Mühendis ve Makina / Engineer and Machinery
https://dergipark.org.tr/tr/pub/muhendismakina

A REVIEW ON COMMERCIAL REFRIGERATOR: THE EFFECT OF LOADING PACKAGES WITH DIFFERENT MATERIALS AND SHAPES ON ENERGY CONSUMPTION AND PERFORMANCE

Hakan TAVUKÇU[1*], Bora DEVRİM[2], Harun Kemal ÖZTÜRK[3]

[1]Uğur Soğutma Makinaları Sanayi ve Ticaret A.Ş., Nazilli, Aydın
ORCID: 0009-0006-6318-2683

[2]Uğur Soğutma Makinaları Sanayi ve Ticaret A.Ş., Nazilli, Aydın,
ORCID: 0009-0008-8749-1012

[3]Pamukkale Üniversitesi, Mühendislik Fakültesi, Makina Mühendisliği Bölümü, Denizli,
ORCID: 0000-0003-4831-1118

Keywords

Commercial coolers, energy consumption, energy efficiency, cooling time

Abstract

Commercial coolers are specifically designed for commercial use in a variety of industries such as food service, hospitality and retail. They come in different shapes, sizes, and configurations, with features and capabilities that vary depending on the intended use. The most common types are beverage coolers, wine cabinets, ice cream cabinets, glass front coolers. The cooling system is an important factor to consider when purchasing a commercial cooler, and the most common type is forced air cooling. Energy consumption can vary depending on size, type and use, and many models are now designed to be energy efficient. Other important factors to consider include capacity, noise level and certain features such as adjustable temperature control, energy efficiency, self-closing doors, interlocks and interior lighting. The study includes an IPD test that measures the energy consumption of a complete cooler, as well as determining the time it takes for a commercial cooler designed to cool beverages to reach the desired temperature from ambient to ambient temperature for Aluminum Cans and PET bottles. Stabilized commercial bottle cooler.

* hakantavukcuu@gmail.com
doi : 10.46399/muhendismakina.1272520

FARKLI MALZEME VE ŞEKİLLERDEKİ PAKETLERİN YÜKLENMESİNİN ENERJİ TÜKETİMİ VE PERFORMANSINA ETKİSİ: TİCARİ BUZDOLABI ÜZERİNE BİR İNCELEME

Anahtar kelimeler

Ticari soğutucular, enerji tüketimi, enerji verimliliği, soğutma süresi

Öz

Ticari soğutucular, gıda servisi, konaklama ve perakende gibi çeşitli endüstrilerde ticari kullanım için özel olarak tasarlanmıştır. Tasarımları amaçlarına göre değişik şekil, boyut ve yapılandırmalarda gelirler. En yaygın olanları arasında, şişe soğutucuları, şarap dolapları, dondurma dolapları yer alır. Soğutma sistemi, ticari bir soğutucu satın alırken göz önünde bulundurulması gereken önemli bir faktördür ve zorlanmış hava taşınımlı soğutma en yaygın tiptir. Enerji tüketimi, boyut, tip ve kullanım durumuna bağlı olarak değişebilir ve birçok model artık enerji tasarruflu olacak şekilde tasarlanmıştır. Kapasite, gürültü seviyesi ve ayarlanabilir sıcaklık kontrolü, enerji verimliliği, otomatik kapanan kapılar, güvenlik kilitlemeleri ve iç aydınlatma gibi belirli özellikler de dikkate alınması gereken diğer önemli faktörler arasındadır. Çalışmaya, içecekleri soğutmak için tasarlanmış bir ticari soğutucunun Alüminyum Kutular ve PET şişeler için istenen sıcaklığa ulaşmak için gereken süreyi belirleyen IPD testi ve istenen aralıktaki sıcaklıkta soğutmak için tasarlanmış bir ticari şişe soğutucusunun tamamen stabil enerji tüketimini ölçen bir enerji testi de dahil edilmiştir.

Araştırma Makalesi			Research Article		
Başvuru Tarihi	:	29.03.2023	Submission Date	:	29.03.2023
Kabul Tarihi	:	18.04.2023	Accepted Date	:	18.04.2023

1. Introduction

Coolers are an indispensable device in every home or workplace. Commercial refrigerants are used in various environments and for various purposes. They are refrigeration units specially designed for commercial use and provide the ideal storage solution for enterprises in various industries. They can be found in restaurants, bars, supermarkets, grocery stores, cafeterias and other food service establishments. and at home. They can also be used in food service, hospitality and retail, as well as in the healthcare, pharmaceutical and science industries. They are useful for keeping food and drinks cool, and some models can also be used to freeze food and ice. They are used for storing and preserving food and beverages at the optimal temperature. The characteristics and capacities of commercial refrigerants vary according to the model and the intended use. It is important to take into account factors such as energy consumption, energy efficiency and capacity when choosing a commercial refrigerant for these enterprises. They provide a safe and convenient way to store and refrigerate food and beverages and come in a variety of shapes, sizes and configurations. A commercial cooler is a specially designed version of a regular cooler and is used by businesses to store food and beverages for sale. Various types of cooling systems, sizes, capacities, energy efficiency and other characteristics are carefully evaluated when purchasing a commercial cooler to ensure that you are getting the right unit for your needs. Other additional features such as digital temperature controls, adjustable shelves and interior lighting are also among the important parameters. In addition, the unit cost and applicable warranties are taken into account in commercial refrigerants. Therefore, manufacturers should take into account all these parameters when designing (Whitman et al., 2012; Stoecker, 1998).

Commercial coolers come in a variety of shapes, sizes and configurations. The most common type of commercial cooler is the access cooler, which is an independent unit with one or two doors. Other types are built-in coolers, pop-up coolers and glass pre-coolers. Each type has its own advantages and disadvantages, which should be carefully considered before purchasing. The cooling system is an important factor to consider when purchasing a commercial refrigerant. Coolers can use one of several different cooling systems, including forced air cooling, gravity cooling, and compressor cooling. Forced air cooling is the most common type of refrigeration system and is used in most commercial refrigerants. Gravity cooling and compressor cooling are more efficient but also more expensive.

The energy consumption of commercial refrigerants depends on many variables, such as the size, type and use of the refrigerant. According to the Office of Energy Efficiency and Renewable Energy, commercial refrigerant can consume 412 kWh for the Current Top Annual Energy User, 690 kWh for ENERGY STAR, and 1621 kWh for Lower-Efficiency Commercial Refrigerator Models; cooling. used. The Maximum Daily Energy Consumption is measured as 1.13 kWh/day, 1.89 kWh / day and 4.44 kWh / day respectively for the current best, ENERGY STAR and Less Efficient (EERE, 2023).

In general, commercial coolers are designed to be more durable and energy efficient than regular household coolers, with features such as adjustable temperature control, air- or water-cooled systems, and digital temperature indicators. In order to reduce energy consumption and costs, many commercial refrigerants are now designed to be energy efficient. Energy-efficient coolers have better insulation, better cooling systems and advanced controls that help reduce energy wastage. To minimize energy consumption, many commercial refrigerants are now designed to be energy efficient. Energy-efficient coolers have better insulation, better cooling systems and more advanced controls that help reduce energy wastage. Many commercial refrigerators also have interior lighting and adjustable shelves for easier storage and arrangement of food items. Some coolers even have features such as automatic defrosting and night covers, which can further reduce energy consumption. By choosing an energy-efficient model, a business can reduce energy costs and help reduce its carbon footprint (Mota-Babiloni et al., 2015).

When choosing a marketable cooler, it's important to consider the size and capacity of the cooler and the type of food or potables you'll be storing. It's also important to consider the type of cooling system the cooler uses and the energy effectiveness of the model. It's also important to consider the noise position of the cooler, as some models can be relatively loud. In terms of capacity, the size of the cooler demanded will depend on the quantum of food and drinks that need to be stored. The standard capacity for a marketable cooler used in caffs and requests is generally between 1 and 4 boxy measures. Some businesses may bear larger capacity coolers, depending on their specific requirements. It's important to choose a cooler with enough capacity to meet the requirements of the business, but not so large that it consumes further energy than necessary (Hardenburg et al., 1986).

The anticipated features from these marketable coolers depend on the specific operation, but generally they're designed to keep food and potables at optimal temperatures for extended ages of time and at the specific temperature. To ensure that a marketable cooler meets the specific requirements of a business, it's important to consider several crucial features. They may include malleable temperature control, quiet operation, energy effectiveness, tone- ending doors, safety cinches, and interior lighting. also, some coolers may include fresh features similar as digital temperature displays, automatic defrost, malleable shelving, and malleable door seals.

When opting a marketable cooler for a eatery, bar, supermarket, or convenience store, it's pivotal to consider the energy consumption, energy effectiveness, and cooling time of the cooler. By doing so, a business can reduce its energy costs, ameliorate its energy effectiveness, and ensure that it has enough capacity to store its food and drinks to the proper temperature in a asked time.

In this study, the results of an IPD (Original Pull Down) test applied for the full cargo condition and an HRR(Half- Reload Recovery) test applied for the half- cargo condition were participated to determine the time it takes for a marketable cooler designed for cooling potables to reach the asked temperature from the ambient temperature at the asked standard. also, the energy consumption of a completely stabilized marketable bottle cooler was measured and the results were participated.

2. Literature Review

Marketable refrigeration systems are designed to maintain optimal temperatures for food safety, quality, and newness. The most common type of marketable refrigeration is the walk- in refrigerator, which is generally a large, enclosed space that's cooled by a cooling system. Other types of marketable refrigeration systems include reach- in refrigerators, undercounter refrigerators, display cases, blast coolers, and specialty coolers. Each type of system has its own advantages and disadvantages, so it's important to choose the right system for the particular requirements of the business.

Literature includes numerous studies about marketable coolers. Studies are generally concentrated on achieving energy effectiveness. In recent times, there has been an increase in studies about the use of different refrigerants in marketable coolers.

Westphalen et al., (1996) issued a report that identifies significant openings for energy savings in the marketable refrigeration sector. The report set up that primary energy savings of about 266 trillion Btu (original to roughly 78 billion kWh) could be achieved, which represents a 29 reduction in energy consumption for the types of outfits examined. The study also set up that the use of indispensable refrigeration cycles, similar as immersion and chemisorption, isn't likely to have a significant impact on reducing primary energy operation. still, waste heat recovery shows some implicit for energy reduction. also, the report underscores the significance of supermarket refrigeration, which consumes about 326 trillion Btu (roughly 96 billion kWh) of primary energy annually. The report identifies significant openings for energy reduction in the display case and libation merchandiser areas, with implicit savings of over to 14 and 45, independently. likewise, the report emphasizes that enforcing high- effectiveness evaporator addict motors, hot gas defrosts, liquid suction heat exchangers, anti-sweat control, and defrost control could each contribute to energy savings.

