A Quantitative Approach to Analyze Total Equivalent Warming Impact (TEWI) for Supermarket Refrigeration System in Japan

Islam, Md. Amirul
International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University | Kyushu University Program for Leading Graduate School, Green Asia Education Center, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University | Bangabandhu Sheikh Mujibur Rahman Science & Technology University

Mitra, Sourav
International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University

Thu, Kyaw
International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University | Kyushu University Program for Leading Graduate School, Green Asia Education Center, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

Saha, Bidyut Baran
International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University | Kyushu University Program for Leading Graduate School, Green Asia Education Center, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

https://doi.org/10.15017/1906165

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 3, pp.97-100, 2017-10-19. Interdisciplinary Graduate School of Engineering Sciences, Kyushu University
バージョン：
権利関係：

A Quantitative Approach to Analyze Total Equivalent Warming Impact (TEWI) for Supermarket Refrigeration System in Japan

Md. Amirul Islam[1,2,4], Sourav Mitra[1], Kyaw Thu[1,2], Bidyut Baran Saha[1,3,*]

[1] International Institute for Carbon-Neutral Energy Research (WPI-I^{2}CNER), Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan
[2] Kyushu University Program for Leading Graduate School, Green Asia Education Center, Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Kasuga-koen 6-1, Kasuga-shi, Fukuoka 816-8580, Japan
[3] Mechanical Engineering Department, Graduate School of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan
[4] Bangabandhu Sheikh Mujibur Rahman Science & Technology University, Gopalganj 8100, Bangladesh
[*] Corresponding author email: saha.baran.bidyut.213@m.kyushu-u.ac.jp

Abstract: *Refrigeration system for supermarket applications significantly contributes to direct and indirect global warming. The aim of this analysis 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). Air-cooled refrigeration system is analyzed for low temperature (LT) evaporation (–20°C) and medium temperature (MT) evaporation (0°C) with condensation at 40°C. The effects of suction superheat and subcooling have also been accounted for. Various refrigerants such as HFC 134a, HFC blend 410A, HFO 1234yf and CO_2 are considered as working fluids for catering to a LT load of 50 kW and MT load of 250 kW. TEWI have been assessed and compared for these refrigerants and their combinations. A quantitative analysis of economic loss due to refrigerant leakage has also been performed.*

Keywords: environmental impact; GWP; HFC; HFO, transcritical carbon dioxide.

1. INTRODUCTION

Air conditioning, heating and refrigeration demands of supermarkets are the primary reasons of extensive energy consumption of the world [1,2]. A typical 3700-5600 m^2 supermarket of sales area consumes about 2-3 GWh of electricity annually [3]. The electricity used for driving cooling system [4] is predominantly derived from fossil fuel- (such as coal, natural gas) based power plants [5] which primarily release global warming gases like CO_2. Although alternative electricity generations such as nuclear, solar, windmill etc. are free from such encumbrance, their contribution to the grid is small [6]. GWP arising due to electricity consumed on site is considered as indirect emission [2,7,8]. 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 [1,9,10]. Current levels of leakage are around 10-15% of stock on site per year [11]. 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 [12]. From the above perspectives, the present study analyzes TEWI for supermarket refrigeration systems using various refrigerants including most commonly used HFCs, potential futuristic HFO refrigerant and low GWP natural refrigerant.

