack should be lifted. It is wiser to review design, selection or even removal of the lowest evaporating temperature cabinet from the group served by the rack.

### 3.14 Lowering Condensing Temperature, \(T_c\)

It is again clear from the integrated energy Equation (7) that the lowering condensing temperature, \(T_c\), is an obvious choice for reducing the energy impact. There are various ways this can be achieved. Reducing the temperature differential against the condenser, balanced air flow, taking advantage of evaporative cooling, floating plant high side pressure with ambient temperature by taking advantage of cooler period of daily and seasonal weather variation etc. are very common methods of designing and operating the system. Regular maintenance is also important to maintain the best design operating condition throughout its life. It is important to keep track of energy impact of any change of equipment, control strategy or maintenance plan.

### 3.15 Refrigeration Heat Recovery in Reducing \(Q_b\)

It is quite a common practice to use part or full of de-superheating or condensing heat rejection from the refrigeration plant for building heating in cooler weather. The potential for actual energy benefit is dependent upon energy optimum tradeoff between the refrigeration plant condensing temperature selection and the alternative heating options. It cannot be taken as given that heat recovery by full condensing with keeping condensing temperature higher is always net energy efficient. Use of de-superheating coils built in the air intake side of air handling unit is a safer option. Benefit is climate dependent. Royal (2010) shown that Minneapolis, a city in northern USA, has 3.6 times more energy savings benefit than Houston in southern USA by using heat recovery for building heating.

### 3.16 Working with \(Q_b\)- Building Design

Building architectural design can make a significant difference in reducing the heating and cooling load of the original building alone excluding refrigeration, processes, lighting etc. but including conduction, radiation, infiltration and ventilation etc. This topic is left out of the current discussion.

### 3.17 Working with \(E_r\)

There are a number of parasitic devices used in a building environment. Potential of energy saving can be there with plant room ventilation, use of pumps, solenoids etc. As an example, a normally- closed solenoid is kept energized...
for the entire period of refrigeration and stopped only for the duration of defrost in a refrigerated display cabinet. It is estimated that in a medium size store having 20 solenoids with 20W energizing coil, the yearly energy consumption could be about 3,060 kWh, in contrary to a normally-open solenoid which consume 440 kWh/year.

3.18 Working with Actual System Performance Factor, \( F \), in Comparison to Ideal Cycle

High design load factor or plant over sizing is found to be energy inefficient. In Australian supermarkets, the refrigeration plants are designed for the highest possible ambient temperature to ensure display functions are not hampered during those possible peak days. It was found that combining load safety factor and ambient temperature factor total system size becomes quite large which almost 90% of the time runs between 40-50% of the capacity. Younes (2006) suggests that oversized air conditioning plants can consume energy in excess of 20% more than an appropriately sized plant in retail buildings. Refrigeration plants would have similar consequences. Various methods can be applied to cope with the supplying peak demand for food safety and improving efficiency. Among those common methods, keeping a separate peak plant or use of modular small plants each doing a rotational duty at the good performance points, use of inverter technology combined with compressors and motors, which can be controlled with wide load range such as use of digital scroll, EC motors for fans etc. Electronic pressure and temperature control can also help to achieve the good plant performance points in coping with varying loads. Reducing line losses, including thermal and pressure losses improves system performance. Good insulation and appropriate pipe sizing is a key to achieving this objective. Reducing hunting in plant and expansion device operation can save energy as good as 15%.

3.19 Energy Generations in Supermarket (\( E_g \))

Alternative energy technologies, such as Combined Cooling Heat and Power (CCHP) and renewable energy technology such as roof top solar photovoltaic (PV) system can be used to generate local power. Maidment and Tozer (2001), suggested that a primary energy resource reduction of about 15% is possible by producing cooling, heating and power using CCHP technology in supermarkets based on simulating a 5000m² store in UK climate. Assuming a 60% of 1500m² roof above a supermarket is free for solar PV system installation without shading in Sydney climate. Using north facing arrays, the potential energy production can be 189MWh/year with an annual average of 518kWh/day for a 124kW solar PV system. Estimated system cost can be under $260,000 and can generate revenue of $37,500 per annum from feed-in-tariff at $0.20/kWh nominal. Such a system can reduce \( \text{CO}_2 \)-e emission by about 202 tons/year considering greenhouse gas factor of 1.07 for NSW at the time of this publication. Anticipated carbon tax offset can be about $4,650/year or a potential large scale renewable energy generation certificate valued at $7,500/year (depending upon regulatory changes).

4. CONCLUSIONS

Supermarkets are an integral part of modern living but they also became a resource and environmental burden to the current and future human existence. This article was mainly focused on elaborating on core values of sustainability in supermarkets. It is important that the integrated approach must be taken into consideration then a sensitivity analysis is to be performed to optimize sustainability goals. Technological, socio-cultural and behavioral facets are connected to environmental and energy resource impact. Though it is a good practice to offer sustainability solutions on individual components of the whole body of supermarkets, but the integrated approach can ensure that one sustainability measures do not oppose another sustainability measure. While we focus on climate change, we must not compromise reducing energy resource depletion, usefulness and safety to human due to application of any alternative practices. Even if it meant that we must change our way of life, then so be it, so we secure a longer term equitable future for coming generations. This article has drawn upon alternative technological options available today and questioned if any more can be done to limit the use of energy by accepting some changes in our comfort shopping at supermarket. It has been demonstrated that simple and sensible things can make a significant difference.

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