Park et al., (2021) explored the energy consumption of reach- in coolers, cooled closets, and dealing machines in various economies, including Australia, Brazil, China, the EU, India, Japan, Mexico, South Africa, and the US, as part of the global cold chain. The authors projected an increase in energy consumption for these products by 2035, but they also linked significant eventuality for energy savings. Technical and profitable studies have handed detailed information on the stocks and energy consumption of these products in the EU and the US, with literal substantiation of perfecting energy effectiveness. Still, the supply chain for refrigerated cabinets can be complex, with varying power arrangements and provocations for energy effectiveness among end users, distributors, and manufacturers. Garcia and Coelho (2010) underlined the significance of energy effectiveness and its relationship with sustainable development in ultramodern engineering systems, particularly in the food assiduity's refrigeration systems. Large supermarkets are one of the most significant sectors in the distribution industry, and their refrigeration outfit accounts for over 50 of total energy consumption costs. Garcia and Coelho (2010) concentrated on strategies to reduce refrigeration energy consumption in hypermarkets, similar as varying evaporation and condensation pressure, using effective control systems and outfit, and exercising scroll compressors. The study suggests that two strategies could achieve sustainability and environmental respect in hypermarkets, namely replacing electric consumption with renewable energy and reducing electric consumption using more effective systems. The composition discusses the challenges of enforcing indispensable forms of energy, similar as immersion cycles and adsorption cycles, and the limitations of renewable energy sources like wind, solar, geothermal, and ocean. The study suggests that the easiest and most realistic way to reduce electric consumption in refrigeration systems of hypermarkets is to use more effective equipment, especially compressors, and use the correct number of compressors to increase the number of possible ways in capacity.

Bahar et al., (2021) conducted a study on energy labeling and energy effectiveness in artificial coolers, specifically perpendicular- type door deep freezer coolers. The experimenters designed and tested two systems that use the natural refrigerant R290 (propane), each with two bay- outlet evaporators, double condensers, and double compressors to give homogeneous refrigeration. The study also focused on the performance of glass with anti-fog film to help condensation on the doors of refrigerators, which can obscure displayed products and increase energy consumption due to the use of resistances in the glass. The results indicate that the use of anti-fog flicks can save significant quantities of energy with zero energy consumption. The experimenters calculated the energy effectiveness indicator (EEI) value of the coolers and determined their energy marker class grounded on the results attained. The study aims to contribute to the literature and raise mindfulness of environmentally friendly refrigerants and accoutrements that can reduce energy consumption and increase energy effectiveness in artificial coolers.

Around half of a supermarket's energy consumption is related with its refrigeration system, and the performance, refrigerant choice, machine design, and determination can significantly have an effect on CO_2 emissions (Rivers, 2005; Söğüt, 2015). Commercial refrigeration structures the use of Hydro Fluoro Carbon (HFC) refrigerants have a massive effect on the greenhouse impact (Koronaki et al., 2012). Girotto et al., (2004) performed a learn about on the viability of the use of carbon dioxide (CO_2) as a refrigerant choice to HFCs in business refrigeration systems. The study examined to analyze an "all-CO_2" supermarket in Italy and compare its overall performance to that of a traditional machine the use of R404A. The study discovered that even though the CO_2 system was once about 10% much less environment friendly than the R404A system, its effectivity ought to be expanded to strategy that of R404A. CO_2 is non-toxic and non-flammable, making it environmentally safe. However, the lack of industrially produced factors makes the CO_2 system about 20% expensive than R404A. Given that refrigerant leakage is fairly high in the industrial sector, it is integral to discover non-HFC selections such as CO_2. The supermarket's CO_2 system had a complete ability of 120 kW in medium temperature and about 25 kW in low temperature, and the learn about suggests that the system's design and the use of two-stage compressors should tackle low-temperature utility issues. Additionally, the find out about suggests some methods to enhance the CO_2 system's efficiency, such as redesigning the evaporator coil.

Mota-Babiloni et al., (2015) performed a learn about on business refrigeration, which is one of the greatest energy-consuming sectors, particularly in retail shops and supermarkets. The study reviewed the modern trends in business refrigeration and targeted on energy-saving strategies that assist to limit oblique CO_2 emissions. Various factors associated to electricity consumption and Green House Gases (GHG-CO_2 and HFC) emission financial savings in industrial refrigeration structures had been analyzed. The article reviewed current lookup on supermarket power consumption evaluation and models, refrigeration cycle improvements, trigeneration technologies, and HFC replacements. The paper concluded that business refrigeration is one of the functions that contributes most to international warming, and efforts to enhance power effectivity and minimize GHG emissions ought to continue.

Polzot et al., (2016) mentioned the applicability and overall performance of CO_2 cooling structures in industrial applications, especially in mild climates where ordinary HFC structures operate more efficiently. The 2014 EU F-gas regulation aimed to reduce the use of fluorinated greenhouse gases, which led to the search for choice options in industrial refrigeration. Carbon dioxide (R744) is a promising choice due to its low GWP, non-toxicity, non-flammability and favorable thermophysical properties. However, CO_2 structures in mild and warm climates function in trans integral provisions over long periods of time, resulting in reduced electrical efficiency. Various options including internal heat exchangers and mechanical subcooling have been accepted and studied to improve the strength efficiency of CO_2 systems. This article explored the use of a fire prevention water tank as a cold sink for subcooling and temperature recovery for HVAC purposes. Heat recovery from the cooling flora for heating functions occurs much less frequently due to the enormous power required and the difficulty in matching requests and availability.

Montagner and Melo (2014) conducted a study on the thermodynamic overall performance of a 4 CO_2- cooling cycle design at high temperatures. The first three cycle designs had similar COP values, but an internal temperature exchanger introduced into the introductory cycle plan increased the cooling capacity and COP with 20 and 28, independently. The flash gas tank cycle layout redounded in a 10 expansion in cooling capacity and a 15 increase in COP, in addition to compromising the discharge line temperature. The aouthors described the impact of artificial refrigerants on the the environment and the gradual replacement with natural refrigerants similar as isobutane, propane and CO_2. The overall performance of CO2- based on the cooling structures is exceptionally affected by the ambient temperature, and this has delved the effect of unique cycle designs at variable ambient temperatures.

Cortella et al., (2021) mentioned the goods of simulations performed on a trans vital CO_2 booster device with a desuperheater device (DMS) in quite a lot of climates. The simulations aimed to take into account the electrical effectiveness of the device and find the most applicable regulations and schemes to minimize power consumption. The study verified that there's a most effective DMS dimension with a corresponding α price between 35 and 45, and choosing the right DMS dimension is a necessary thing that should be estimated grounded serviceably on economic considerations. The result of study indicated that a set temperature of around 5 °C or 10 °C provides affable advantages for all climates, except hottest one where a severed temperature between 10 °C and 15 °C is recommended. The results also verified that the use of DMS in warmer original rainfall conditions can achieve great power savings and that the optimal energy- saving situation is available. Eventually, a figure assessment is obligatory in order to consider the most environmentally friendly way of operating the factory.

Llopis et al., (2017a) theoretically investigated the use of two refrigerants such as R-513A and R-450A, developed for use in medium temperature applications and developed to replace R-134a. At -14°C evaporating temperature and three condensing temperature (A theoretical study was carried out for an ideal single-stage vapor compression system for different refrigerants for 25, 35 and 45°C). In addition, the test method used to evaluate the effect of refrigerant mixtures, as well as the uncertainties of the measurement system and the experimental setup, are presented in the article. The 24-hour energy consumption tests in a small supermarket were monitored and the results evaluated. As a result of the study, it was concluded that the energy consumption of R-513A and R-450A was lower than R-507A under the tested conditions.

Llopis (2017b) conducted a study to assess the feasibility of using R-407H refrigerant in a cooler that currently uses R-404A refrigerant. Two types of tests were performed: a top-up test and an energy consumption test. The experimental plant used in the study consisted of a semi-airtight compressor, a condenser, and a single-level loop driven by a liquid receiver. The cooler was strictly instrumented to measure the power parameters. Although there was concern about adding R-407H to a system running on R-404A, the power input trial evaluated the performance of the plant using various refrigerant blends. The results of the study are presented in tables and graphs, confirming the overall power performance of the machine under different conditions.

Minetto and Marinetti (2018) developed a method by conducting a study to investigate the efficient use of energy in commercial cooling systems that comply with EN 14825 and EN 13215 standards. With the developed method, sensitivity analysis for different climatic conditions and estimation of the Seasonal Energy Performance Ratio (SEPR) were made. The solution suggestions obtained as a result of the study were compared. The reliability and usefulness of the developed method was discussed by comparing different systems with the study carried out by the authors.

Kaushik Bhattacharje (2008) analyzed an industrial refrigeration system using ammonia as the refrigerant. The study analyzed various energy saving possibilities such as floating head pressure control, variable frequency drives in evaporator fans, hot gas defrost optimization and heat recovery opportunities. Evaluating the results of the study, the author also suggested reducing the air leakage in the cold storage, applying the two-level control of the lighting system used in the cold storage, and using the screw compressor VFD controls in order to save energy. The study highlights the importance of reducing energy consumption in industrial cooling systems to achieve significant cost savings.

Albayati et al., (2020) investigated the effect of Demand Side Response (DSR) events on energy efficiency and power profile in commercial refrigeration systems. In this context, author conducted a series of experimental studies. Within the scope of the study, it has been shown that the use of bulk cooling loads in coolers used in small and medium-sized supermarkets contributes to unloading. This has been shown to provide energy savings of between 3.8% and 9.3% compared to normal operation. The study also investigated the effect of using DSR on the local power grid on the synchronous operation of batch cooling systems. The results show that DSR events can save energy and the use of bulk cooling loads can help manage the power system during peak demand.

Garces et al., (2017) examined the importance of identifying qualified experts in technology research and development efforts to ensure the quality of results. They stated that finding these experts is difficult but necessary. In the study, Social Network Analysis (SNA), Bibliometric Analysis and Patent Analysis were used to identify knowledgeable people in a community, as an example, energy-efficient commercial refrigeration technologies were used. The methodology included keyword identification, data mining, and calculation of centrality metrics, with customer feedback included to tailor the process. A software tool developed in R and Shiny for this purpose is also discussed in the study.