2. ASSESSMENT PROCEDURE

A typical super market refrigeration system 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. TEWI is the sum of direct and indirect GWP discharged from a system. The following equation is used for the assessment of TEWI [13]:

$$TEWI = (GWP \times L_a \times n) + (E_a \times \beta \times n) \quad ....(1)$$

Table 1. Problem statement and assumptions

MT cooling load (T_{evap} = 0°C)	250 kW
LT cooling load (T_{evap}= –20°C)	50 kW
Condensation (T_{con}) /gas cooler outlet temperature	40°C
Suction gas superheat (K)	10 K
Liquid subcooling (K)	10 K
Operation time (hours/day)	6 hours/day
Refrigerants	HFC 134a, HFC blend 410A, HFO 1234yf, CO_2
GWP values for refrigerant Leakage (kg eq CO_2/kg)	1300 (HFC 134a), 2088 (HFC blend 410A), 4 (HFO 1234yf), 1 (CO_2) [14–18]
Percentage of leakage from initially charged amount per year	10% for HFC 134a and HFO 1234yf, 12% for HFC blend 410A, 15% for CO_2
GWP for electricity production in Japan (kg eq CO_2/kWhr)	0.571 [19,20]
Initial refrigerant charging amount (kg)	2 kg for per kW cooling load [21]
Refrigerant price ($/kg)	HFC 134a ›› 15; HFC blend 410A ›› 16; R1234yf ›› 150; CO_2 ›› 2 ($/kg) [22,18]

RESULTS AND DISCUSSION

The P-h diagram and refrigeration cycle of HFC 134a compressor operation modes are shown in Fig. 1. The diagrams have been produced based on the manufacturer's data sheet and thermophysical properties of the refrigerants obtained from REFPROP v.9.1 [30]. A practical supermarket refrigeration system invariably has suction gas superheating as the vapour flows from cases to the compressor and also require adequate liquid subcooling to avoid flashing of refrigerant between the receiver in the plant room and the expansion valve. These collateral issues cause an increase of the electricity consumption which can be calculated from the manufacturers' data sheets. This electricity production contributes to the global warming indirectly.

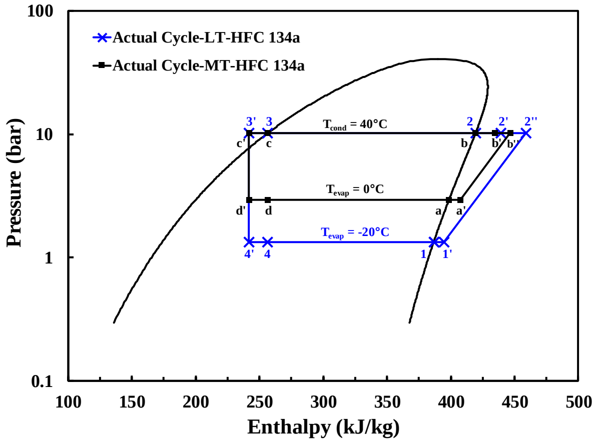

Fig. 1: P-h diagram of refrigeration cycles with suction gas superheating and liquid subcooling for HFC 134a for LT and MT; 4'-1 or d'-a: evaporation; 1-1' or a-a': suction superheating; and 1'-2'' or a'-b'': compression; 2''-3 or b''-c: condensation; 3-3' or c-c': liquid subcooling; 3'-4' or c'-d': expansion

Indirect emission and direct emission have been calculated and combined to get the total equivalent warming impact which is depicted in Fig. 2. Evidently, HFCs have highest direct emission due to high GWP values. On the other hand, direct emission of HFO 1234yf and CO_2 is negligible. However, indirect emission for CO_2 system is highest because it operates in transcritical state and consumes more electricity than the other refrigerants. Apparently, HFC blend 410A compressors originates highest and HFO1234yf compressors have the lowest TEWI.

