Assessment of total equivalent warming impact (TEWI) of supermarket refrigeration systems

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**Abstract**

Refrigeration system of supermarket applications significantly contributes to direct and indirect global warming. The aim of this paper is to present a methodology of assessing such systems in terms of refrigerants, machinery and operational protocol to minimize the total equivalent warming impact (TEWI). Another perspective is painted for the refrigeration industry to ameliorate environmental impact. Air-cooled refrigeration system is analyzed for low temperature (LT) evaporation at $-20\,^\circ C$ and medium temperature one (MT) at $0\,^\circ C$ with condensation at $40\,^\circ C$. The effects of suction superheat and subcooling have also been accounted for. Various refrigerants such as HFC 134a, HFC blend 507A and their combinations are considered as working fluids for catering to a LT load of 50 kW and MT load of 250 kW. It is observed that HFC 134a for LT and MT gives the best combination. In addition, the impacts of COP on the TEWI for transcritical CO\textsubscript{2} systems were also estimated. Based on our results, HFC blend 507A refrigerants have the highest TEWI along with the maximum economic loss. Transcritical CO\textsubscript{2} refrigeration system with conceivably higher COP in the operating conditions are found to be the best from the TEWI perspectives with minimum economic loss due to refrigerant leakage because of its abundance availability.

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**Introduction**

Shopping malls are highly energy-intensive commercial buildings, as a result of huge heating, air conditioning and refrigeration demands [1,2]. In particular, supermarkets have played a key role not only in even food distribution but also in reduction of wastage and enhancing food security. This sector is subjected to tight controls and is also continuously monitored for legislative compliances as well [3,4]. In the US, a typical...
supermarkets with approximately 3700–5600 m² of sales area consumes about 2–3 GW h of electricity annually [5]. In the case of Japan also, energy usage pattern is almost the same because the hardware used there in (e.g. compressors, condensers, evaporators and expansion valves) and refrigerants adopted are more or less the same. The electricity used for driving compressors [6] is predominantly derived from fossil fuel- (such as coal, natural gas) based power plants [7] which primarily release global warming gases like CO₂. Although alternative electricity generations such as nuclear, solar, windmill etc. are free from such encumbrance, their contribution to the grid is small [8]. Global warming potential (GWP) arising due to electricity consumed on site is considered as indirect emission [2,9,10]. Currently, global per capita CO₂ equivalent emission has been estimated to be 1.1 t/year [11–13] which can be abated by sourcing clean energy such as hydrogen [14–16]. Fuel cell, perhaps, a farfetched futuristic source can be constructed to be an avenue for supermarket refrigeration. In order to clarify the advantages of fuel cell based refrigeration systems for supermarket applications, it is inevitable to assess the environmental impacts of the current refrigeration systems. In the case of supermarkets, a more serious source of emissions is the refrigerant leakage. Rightly, its impact is regarded as direct emission of global warming gases [1,17,18]. Current levels of leakage are around 10–15% of stock on site per year [19], most of which is held on the high pressure side of the system. It is also necessary to emphasize that the fluorocarbon refrigerants currently in vogue leverage that impact by factors a few 1000's. Logically, the environmental performance indicator for a supermarket must be assessed through the total equivalent warming impact (TEWI) which is the sum of direct and indirect emissions [20]. From the above perspectives, the present paper analyzes the total equivalent warming impact (TEWI) for supermarket refrigeration systems using various refrigerants including the combinations of most commonly used refrigerants such as HFCs and HFC blends. Two manufacturers for compressors and refrigeration systems are selected for the analysis and here we will refer them as manufacturer X and Y. These data are useful in determining the compulsion of futuristic fuel cell based supermarket refrigeration systems which will be the answer towards world’s irresistible need for efficient and environmentally benign technologies.

### Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>COP</td>
<td>coefficient of performance</td>
</tr>
<tr>
<td>( E_a )</td>
<td>energy consumption, kWh per annum</td>
</tr>
<tr>
<td>( D )</td>
<td>piston bore, m</td>
</tr>
<tr>
<td>eq</td>
<td>equivalent</td>
</tr>
<tr>
<td>GWh</td>
<td>giga watt hour</td>
</tr>
<tr>
<td>GWP</td>
<td>global warming potential (100 years integration)</td>
</tr>
<tr>
<td>( h )</td>
<td>specific enthalpy, ( \text{kJ kg}^{-1} )</td>
</tr>
<tr>
<td>( L )</td>
<td>piston stroke length, m</td>
</tr>
<tr>
<td>( L_a )</td>
<td>leakage rate per annum, kg</td>
</tr>
<tr>
<td>( LT )</td>
<td>low temperature</td>
</tr>
<tr>
<td>( m )</td>
<td>mass flow rate, ( \text{kg s}^{-1} )</td>
</tr>
<tr>
<td>( MT )</td>
<td>medium temperature</td>
</tr>
<tr>
<td>( N )</td>
<td>compressor speed, ( \text{s}^{-1} )</td>
</tr>
<tr>
<td>( n )</td>
<td>number of years</td>
</tr>
<tr>
<td>( p )</td>
<td>pressure, ( \text{bar} )</td>
</tr>
<tr>
<td>( P )</td>
<td>power, ( \text{kW} )</td>
</tr>
<tr>
<td>( Q )</td>
<td>cooling load, ( \text{kW} )</td>
</tr>
<tr>
<td>( S )</td>
<td>entropy, ( \text{kJ kg}^{-1} \text{K}^{-1} )</td>
</tr>
<tr>
<td>( t )</td>
<td>tonne</td>
</tr>
<tr>
<td>( T )</td>
<td>temperature, ( \text{°C} )</td>
</tr>
<tr>
<td>( \text{TEWI} )</td>
<td>total equivalent warming impact, ( \text{t eq CO}_2/\text{year} )</td>
</tr>
<tr>
<td>( Z )</td>
<td>number of cylinders</td>
</tr>
</tbody>
</table>

**Greek symbols**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta )</td>
<td>( \text{CO}_2 ) emission for per kWh electricity generation, ( \text{kg eq CO}_2/\text{kWh} )</td>
</tr>
<tr>
<td>( \Delta )</td>
<td>difference</td>
</tr>
<tr>
<td>( \eta )</td>
<td>efficiency of compressor, %</td>
</tr>
<tr>
<td>( \rho )</td>
<td>density, ( \text{kg m}^{-3} )</td>
</tr>
</tbody>
</table>

**Subscripts**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c )</td>
<td>compressor</td>
</tr>
<tr>
<td>( \text{cond} )</td>
<td>condenser</td>
</tr>
<tr>
<td>( e )</td>
<td>evaporator</td>
</tr>
<tr>
<td>( \text{evap} )</td>
<td>evaporator</td>
</tr>
</tbody>
</table>

1–4', \( a–d' \) states in refrigeration cycle

### Assessment procedure

#### System description

A typical super market refrigeration system is shown in Fig. 1 which has several display cases for various refrigerated items such as vegetables, fish, meat, beverage, ice-cream. Each case is serviced by a separate evaporator. Compressor racks are housed in a plant room and the condensers are normally located on the roof.

Liquid refrigerant from the condenser is often stored in a receiver. Obviously, liquid refrigerant flows a long distance from the plant room to the expansion valve which is located close to the evaporator. Analogously, the vapour refrigerant also travels such distances to return the compressor. Separate compressor racks are used for servicing LT and MT display cases because they operate at significantly different evaporating temperatures (e.g. \( -20 \)°C or \( 0 \)°C).

#### TEWI definition

TEWI is the sum of direct and indirect GWP discharged from a system. The following equation is used for the assessment of TEWI [21]:

\[
\text{TEWI} = (\text{GWP} \times L_a \times n) + (E_a \times \beta \times n)
\] (1)

#### Problem statement and assumptions

The following table (Table 1) lists the criteria used for assessment of TEWI:

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