3. Overview of Commercial Refrigeration

Commercial coolers must comply with various regulations and standards regarding energy efficiency and environmental impact, while also being designed and manufactured to be efficient and reliable. At the same time, regular maintenance and inspection should be done to operate properly and safely. The commercial refrigeration industry is constantly monitoring developments in technology to make them more efficient and with minimal environmental impact. As the refrigeration industry places emphasis on sustainability and energy efficiency, the demand for more environmentally friendly commercial refrigeration systems is expected to increase (Deneen, 2002).

Increased Storage Space: Commercial coolers are different from residential coolers and offer more storage space. This allows restaurants, catering establishments and other food service establishments to store more food or beverages and reduce the need for frequent restocking (Wang et al., 2010).

Improved Food Safety: Commercial coolers are designed to maintain a lower temperature than residential models, ensuring food remains at a safe temperature and preventing the growth of harmful bacteria. This helps keep food fresh and safe to consume (Bierm et al., 2019).

More Efficient: In general, commercial coolers are designed and manufactured to be more energy efficient compared to residential models. The most important reason for this situation is to enable businesses to save energy costs over time (Thompson et al., 2010).

Longer Lasting: Commercial coolers are products used by many different consumers and are therefore made with heavy-duty components and materials that can withstand frequent use. Businesses expect their investments to last for many years (Maina and Huan, 2015).

More Customizable: Commercial coolers are designed and produced in a variety of sizes, features and configurations. Thus, different and special needs of businesses are met.

Capacity: Commercial coolers should offer enough space to store the products of the enterprises in the capacity they need. For businesses, the capacity of a commercial cooler is an important consideration. Companies that design and manufacture coolers have to offer the user companies a refrigerator of the right size, taking into account the required space and the size of the products to be stored. is important (Thompson et al., 2010).

4. Types of Commercial Coolers

Commercial coolers are designed and produced in various shapes, colors, and sizes to suit the needs of user enterprises. There are three main types of commercial coolers: built-in, roll-in, and walk-in. These products are the most widely used coolers on the market and are often used in grocery stores, restaurants, and other foodservice companies. Doors can be front or side. It may have adjustable shelves and various sizes so that different products can be placed inside. Roll-in coolers are designed to store large quantities of food and beverage and are often used in hospitals, cafeterias, and large-scale catering establishments. They can be large enough to store a large number of products and often have wheels for easy transportation within the business. Finally, built-in coolers are the largest of the three types and are typically used in large-scale food service operations. They are large enough to store large quantities of product and feature shelves and doors.

4.1 Types of Door Configurations

Commercial cooler can have many door types, depending on the characteristics, shape and function of the door. The most common types are single doors, double doors, sliding doors and folding doors. Single door coolers are the simplest and most widely used type. It consists of a single panel and can be opened inwards or outwards as needed. Double-door ones, on the other hand, consist of two hinged or sliding doors opening in opposite directions. Sliding doors, on the other hand, are used in larger areas and are opened by sliding one panel over the other. Those with folding doors are used where space is limited. It consists of several panels that can be folded in both directions. Each type of door configuration has its advantages and disadvantages and should be chosen according to the specific application (Waide et al., 2014).

4.2 Types of Shelves and Storage Capacity

Commercial refrigerators' shelf and storage areas can come in a variety of shapes, sizes, and types. Each shelf type offers different levels of storage capacity. It is very important to choose a shelf in the shape and size that will meet the need (Waide et al., 2014).

4.3 Factors to Consider When Purchasing a Commercial Cooler

There are several factors businesses should consider when purchasing a commercial cooler. The size, capacity, energy consumption and energy efficiency of the cooler are among the most important factors. In addition, it is important to consider the features and accessories of the cooler, such as adjustable shelves, temperature control and defrosting systems. Refrigerant cost, warranty and service options are also among the important parameters to be evaluated. The fact that the cooler meets safety and health regulations and that it has a long life is also among the parameters that businesses pay attention to. Considering all these factors, a suitable commercial cooler can be selected for the needs.

4.4 Space Requirements

The space requirement is one of the most important parameters to consider when designing a commercial cooler. Because space in businesses is quite limited. There is a design expectation that will ensure maximum product cooling in minimum space (Wang et al., 2010).

4.5 Temperature Control

Commercial refrigerators require that the products stored in them be kept at the right temperature to prevent spoilage and waste. In addition, it is expected to keep the product inside the cooler at the desired temperature. Commercial coolers are critical equipment for businesses used in industries as diverse as food service, hospitality and retail. A commercial refrigerator must be designed and manufactured to provide optimum temperature storage for food, beverages, and perishable products.

Temperature control should ensure that the temperature of a system or environment is maintained within a desired range. It is used in a wide variety of applications such as temperature control, food, and beverage manufacturing, monitoring of medical equipment and operating heating, ventilation, and air conditioning systems. Temperature control is mostly accomplished using thermostats, thermocouples, and other temperature sensing devices. Temperature control systems are often used to sense changes in temperature and start and stop heating or cooling systems as needed to maintain the desired temperature. Temperature control can also be achieved by manually adjusting the settings on a thermostat or other temperature controller (Stovall and . Tomlinson, 1990)

Commercial coolers are used in many businesses as they are used to store food and beverages at the optimum temperature. In particular, the storage temperature of a commercial refrigerator where food and drink are stored must be precisely controlled to ensure that the food stored in it is safe. Adjusting the coolant to the desired temperature is achieved using a thermostat. The thermostat monitors the temperature inside the cooler and automatically adjusts the cooling system to achieve the desired temperature. If the temperature inside the cooler rises above the set temperature, the thermostat sends information to lower the temperature again and starts the cooling system. Similarly, if the temperature inside the cooler falls below the set temperature, the thermostat turns off the cooling system to prevent further cooling of food or beverages (Liu et al., 2022).

4.6 Energy Efficiency

One of the most important parameters in reducing operating costs is to provide energy efficiency. Energy-efficient commercial coolers not only reduce the cost of electricity but also help reduce the environmental impact of the business.

The basic approach in energy efficiency is to use less energy to achieve the same result. Energy efficiency is an important concept to reduce emissions to the environment, reduce energy costs and improve overall quality of life. Energy efficiency can be thought of as better management and more efficient use of existing resources. In order to maximize energy efficiency, it is necessary to reduce wasted energy consumption and to better use available energy resources. Energy efficiency is a technological approach (Mukherjee et al., 2020).

Commercial coolers are among the most energy-intensive equipment in the refrigeration industries, and businesses must be energy efficient and operate with low energy consumption to minimize costs and reduce their carbon footprint. The energy efficiency of a commercial cooler depends on several factors, such as the type of refrigerant used, the insulation material and insulation thickness of the cooler, and the efficiency of the refrigeration system (Chua et al., 2013).

The importance of energy efficiency in commercial coolers is among the parameters. A more energy efficient unit not only reduces operating costs but also reduces the carbon footprint of the business. It can also help increase the reliability and life of the cooler.

Commercial coolers are becoming more and more energy efficient, using advanced technologies and materials that reduce the amount of energy needed to keep food and beverages cold. Coolers are insulated using materials such as foam and fiberglass to reduce energy consumption. At the same time, many commercial coolers use energy-efficient LED lighting to reduce the heat dissipation created by the lighting system. Commercial coolers with all these features provide customers with the desired storage temperature with low energy consumption.

4.7 Durability

Commercial coolers wear out over time as they are used by many different users, so they must be built to last. Rugged commercial coolers must be designed and built to provide years of reliable performance, even with their daily use.

Durability is critical for industries that use commercial refrigerants to store and store food and beverage. A durable cooler should be able to protect the food and beverages stored in it from external factors, keep it at the desired optimum temperature, and work reliably even in the most challenging environments.

The importance of durability in commercial cooler cannot be underestimated. Businesses often require long-lasting coolers that can withstand the daily wear and tear of the food service, catering and hospitality industries. A durable cooler should allow the business to run more smoothly and efficiently, while minimizing the risk of failure and reducing the need for costly repairs and replacements (Maina and Huan, 2015).

Companies attach great importance to the durability of their products. Robust and well-insulated coolers made of high-quality materials are among the most preferred coolers. In addition, companies choose coolers with robust, reliable and energy-saving technologies to maximize their lifespan and minimize the risk of equipment failure.

4.8 Easy Maintenance

Commercial refrigerants need to be cleaned and maintained regularly, which makes it important to choose a unit that is easy to clean and maintain. Some models have removable shelves and doors that make it easier to clean the interior (Brown, 2000).

Commercial coolers are a critical component of the food service and hospitality industries, and they play a crucial role in the storage and preservation of food and beverages. Regular maintenance is essential to ensure that commercial refrigerants continue to operate at optimal levels and minimize the risk of equipment failure and downtime.

The importance of refrigerants used in commercial refrigerants cannot be underestimated. Businesses need well-maintained and optimally operating coolers to protect the food and beverages stored inside and to maintain the safe and optimum storage temperatures required by legal standards. Regular maintenance helps minimize the risk of equipment failure and reduces the need for costly repairs and replacements, allowing the organization to run more smoothly and efficiently.

Companies attach great importance to the maintenance of their products and expect their commercial refrigerants to work well-maintained and at optimum levels. They need coolers that are easy to clean and maintain with simple and simple maintenance procedures that can be performed quickly and efficiently. In addition, companies are looking for refrigerants with advanced cooling systems and energy-saving technologies to maximize their service life and minimize the risk of equipment failure (Wang et al., 2022).

The maintenance periods of commercial refrigerants vary depending on factors such as the type of refrigerant, frequency of use, and the environment in which it is used. However, it is generally recommended that commercial refrigerants undergo regular maintenance at least once every 6 months or more often in harsh environments.

4.9 Energy Consumption

Commercial refrigerants are one of the critical devices used for storing food and beverages at safe storage temperatures. The importance of energy consumption in commercial refrigerants cannot be underestimated. Companies need energy-efficient refrigerants to minimize energy costs and their impact on the environment. Energy-saving refrigerants help to reduce the daily and annual energy consumption value and significantly reduce the cost over time (Sánchez et al., 2022).

Companies that use refrigerants attach great importance to the energy consumption of refrigeration units and prefer their commercial refrigerants to be energy efficient. In order to minimize energy costs and their impact on the environment, companies need refrigerants with advanced cooling systems and technologies.