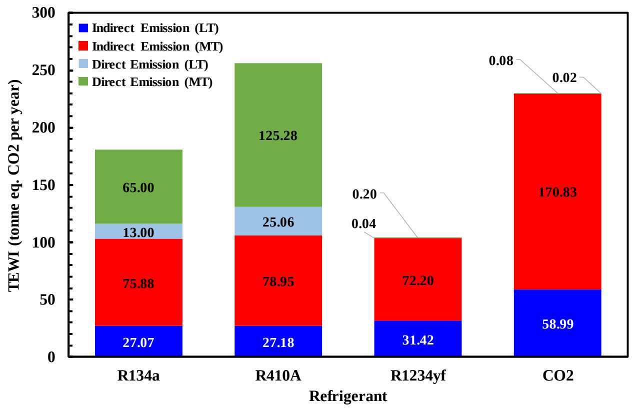

Fig. 2: TEWI for various refrigerants

The economic loss due to the refrigerant leakage per annum is shown in Fig. 3. HFO 1234yf is a relatively new refrigerant and much costlier than the other refrigerants. Thus economic loss to refill HFO 1234yf system is much higher than other refrigerants. HFC refrigerants leakage loss is moderate and comparable. On the other hand, CO_2 is much cheaper and economic loss is also much lower.

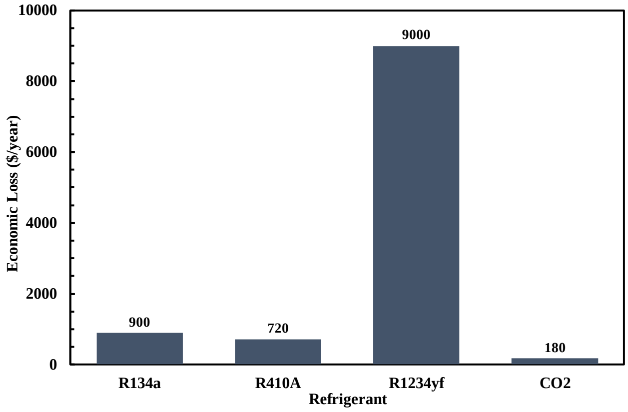

Fig. 3: Economic loss per year due to refrigerant leakage

TEWI calculations were supplemented with apportion of power distribution at various sections of the compressor-motor ensemble. Power distribution on various section of the compressor is depicted in fig. 4.

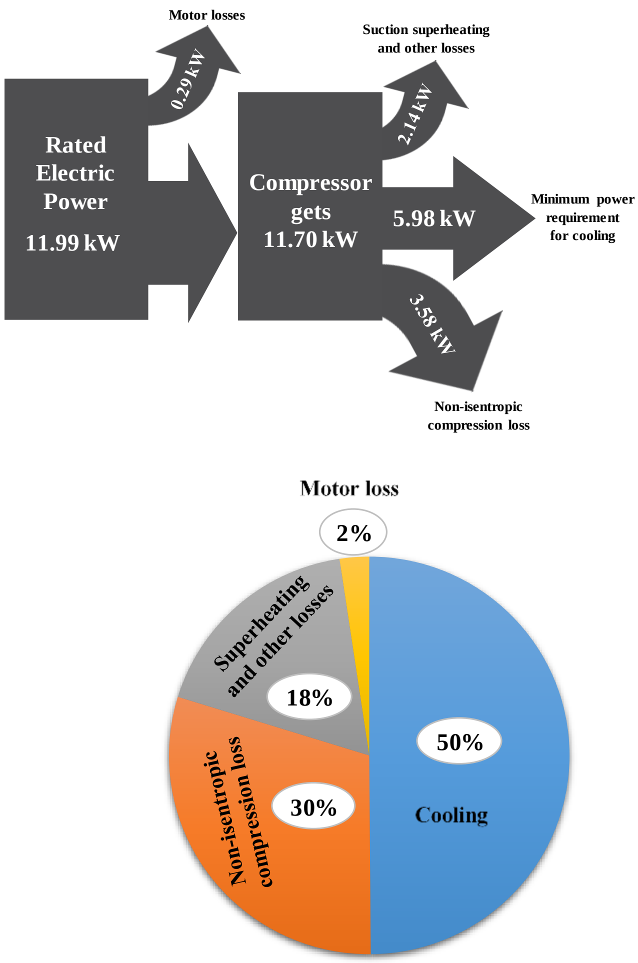

Fig. 4: Power distribution of a 27.7 kW (LT) compressor with HFC 134a refrigerant.