The daily and annual energy consumption of commercial refrigerants varies significantly depending on numerous factors such as the size of the refrigerant, frequency of use, duration of use, amount of product stored in it, the environment in which it is used, temperature and humidity value of the environment it uses. Changes in energy consumption according to climatic conditions can also affect the energy efficiency of commercial refrigerants, as they may need to work harder in hot or humid environments to maintain safe storage temperatures.

4.10 Cooling Time:

Commercial coolers are essential equipment in the food service and hospitality industries and play a critical role in maintaining food and beverages at safe storage temperatures. The cooling time of commercial refrigerants is an important consideration for enterprises, as it can affect the quality and safety of stored products, as well as the overall efficiency and performance of the refrigerant (Thompson et al., 2008).

Cooling time is very important in commercial refrigerants and cannot be ignored.

The speed at which the refrigerant cools down and reaches safe storage temperatures is critical for the preservation of food and beverages as well as the efficiency of the refrigerant. The fast-cooling time can help reduce the risk of spoilage and food waste, and ensure that products are stored at safe temperatures in a timely manner.

Companies attach great importance to the cooling time of their commercial refrigerants and have special expectations about the cooling time of their products. Companies expect that when a new product is placed at full load and ambient temperature, the coolant will cool down quickly and reach safe storage temperatures on time. The cooling time of commercial refrigerants may vary depending on factors such as the size of the refrigerant, the volume of product stored and the environment in which it is used (Thompson et al., 2010).

5. Result and Discussion

In the study, a set of experiments was designed and conducted to measure and evaluate the cooling performance of a commercial refrigerator for cans and PET bottles. The main objective of the study was to investigate the cooling behavior of the products inside the refrigerator and to quantify the energy consumption associated with cooling. To achieve this objective, the cooling times and cooling curves for the products were determined by monitoring the temperature changes of the products over time. The results of the study were then analyzed and presented using tables and figures, which provided a clear visualization of the cooling behavior and energy consumption of the products inside the refrigerator.

In this study, an investigation was conducted on a cooling system with the model designation of UCOOL1500 D3K HV. The system employed R290a as its refrigerant type. The gross volume of the system, as measured by EN22044, was 1552 liters, while the net volume was 975 liters. The internal dimensions of the system, measured in terms of width, depth, and height, were 1423 mm x 599 mm x 1901 mm, respectively. The external dimensions of the system were 1500 mm x 760 mm x 2137 mm (width x depth x height) (see Figure 1).

Figure 1. The three-door commercial refrigerator in which the experimental study was conducted.

The thermodynamic cycle used in refrigeration and air conditioning systems is known as the vapor compression cycle. This cycle involves four main components: a compressor, a condenser, an expansion valve, and an evaporator. The cycle begins with the refrigerant compressed by the compressor, which increases both its pressure and temperature.

The high-pressure, high-temperature vapor then moves into the condenser, where it releases heat to the surroundings and condenses into a high-pressure liquid. The liquid refrigerant then passes through the capillary tube, where its pressure and temperature are reduced.

Finally, the low-pressure, low-temperature refrigerant returns to the evaporator, where it absorbs heat from the surroundings and the cycle repeats. The overall effect of the cycle is to transfer heat from a cool environment to a warm environment, thereby cooling the cool environment and warming the warm environment. This cycle is used in various refrigeration and air conditioning applications, from small household refrigerators to large industrial systems. A thermodynamic cycle that is commonly used in refrigeration and air conditioning systems is presented in Figure 2.

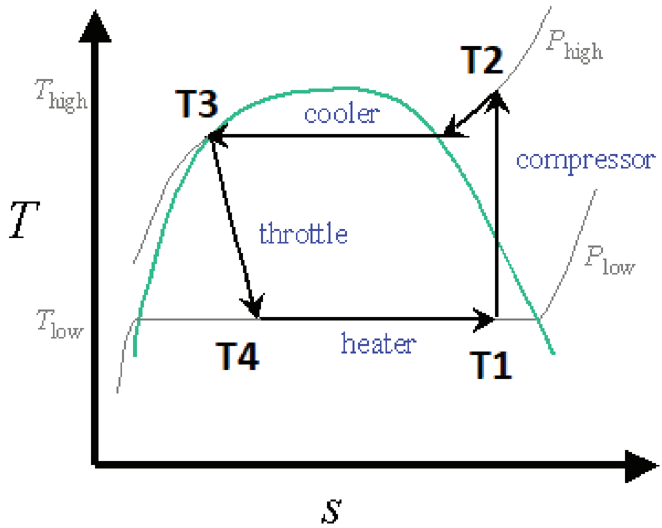


Figure 2. Schematic representation of a commonly used thermodynamic cycle in refrigeration and air conditioning systems.

Figure 3 shows the main components of a thermodynamic refrigeration cycle. These components include the condenser, condenser fan, dryer inlet pipe, dryer, spiral pipe, compressor discharge pipe, heat exchanger, fin evaporator, and fin evaporator fan.

The cycle starts with the compressor, which compresses the refrigerant gas and increases its pressure and temperature. The high-pressure gas then enters the condenser, where it is cooled down by the condenser fan and releases heat to the surroundings. The cooled refrigerant then passes through the dryer inlet pipe and the dryer, which remove any moisture and contaminants from the refrigerant. The refrigerant passes through the fin evaporator and the fin evaporator fan, where it absorbs heat from the surroundings and cools the cool environment.

The refrigerant then flows through the heat exchanger and into the compressor, where the cycle repeats. During the cycle, the refrigerant passes through the heat exchanger, which allows heat to be exchanged between the refrigerant and the surrounding environment.

The overall effect of the cycle is to transfer heat from a cool environment to a warm environment, thereby cooling the cool environment and warming the warm environment.

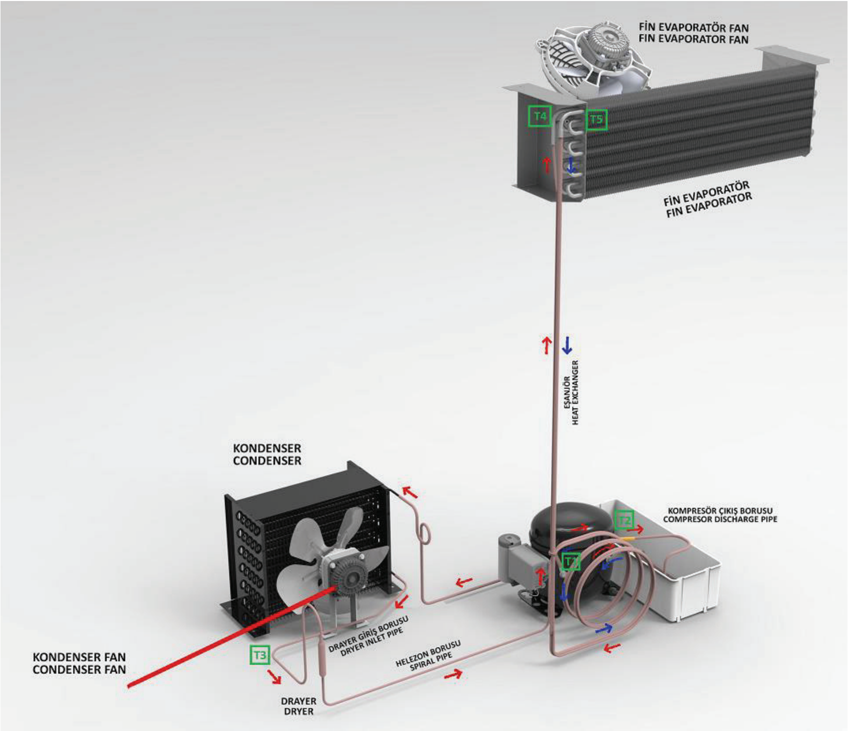


Figure 3. Vapor compression cycle

Table 1 shows the measured temperatures during the UCOOL 1500 Al. Can energy test for the suction temperature (T1), discharge temperature (T2), condenser out temperature (T3), evaporator in temperature (T4), and evaporator out temperature (T5). As shown in Table 1, the UCOOL 1500 underwent an energy test with temperature measurements taken at various points in the system. The average suction temperature T1 was 35,2 °C, with a minimum of 7,8°C and a maximum of 49.5°C. The discharge temperature T2 had an average of 71,3°C, with a minimum of 45,3°C and a maximum of 103,1°C.

The condenser out temperature T3 had an average of 36,4°C, with a minimum of 20.5°C and a maximum of 45.1°C. The evaporator in temperature T4 had an average of -5,9°C, with a minimum of -17,9°C and a maximum of 3,5°C. Finally, the evaporator out temperature T5 had an average of 0°C, with a minimum of -5,6°C and a maximum of 4,1°C.

These temperature measurements provide important information about the efficiency and performance of the UCOOL 1500 system. In particular, the low minimum temperature at the evaporator in (T4) and evaporator out (T5) suggest that the system is capable of effective cooling even at very low temperatures. However, the relatively high maximum temperatures at the suction (T1) and discharge (T2) points may indicate the need for improved temperature regulation to prevent potential damage to the system.

Tablo 1. UCOOL 1500 Al. Can Temperatures Measured During Energy Testing

	Minimum	Average	Maximum
Suction Temperature T1 (°C)	7.8	35.2	49.5
Discharge Temperature T2 (°C)	45.3	71.3	103.1
Condenser Out Temperature T3 (°C)	20.5	36.4	45.1
Evaporator In Temperature T4 (°C)	-17.9	-5.9	3.5
Evaporator Out Temperature T5 (°C)	-5.6	0	4.1

The following Table 2. presents the minimum, average, and maximum temperature values measured during the UCOOL 1500 PET energy test. As seen in Table 2, the Suction Temperature ranged from 4.2°C to 50.8°C, the Discharge Temperature ranged from 45.3°C to 96.6°C, and the Condenser Out Temperature ranged from 20.2°C to 45.7°C. The Evaporator In Temperature had a minimum of -18.2°C and a maximum of 2.2°C, while the Evaporator Out Temperature had a minimum of -7.4°C and a maximum of 2.7°C.

It is noteworthy that the suction temperature and condenser out temperature for both UCOOL models are similar, indicating that these components function similarly in both models. The evaporator in and out temperatures show that the UCOOL 1500 PET had a colder evaporator than the UCOOL 1500 Al.

Tablo 2. UCOOL 1500 PET Temperatures Measured During Energy Testing

	Minimum	Average	Maximum
Suction Temperature (°C)	4.2	36.4	50.8
Discharge Temperature (°C)	45.3	66.6	96.6
Condenser Out Temperature (°C)	20.2	36.4	45.7
Evaporator In Temperature (°C)	-18.2	-6	2.2
Evaporator Out Temperature (°C)	-7.4	-1	2.7

5.1 Thermal Conduction Diagram

Figure 4 and Table 3 displays the parameters of the side surfaces of a refrigerator. The thickness of the outer and inner shell is 0.5mm, while the thickness of the polyurethane insulation is different for each surface, ranging from 37.5mm to 58.5mm. The heat transfer coefficient of the metal shell is the same for all surfaces, at 41.5 W/m^2K, while the heat transfer coefficient of the polyurethane insulation is 0.021945 W/m^{2}K. The external ambient temperature is constant at 32°C, and the internal temperature of the refrigerator is maintained at 2°C.

The thickness of the insulation material plays a crucial role in determining the heat transfer rate of a refrigerator. As the insulation thickness increases, the rate of heat transfer decreases, leading to improved insulation performance. In this case, the thickness of the polyurethane insulation ranges from 37.5mm to 58.5mm, suggesting that different surfaces of the refrigerator have different insulation properties. This is because some surfaces are exposed to higher temperatures and require thicker insulation to maintain a lower temperature inside the refrigerator. The heat transfer coefficient of the metal shell is also an important parameter, as it determines how easily heat is transferred through the walls of the refrigerator.

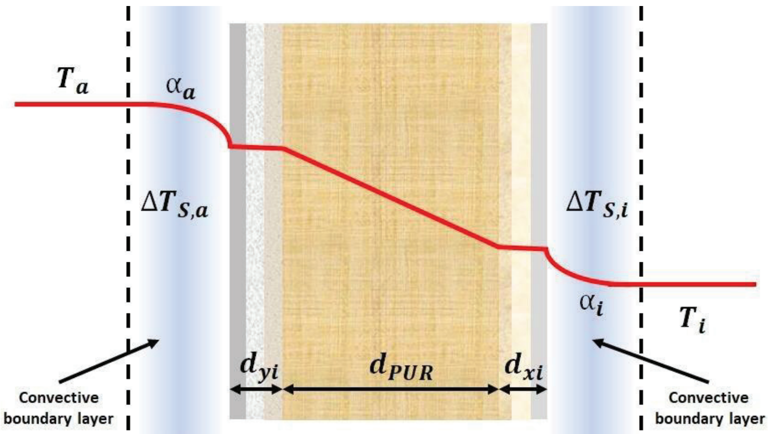


Figure 4. Parameters related to the lateral surfaces of the refrigerator

Table 3. Thicknesses and Thermal Conductivities of Cabinet Components

	Roof	Floor	Right	Left	Rear
External Sheet Thickness (dyi) (mm)	0.5	0.5	0.5	0.5	0.5
Polyurethane Thickness (dpur) (mm)	57.5	58.5	37.5	37.5	48
Internal Sheet Thickness (dxi) (mm)	0.5	0.5	0.5	0.5	0.5
Heat Transfer Coefficient of Sheet (W/m^{2}K)	41.	41.	41.5	41.5	41.5
Heat Transfer Coefficient of Polyurethane (W/m^{2}K)	0.021945	0.021945	0.021945	0.021945	0.021945
Ambient Temperature (°C)	32°C	32°C	32°C	32°C	32°C
Indoor Temperature (°C)	2°C	2°C	2°C	2°C	2°C

5.2 Refrigerator Cabinet Glass Properties

The glass used in the commercial refrigeration doors plays an important role in the energy efficiency of the system. The specifications of the glass used in the 4TLEM-16-4T+ARGON model are as follows: T (Tempered), LEM (Low-e Magnetronic), F (Float Glass), and U-value of 1.1 W/(m^2K).

Tempered glass is a type of safety glass that is four times stronger than regular glass, making it more durable and resistant to breakage. Low-e Magnetronic coating is a thin layer of metal oxide that is applied to the glass to reduce the amount of heat that passes through it, which helps to maintain a stable temperature inside the refrigerator. Float glass is a type of glass that is made by floating molten glass on a bed of molten metal, resulting in a smooth and uniform surface.

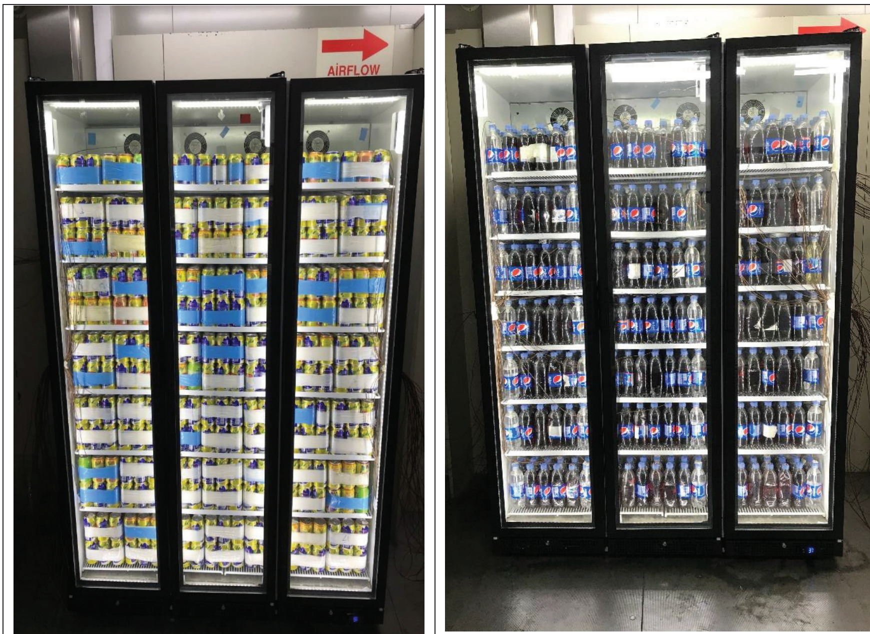
The U-value of the glass refers to its ability to conduct heat, and a lower U-value indicates better insulation. In this case, the U-value of 1.1 W/(m^2K) suggests that the glass used in the 4TLEM-16-4T+ARGON model has good insulating properties and can help to reduce energy consumption.

Figure 5. Refrigerator Cabinet Glass

5.3 Loading Plan

A 3-door commercial refrigerator was loaded with beverages in PET bottles and aluminum cans as shown in Figure 1. The Aluminum can and PET bottle loaded states are depicted in Figure 5. Figure 6 displays the total number of loaded PET bottles (990) and aluminum cans (1743), with the red filled circles indicating the locations where temperature measurements were taken. For PET bottles, measurements were taken at 11 points on each shelf, as seen in Figure 6, for a total of 77 points. For aluminum cans, measurements were taken at 8 points on each shelf, for a total of 56 points.

By adhering to these loading plan, the temperature measurements taken in the refrigerator can be relied upon to provide accurate insights into its performance and efficiency.



Aluminum CAN loaded	PET bottle loaded

Figure 6. Aluminum CAN Loaded and PET Bottle Loaded States of a 3-door Commercial Refrigerator.

The experimental results presented in this study describe two tests that were conducted to evaluate the performance of a commercial cooler in a scientific manner. The first test, the Initial Pull Down (IPD) test, is a widely recognized method for measuring the cooling performance of refrigeration equipment. It measures the cooler's ability to rapidly cool down its contents from room temperature to the desired temperature. This is important because it determines the cooler's ability to quickly chill beverages for immediate consumption, which is a critical factor for commercial use.

To perform the IPD test, cans or bottles of room temperature beverages were loaded into the cooler, and the starting temperature was recorded. The cooler was then set to the desired temperature, and the time it took for the beverages to reach that temperature was monitored. The results of this test provided important data on the cooler's cooling performance, which is crucial for ensuring that the beverages are kept at the desired temperature for consumption.

The second test, the Energy Consumption test, measured the amount of energy the cooler used over a set period of time. This is an important test for determining the energy efficiency of the cooler and the associated costs of operating it over time. To conduct this test, the cooler was plugged into an energy monitor and left to run for 24 hours. The total amount of energy used was recorded, and the average energy consumption per hour was calculated.

The results of both tests provide valuable information that is essential for evaluating the performance and efficiency of commercial coolers. This information is important for consumers who want to make informed decisions when purchasing commercial refrigeration equipment. By knowing the cooling performance and energy consumption of a cooler, consumers can make informed decisions and choose equipment that meets their needs while also being energy-efficient and cost-effective.

The results of the Initial Pull Down (IPD) test conducted on a commercial cooler with PET bottles and cans loaded in cooler (Figure 6b) are shown in Figure 7, which displays the temperature changes over time during the cooling process. According to industry standards, the temperature of any beverage at any point inside the cooler should not drop below 0°C, and all beverages should be cooled below 7°C. The highest, lowest, and average temperatures measured over time are shown in the figure. As can be seen from Figure 7a, within 23 hours and 51 minutes, all PET bottles inside the cooler cooled below 7°C, and none of them dropped below 0°C. On the other hand, the aluminum cans reached the desired temperature within 28 hours.

These experimental results provide important information regarding the cooling performance of the commercial cooler for both PET bottles and cans. The IPD test is crucial in determining the cooler's ability to rapidly cooled beverages for immediate consumption, and the results indicate that the cooler is capable of meeting industry standards for temperature regulation. Additionally, the Energy Consumption test can provide valuable insight into the cost-effectiveness of the cooler over time, and further experiments could be conducted to determine its long-term energy efficiency. Overall, this information can assist consumers in making informed decisions when selecting a commercial cooler for their needs.