Most commercial compressors are semi-hermetic direct drive types. Power consumption for various operating conditions can be obtained from manufacturers' data sheets. Apportioning of losses is done on following basis:

a) Losses in motor due to windage, friction and heating of windings
b) Losses in compressor due to pressure drops across reed valves, non-isentropic compression (friction and heating)
c) Losses arising out of suction gas superheating

The general equation for calculating the power input can be written as:

$$P = \dot{m} \times \Delta h \quad \ldots\ldots\ldots\ldots (2)$$

Where Δh can be calculated using inlet and outlet enthalpies of operating conditions such as superheat, without superheat, isentropic and non-isentropic compression.

3. CONCLUSION

TEWI assessments have been conducted for supermarket refrigeration system using HFC 134a, HFC blend 410A, HFO 1234yf and CO_2 refrigerants for LT and MT cooling loads. HFO 1234yf compressors for MT and LT have the lowest TEWI because of low GWP value and high COP in the operating condiotions. HFC blend 410A compressors/chillers for both LT and MT have the highest TEWI. However, economic loss due to refrigerant leakage is maximum for HFO 1234yf system because the refrigerant is relatively new and expensive. On the otherhand, loss is minimum for CO_2 system because of the abundance availability. Thus, CO_2 compressors with conceivably high COP can be an appropriate substitute of HFC compressors in the future. Another alternative could be HFO mixtures. Since HFO 1234yf is flammable and expensive, binary mixture of HFO 1234yf with relatively low GWP and lower price refrigerant such as R32 can be a promising alternative of supermarket refrigeration systems. Since an enormous amount of energy (2-3 GWh annually) is utilized in a supermarket refrigeration system using refrigerants such as HFC 134a, HFC blend 410A, HFO 1234yf, CO_2 etc. with high TEWI, the contribution to the global warming by this industry is rather significant. Clean technology such as solar, wind, hydroelectricity or fuel cell is crucial to avoid this colossal indirect emission.

4. REFERENCE

[1] C. Francis, G. Maidment, G. Davies, An investigation of refrigerant leakage in commercial refrigeration, Int. J. Refrig. 74 (2017) 10–19. doi:10.1016/j.ijrefrig.2016.10.009.

[2] A. Mota-Babiloni, J. Navarro-Esbrí, Á. Barragán-Cervera, F. Molés, B. Peris, G. Verdú, Commercial refrigeration – An overview of current status, Int. J. Refrig. 57 (2015) 186–196. doi:10.1016/j.ijrefrig.2015.04.013.

[3] M.A. Marimón, J. Arias, P. Lundqvist, J.C. Bruno, A. Coronas, Integration of trigeneration in an indirect cascade refrigeration system in supermarkets, Energy Build. 43 (2011) 1427–1434. doi:10.1016/j.enbuild.2011.02.003.

[4] M.A. Alzoubi, T. Zhang, Characterization of Energy Efficient Vapor Compression Cycle Prototype with a Linear Compressor, Energy Procedia. 75 (2015) 3253–3258. doi:10.1016/j.egypro.2015.07.695.

[5] A. Cherp, V. Vinichenko, J. Jewell, M. Suzuki, M. Antal, Comparing electricity transitions: A historical analysis of nuclear, wind and solar power in Germany and Japan, Energy Policy. 101 (2016) 612–628. doi:10.1016/j.enpol.2016.10.044.

[6] N. Nomura, M. Akai, Willingness to pay for green electricity in Japan as estimated through contingent valuation method, Appl. Energy. 78 (2004) 453–463. doi:10.1016/j.apenergy.2003.10.001.

[7] M. Beshr, V. Aute, V. Sharma, O. Abdelaziz, B. Fricke, R. Radermacher, A comparative study on the environmental impact of supermarket refrigeration systems using low GWP refrigerants, Int. J. Refrig. 56 (2015) 154–164. doi:10.1016/j.ijrefrig.2015.03.025.