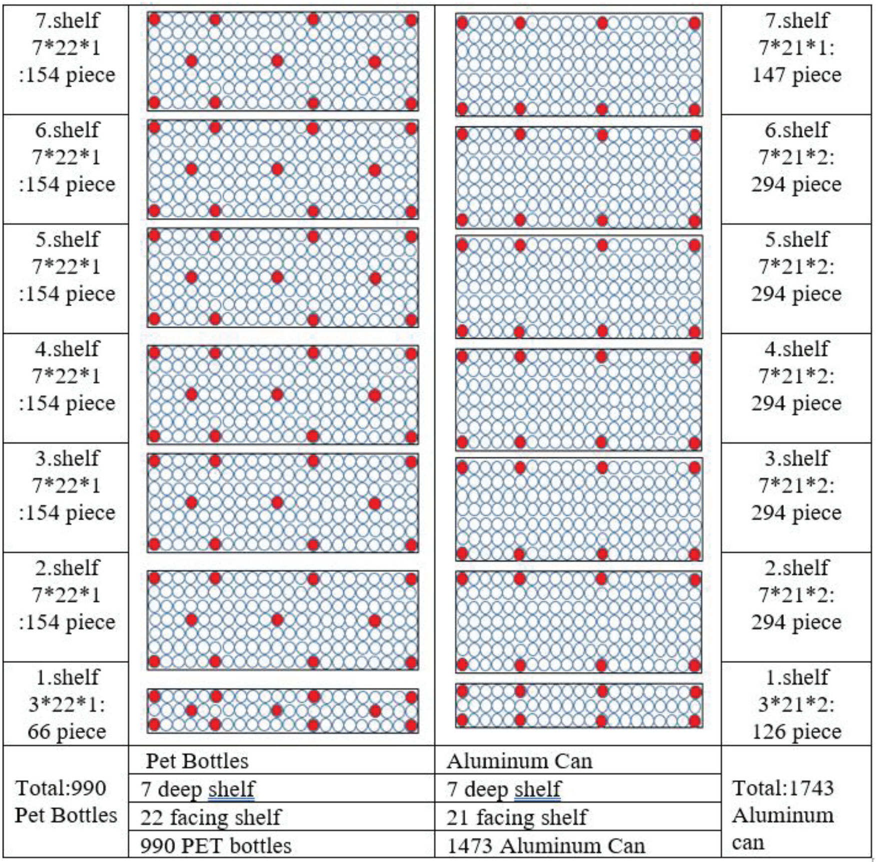
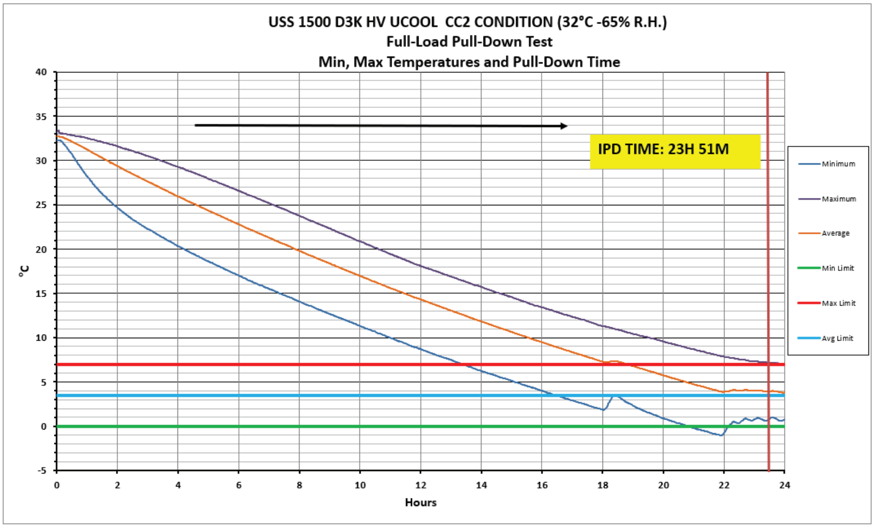


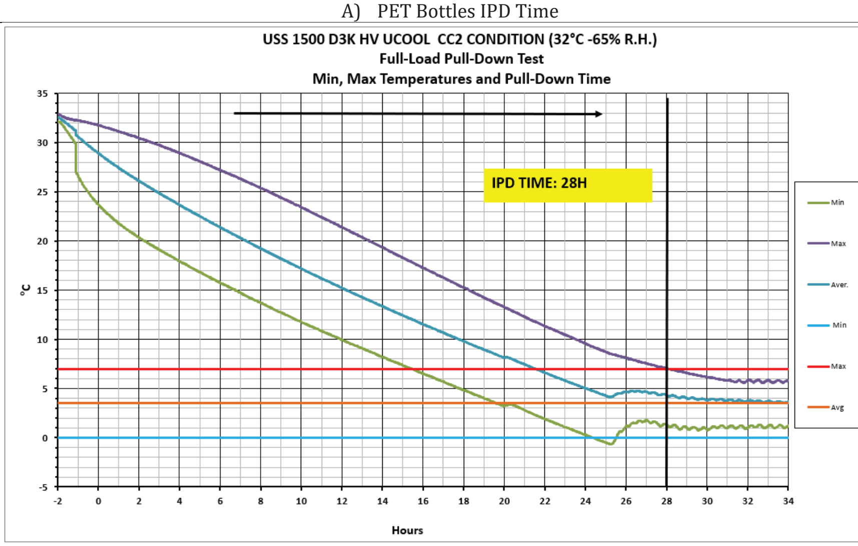
Figure 7. Loading plan and measurement points for Aluminum CAN loaded and PET bottle loaded states of a 3-door commercial refrigerator.

Commercial coolers play an important role in the food and beverage industry, providing a means for storing and serving beverages at the desired temperature. However, their energy consumption can have significant environmental and economic impacts. As such, it is crucial to evaluate the energy efficiency of these appliances.

In this study, a commercial cooler was tested using a total of 990 plastic bottles and 1743 aluminum cans, with a starting package temperature of 32°C in an ambient environment of 32°C. The initial pull-down time, or the time it took for the maximum package temperature to reach a temperature of 7°C, was recorded for each type of packaging. During this time, the energy consumption of the cooler was monitored to determine its efficiency.



A) PET Bottles IPD Time

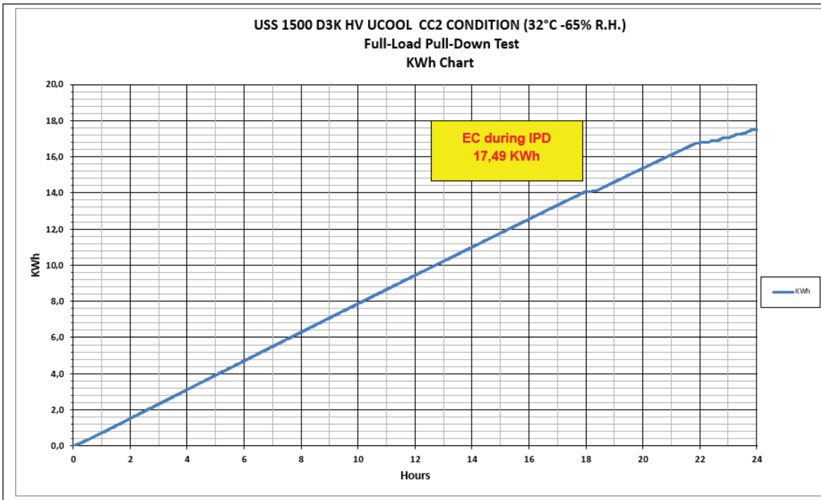


B) Aluminum Can IPD Time

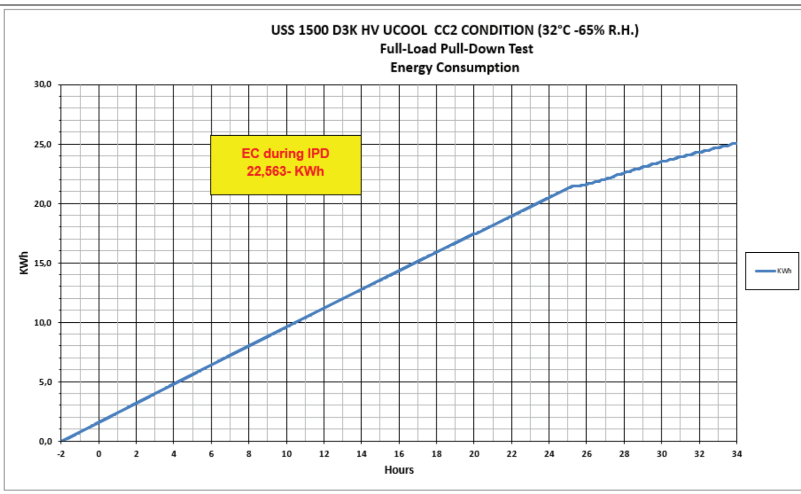
Figure 8. Initial Pull Down (IPD) test

The results showed that the total energy consumption of the cooler during the pull-down time for the plastic bottles was 17.49 kWh (Figure 8a), while the energy consumption for the aluminum cans was 22.563 kWh (Figure 8a). These findings indicate that the commercial cooler is less energy-efficient when cooling plastic bottles compared to aluminum cans.

Additionally, the higher energy consumption for cooling aluminum cans could be attributed to the larger total volume of beverages that need to be cooled in the same amount of time. It is also possible that the design and construction of the cooler may have contributed to the difference in energy consumption between the two types of packaging materials. These results highlight the importance of considering the type of packaging material used when evaluating the energy efficiency of commercial coolers. By choosing packaging materials that require less



a



b

Figure 9. Energy Consumption Test Results for cooling 32 °C to 7 °C

energy to cool, such as plastic bottles, businesses can reduce their energy costs and minimize their environmental impact. Furthermore, this study provides valuable information for manufacturers to improve the energy efficiency of their commercial coolers and can aid in the development of more sustainable and environmentally friendly cooling technologies.

Additionally, this research highlights the need for more sustainable and energy-

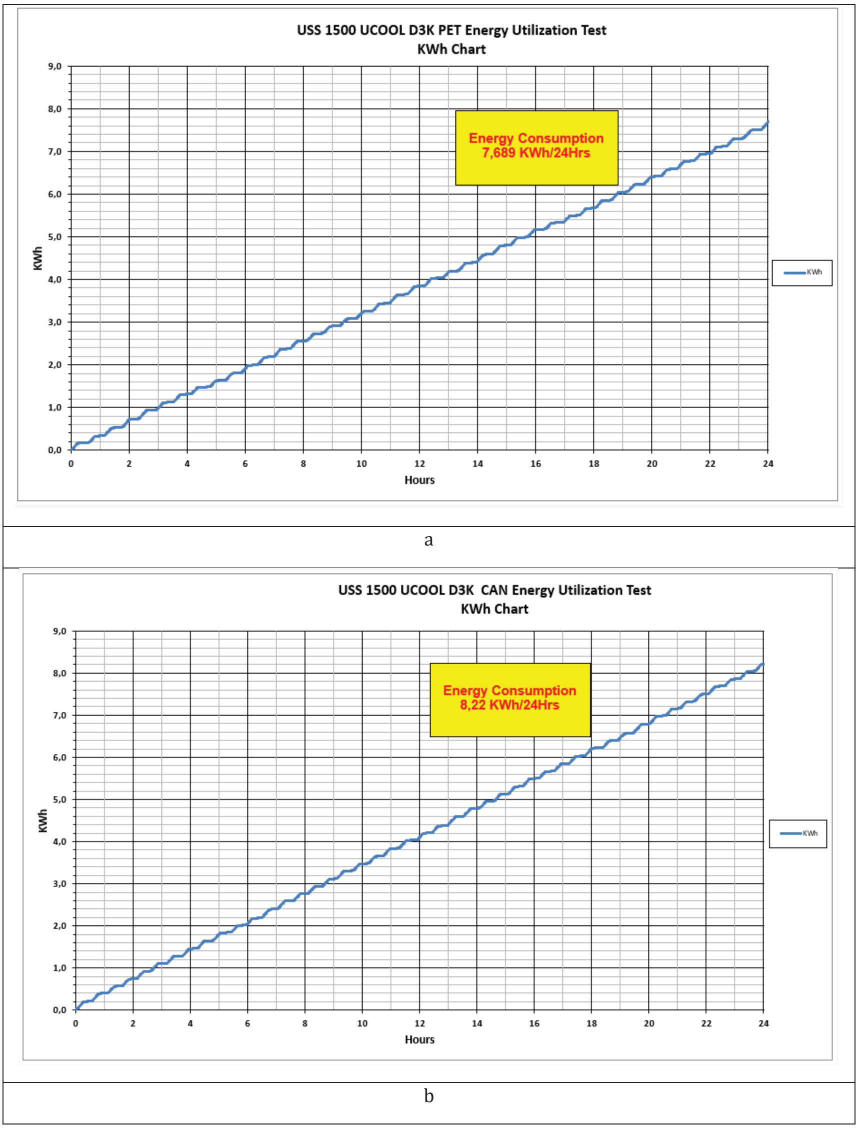
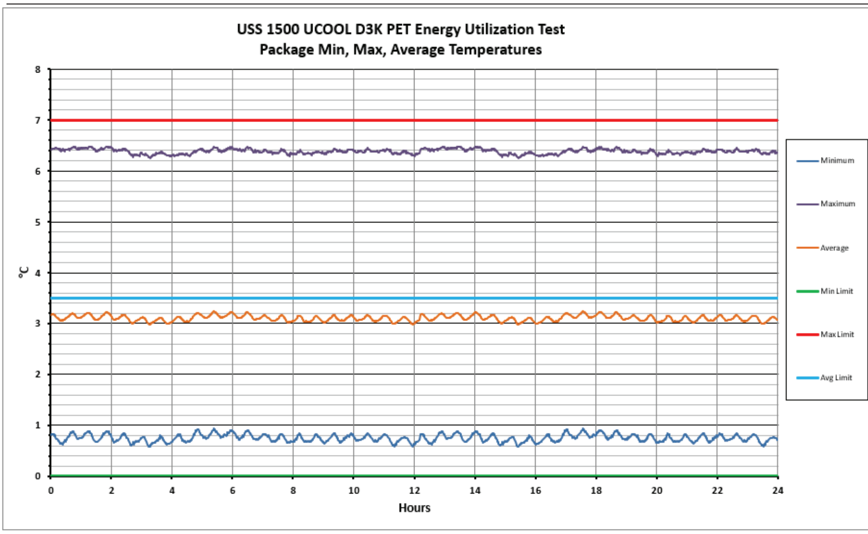
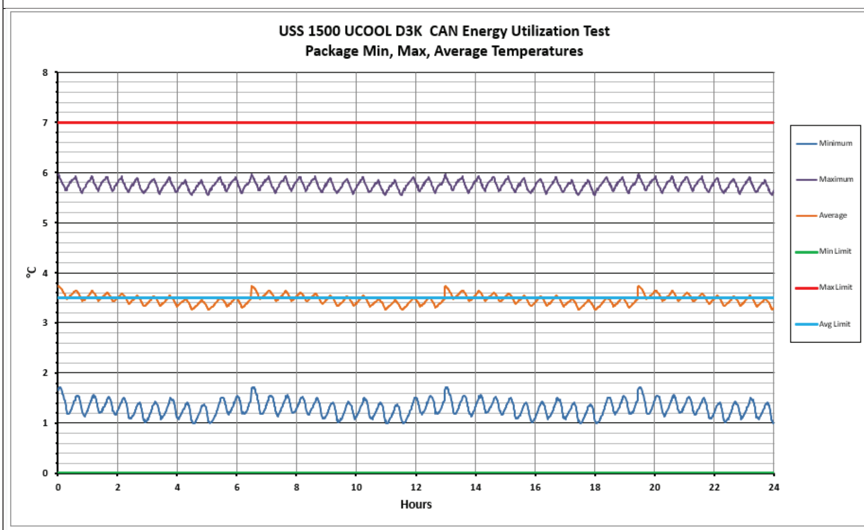


Figure 10. Energy Consumption Test Results for keep to temperature at 7 °C



a



b

Figure 10. Maximum, Minimum, and Average Temperature Ranges Set For The Energy Consumption Test

efficient cooling technologies in the food and beverage industry to reduce energy consumption and minimize environmental impacts.

After bringing the beverages in both the plastic bottles and aluminum cans to the specified temperature, they were stored at the temperature range (Figure.10) while the energy consumption over time and the total energy consumption were recorded and plotted in Figure 9. Over a 24-hour period, with an ambient temperature of 32°C, the total energy consumption required to maintain a temperature between 7°C-0°C was 7.689 kWh for the plastic bottles (Figure 9a) and 8.22 kWh (Figure 9b) for the aluminum cans. The higher energy consumption for the aluminum cans may be attributed to the larger volume of beverages stored in the cans. The results of this study suggest that consumers should consider the energy efficiency of the container material when selecting their beverage packaging, as it can have a significant impact on energy consumption and environmental sustainability.

The maximum, minimum, and average temperature ranges were determined for the energy consumption test, and the changes in the temperature of the PET bottles and aluminum cans inside the cooler were recorded for 24 hours after they were cooled to between temperature range from an ambient temperature of 32°C, as shown in Figure 10. It is important for the measured packages to stay within the designated limits of minimum and maximum temperature ranges, maximum temperature of package should be below 7°C.

Additionally, the average temperature of the packages should be below 3.5°C and also it is not desirable for the temperature of any beverage to drop below 0°C. These temperature ranges ensure that the beverages are stored at safe and optimal temperatures, providing valuable information for consumers and manufacturers in terms of maintaining beverage quality and safety.

This study examines the energy consumption and heat conductivity of beverage coolers for PET bottles and aluminum cans. A total of 990 PET bottles (450 ml each) were loaded into a cooler, resulting in a total cooled volume of 445.5 liters. The daily electricity consumption required to maintain this volume at a stable temperature was 7.689 kWh/24h, with an energy consumption of 7.76 W per PET bottle per day. In comparison, a total of 1743 aluminum cans (330 ml each) were loaded into a cooler, resulting in a total cooled volume of 575.19 liters. The daily electricity consumption required to maintain this volume at a stable temperature was 8.22 kWh/24h, with an energy consumption of 4.71 W per aluminum can per day (See Table 5).

The results show that total energy consumption for 990 numbers PET bottles have a lower energy consumption than 1743 numbers of Aluminum Can. Although aluminum has a higher heat conduction coefficient than plastic, IPD time and energy consumption are higher. The reason for this, there is a significant difference in the number of test packages. According to Table.5 the energy consumption for per Aluminum Can and per PET bottle, we see that aluminum consumes about 1.64 times less energy. The choice of material for beverage packaging will depend on various factors, including cost, availability, and environmental considerations. While aluminum has advantages in terms of durability and recyclability, its high heat conductivity makes it less effective at insulating beverages. Overall, this study highlights the importance of considering packaging materials in the design and operation of beverage coolers to optimize energy efficiency and reduce environmental impact.

Table 5. Summary of Test Results

Description	PET	Al. Can
Amount	990 (450ml)	1743 (330ml)
Total cool down liters	445,5	575,19
Initial Pull Down Time IPDT	23H 51M	28H
Energy Consumption During IPDT	17,49	22,563
Steady State Energy Consumed kWh/24h	7,689	8,22
Energy per can/pet Watts	7,76	4,71

In conclusion, the choice of packaging material can have a significant impact on heat conductivity and energy consumption in beverage coolers. While aluminum has advantages in terms of durability and recyclability, it has high thermal conductivity, results show that one aluminum can requires less energy and cools faster. PET, on the other hand, has a low heat conductivity, which makes it a better choice for insulating beverages and thus allowing them to cool down later. Ultimately, the choice of material will depend on a range of factors, including cost, availability, and environmental considerations.

5. Conclusion

Commercial coolers are an essential tool for businesses in a variety of industries, providing the ideal solution for cold storage and temperature-sensitive products. When choosing a commercial cooler, businesses need to consider the capacity, temperature control, energy efficiency, durability, and ease of maintenance to ensure that the unit meets their specific needs. With the right commercial cooler, businesses can keep their products at a safe and consistent temperature, reducing waste and increasing efficiency.

The energy efficiency of commercial coolers is a critical consideration for businesses in the food service and hospitality industries. Energy-efficient coolers help to reduce operating costs, minimize the business's carbon footprint, and improve the reliability and longevity of the unit. Companies are increasingly attaching importance to energy efficiency and are looking for coolers that are designed to meet their energy efficiency expectations. By purchasing an energy-efficient cooler, businesses can make a positive impact on the environment and their bottom line.

Aluminum has a high heat conductivity, which makes it a poor choice for insulating beverages. Heat can easily pass through aluminum, making it less effective at keeping beverages cold. The thermal conductivity of aluminum is relatively high, which means that aluminum cans allow for faster heat transfer. As a result, beverages inside aluminum cans tend to cool more quickly than PET types of containers. Aluminum has other advantages that make it a popular choice for packaging beverages. Aluminum is lightweight, easy to shape, and durable, making it ideal for packaging and transporting beverages. In addition, aluminum is recyclable, making it an environmentally friendly choice.

PET, on the other hand, has a low heat conductivity, which makes it a better choice for insulating beverages. PET is a type of plastic that is commonly used for food and beverage packaging. It is lightweight, shatterproof, and has good barrier properties, which help to keep beverages fresh. PET is also recyclable, making it an environmentally friendly choice.

When it comes to energy consumption, the choice of packaging material can have a significant impact on the amount of energy needed to keep beverages cool. In general, materials with low heat conductivity will require less energy to maintain a certain temperature. This is because less heat is able to penetrate the material, meaning that less energy is needed to remove that heat.