[8] S. Acha, Y. Du, N. Shah, Enhancing energy efficiency in supermarket refrigeration systems through a robust energy performance indicator, Int. J. Refrig. 64 (2016) 40–50. doi:10.1016/j.ijrefrig.2015.12.003.

[9] J.L. Gasche, T. Andreotti, C.R.M. Maia, A model to predict R134a refrigerant leakage through the radial clearance of rolling piston compressors, Int. J. Refrig. 35 (2012) 2223–2232. doi:10.1016/j.ijrefrig.2012.07.015.

[10] Y.T. Ge, S.A. Tassou, Performance evaluation and optimal design of supermarket refrigeration systems with supermarket model "superSim", Part I: Model description and validation, Int. J. Refrig. 34 (2011) 527–539. doi:10.1016/j.ijrefrig.2010.11.010.

[11] C. Sanz-Kock, R. Llopis, D. Sánchez, R. Cabello, E. Torrella, Experimental evaluation of a R134a/CO2 cascade refrigeration plant, Appl. Therm. Eng. 73 (2014) 39–48. doi:10.1016/j.applthermaleng.2014.07.041.

[12] P. Makhnatch, R. Khodabandeh, The Role of Environmental Metrics (GWP, TEWI, LCCP) in the Selection Of Low GWP Refrigerant, Energy Procedia. 61 (2014) 2460–2463. doi:10.1016/j.egypro.2014.12.023.

[13] T. Grof, Greening of Industry under the Montreal Protocol, United Nations Industrial Development Organization (UNIDO), (2009) 30.

[14] D.Q. T.F. Stocker, P.M. G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, M. (Eds.), Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013, 2013. doi:http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf.

[15] L. Vaitkus, V. Dagilis, Analysis of alternatives to high GWP refrigerants for eutectic refrigerating systems, Int. J. Refrig. (2017). doi:10.1016/j.ijrefrig.2017.01.024.

[16] J.M. Mendoza-Miranda, A. Mota-Babiloni, J. Navarro-Esbrí, Evaluation of R448A and R450A

as low-GWP alternatives for R404A and R134a using a micro-fin tube evaporator model, Appl. Therm. Eng. 98 (2016) 330–339. doi:10.1016/j.applthermaleng.2015.12.064.

[17] G. Lorentzen, The use of natural refrigerants: a complete solution to the CFC/HCFC predicament, Int. J. Refrig. 18 (1995) 190–197. doi:10.1016/0140-7007(94)00001-E.

[18] J.C. Thermodynamics, H. Hashemi, S. Babaee, A.H. Mohammadi, P. Naidoo, D. Ramjugernath, Experimental study and modeling of the kinetics of refrigerant hydrate formation, J. Chem. Thermodyn. 82 (2015) 47–52. doi:10.1016/j.jct.2014.10.017.

[19] M. Akai, CCS Activities and Support by Japan:, 2016. https://d2oc0ihd6a5bt.cloudfront.net/wp-content/uploads/sites/837/2016/03/160606_Akai-1.pdf.

[20] K. Sakai, Japan ' s Greenhouse Gas (GHG) Inventories and Related, in: IPCC Open Symp., 2013. http://www.iges.or.jp/files/research/alliges/pdf/20131210/7_Kohei Sakai_E.pdf.

[21] Refrigerant Charge Reduction in Refrigerating Sytems, Internatio (2014). http://www.iifiir.org/userfiles/file/publications/notes/NoteTech_25_EN.pdf (accessed April 11, 2017).

[22] A. Da Silva, E.P. Bandarra Filho, A.H.P. Antunes, Comparison of a R744 cascade refrigeration system with R404A and R22 conventional systems for supermarkets, Appl. Therm. Eng. 41 (2012) 30–35. doi:10.1016/j.applthermaleng.2011.12.019.