The study showed that the choice of packaging material can have an impact on the energy consumption and heat conductivity of beverage coolers. The cooling load of the bottle cooler varies, especially according to the amount of beverage inside. UCOOL 1500 D3K HV UCOOL 1500 D3K HV was tested with 1743 aluminum 990 PET bottles. Aluminum Cans allows more loading by the seller, but also leads to more energy consumption. On the other hand, the test with PET bottles resulted in lower energy consumption as the cooling load in the cabin was lower. The choice of material for beverage packaging will depend on various factors such as number of loads, cost, availability, and environmental considerations. Therefore, it is essential to consider packaging materials in the design and operation of beverage coolers to optimize energy efficiency and reduce environmental impact. On the other hand, the aluminum can count and PET bottle count varied in the experiments, and the beverages and their volumes inside each container also differed. Therefore, conducting a comprehensive comparison in terms of cooling times and energy consumption could be misleading.

The thermodynamic cycle used in refrigeration and air conditioning systems is the vapor compression cycle. This cycle consists of four main components: a compressor, a condenser, an expansion valve, and an evaporator. The cycle transfers heat from a cool environment to a warm environment, thereby cooling the cool environment and warming the warm environment. Temperature measurements taken during energy tests provide important information about the efficiency and performance of the refrigeration system.

6. Declaration of Competing Interest

We have recently submitted a research paper with the title: "A Review on Commercial Refrigerator: The Effect of Loading Packages with Different Materials and Shapes on Energy Consumption and Performance". The work described in this paper has been neither copyrighted, classified, published, nor is being considered for publication elsewhere. The authors declare that research and publication ethics were adhered to in this study. There is no conflict of interest among the authors.

References

Albayati, I. M., Postnikov, A., Pearson, S., Bickerton, R., Zolotas, A., and Bingham, C. (2020). Power and energy analysis for a commercial retail refrigeration system responding to a static demand side response. *International Journal of Electrical Power & Energy Systems, 117,* 105645. https://doi.org/10.1016/j.ijepes.2019.105645

Bahar, E. M., Erten, S., and Aktaş, M. (2021). An Experimental Study Towards Decreasing the Energy Efficiency Index Value in Industrial Refrigerators. *Gazi University Journal of Science Part C: Design and Technology, 9* (3), 432-445. https://doi.org/10.29109/gujsc.903320

Bierma, T. J., Jin, G., and Bazan, C. N. (2019). Food Donation and Food Safety: Challenges, Current Practices, and the Road Ahead. *Journal of Environmental Health,* 81(10).

Brown, W. K. (2000). Operation and maintenance of evaporative coolers. ASHRAE journal, 42(7), 27.

Chua, K. J., Chou, S. K., Yang, W. M., and Yan, J. (2013). Achieving better energy-efficient air conditioning–a review of technologies and strategies. Applied Energy, 104, 87-104. https://doi.org/10.1016/j.apenergy.2012.10.037

Cortella, G., Coppola, M. A., and D'Agaro, P. (2021). Sizing and control rules of dedicated mechanical subcooler in trans critical CO2 booster systems for commercial refrigeration. *Applied Thermal Engineering, 193,* 116953. https://doi.org/10.1016/j.applthermaleng.2021.116953

Deneen, M. A., and Gross, A. C. (2002). The global commercial refrigeration equipment market. (Focus on Industries and Markets). *Business Economics,* 37(1), 54-61.

EERE, 2023, Energy Efficiency & Renewable Energy, Purchasing Energy-Efficient Commercial Refrigerators and Freezers, https://www.energy.gov/eere/femp/purchasing-energy-efficient-commercial-refrigerators-and-freezers

Garces, E., van Blommestein, K., Anthony, J., Hillegas-Elting, J., Daim, T., and Yoon, B. S. (2017). Technology domain analysis: A case of energy-efficient advanced commercial refrigeration technologies. *Sustainable Production and Consumption, 12,* 221-233. https://doi.org/10.1016/j.spc.2017.08.002

Garcia, J. M., and Coelho, L. M. R. (2010). Energy efficiency strategies in refrigeration systems of large supermarkets. *International Journal of Energy and Environment, 4* (3), 63-70.

Girotto, S., Minetto, S., and Neksa, P. (2004). Commercial refrigeration system using CO2 as the refrigerant. *International journal of refrigeration, 27* (7), 717-723. https://doi.org/10.1016/j.ijrefrig.2004.07.004

Hardenburg, R. E., Watada, A. E., and Wang, C. Y. (1986). The commercial storage of fruits, vegetables, and florist and nursery stocks (No. 66). US Department of Agriculture, Agricultural Research Service.

Kaushik Bhattacharje CEM (2008) Energy Conservation Opportunities in an Industrial Refrigeration System, Energy Engineering, 105:5, 55-63, https://doi: 10.1080/01998590809509389

Liu, X., Zhang, C. F., Zhou, J. G., Xiong, X., and Wang, Y. P. (2022). Thermal performance of battery thermal management system using fins to enhance the combination of thermoelectric Cooler and phase change. *Material. Applied Energy,* 322, 119503. https://doi.org/10.1016/j.apenergy.2022.119503

Llopis, R., Sánchez, D., Cabello, R., Catalán-Gil, J., and Nebot-Andrés, L. (2017a). Experimental analysis of R-450A and R-513A as replacements of R-134a and R-507A in a medium temperature commercial refrigeration system. *International journal of refrigeration, 84,* 52-66. https://doi.org/10.1016/j.ijrefrig.2017.08.022

Llopis, R., Sánchez, D., Cabello, R., Nebot-Andrés, L., and Catalán-Gil, J. (2017b). R-407H as drop-in of R-404A. Experimental analysis in a low temperature direct expansion commercial refrigeration system. *International Journal of Refrigeration, 80,* 11-23. https://doi.org/10.1016/j.ijrefrig.2017.08.022

Llopis, R., Sánchez, D., Sanz-Kock, C., Cabello, R., and Torrella, E. (2015). Energy and environmental comparison of two-stage solutions for commercial refrigeration at low temperature: Fluids and systems. *Applied Energy,* 138, 133-142. https://doi.org/10.1016/j.apenergy.2014.10.069

Maina, P., and Huan, Z. (2015). A review of carbon dioxide as a refrigerant in refrigeration technology. *South African Journal of Science, 111* (9-10), 01-10. https://doi.10.17159/sajs.2015/20140258

Minetto, S., Rossetti, A., and Marinetti, S. (2018). Seasonal energy efficiency ratio for remote condensing units in commercial refrigeration systems. *International Journal of Refrigeration, 85,* 85-96. https://doi.org/10.1016/j.ijrefrig.2017.09.013

Montagner, G. P., and Melo, C. (2014). A study on carbon dioxide cycle architectures for light-commercial refrigeration systems. *International journal of refrigeration, 42,* 90-96. https://doi.org/10.1016/j.ijrefrig.2014.02.001

Mota-Babiloni, A., Navarro-Esbrí, J., Barragán-Cervera, Á., Molés, F., Peris, B., and Verdú, G. (2015). Commercial refrigeration–an overview of current status. *International journal of refrigeration, 57,* 186-196. https://doi.org/10.1016/j.ijrefrig.2015.04.013

Mota-Babiloni, A., Navarro-Esbrí, J., Barragán-Cervera, Á., Molés, F., Peris, B., & Verdú, G., (2015). Commercial refrigeration–an overview of current status. *International journal of refrigeration, 57,* 186-196. https://doi.org/10.1016/j.ijrefrig.2015.04.013

Mukherjee, P. K., Gibbs, E., Walia, A., and Taylor, C. (2020). Staying cool: The development of India's pioneering energy efficiency policy for chillers. *Wiley Interdisciplinary Reviews: Energy and Environment, 9* (4), e372. https://doi.org/10.1002/wene.372

Park, W. Y., Shah, N., Jacob T., Ding, C. and Karali N., (2021). Climate-Friendly and Energy-Efficient Commercial Refrigerators, Energy-Efficient and Climate-Friendly Commercial Refrigeration Equipment, United Nations Environment Programme – United for Efficiency (U4E).

Polzot, A., D'Agaro, P., Gullo, P., and Cortella, G. (2016). Modelling commercial refrigeration systems coupled with water storage to improve energy efficiency and perform heat recovery. *International Journal of Refrigeration, 69,* 313-323.

Rivers, N. (2005). Management of energy usage in a supermarket refrigeration systems. *The Institute of Refrigeration session.* https://doi.org/10.1016/j.ijrefrig.2016.06.012

Sánchez, D., Andreu-Nácher, A., Calleja-Anta, D., Llopis, R., and Cabello, R. (2022). Energy impact evaluation of different low-GWP alternatives to replace

R134a in a beverage cooler. Experimental analysis and optimization for the pure refrigerants R152a, R1234yf, R290, R1270, R600a and R744. *Energy Conversion and Management,* 256, 115388. https://doi.org/10.1016/j.enconman.2022.115388

Stoecker, W. F. (1998). Industrial refrigeration handbook. McGraw-Hill Education.

Stovall, T. K., and Tomlinson, J. J. (1990). Commercial cool storage laboratory test procedure (No. ORNL/TM-11511). Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States).

Thompson, J. F., Mejia, D. C., and Singh, R. P. (2010). Energy use of commercial forced-air coolers for fruit. *Applied Engineering in Agriculture, 26* (5), 919-924. doi: 10.13031/2013.34934

Thompson, J. F., Mitchell, F. G., and Rumsay, T. R. (2008). *Commercial Cooling Of Fruits, Vegetables, and Flowers* (Vol. 21567). UCANR Publications.

Waide, P., van der Sluis, S., and Michineau, T. (2014). CLASP Commercial refrigeration equipment: mapping and benchmarking. Waide Strategic Efficiency Ltd.

Wang, K., Eisele, M., Hwang, Y., and Radermacher, R. (2010). Review of secondary loop refrigeration systems. *International Journal of Refrigeration, 33* (2), 212-234. https://doi.org/10.1016/j.ijrefrig.2009.09.018

Wang, N., Lv, Y., Zhao, D., Zhao, W., Xu, J., and Yang, R. (2022). Performance evaluation of radiative cooling for commercial-scale warehouse. *Materials Today Energy,* 24, 100927. https://doi.org/10.1016/j.mtener.2021.100927

Westphalen, D., Zogg, R. A., Varone, A. F., Foran, M. A., Brodrick, J. R., and DuBois, T. (1996). Energy savings potential for commercial refrigeration equipment. *Final Report Prepared for Building Equipment Division Office of Building Technologies.*

Whitman, B., Johnson, B., Tomczyk, J., and Silberstein, E. (2012). Refrigeration and air conditioning technology. Delmar Cengage Learning. New York, USA.