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Temperature and energy performance of open refrigerated display cabinets using heat pipe shelves

H. Jouhara[a,*], T. Nannou[a], H. Ghazal[b,c], R. Kayyali[b], S. A. Tassou[a], S. Lester[c]

[a]*Brunel University London, Institute of Energy Futures, Center for Sustainable Energy Use in Food Chains, Uxbridge, Middlesex UB8 3PH, UK*
[b]*Kingston University, Kingston upon Thames, KT1 2EE, UK*
[c]*Flint Engineering Limited, The Paddocks, Five Ashes, Mayfield TN20 6JL, UK*

Abstract

The paper describes an innovative design of open display cabinet's shelves, based on flat heat pipe technology is presented. Their influence on the energy consumption of the cabinet and their effect on enhancing the preservation conditions of food products are analyzed. The experimental work was carried out using two identical commercial open display cabinets; one cabinet equipped with conventional/commercial shelves while the other one equipped with the new actively-cooled flat heat pipe shelves. Both cabinets were placed inside an ISO-certified environmentally controlled test chamber and experiments were carried out under stable environmental conditions. Food block simulators and real food products were used for the tests. The temperature distribution inside the real food products and the power consumption of the cabinets were measured for the cabinets' set point of 2.0°C. The experimental outcomes were that the use of the heat pipe shelves can homogenize the temperature profile of the products and improve the heat transfer between the cabinet, the shelves and the products. Moreover, the heat pipe shelves facilitated the reduction of the electrical energy consumption of the cabinet by 12% approximately. Finally, a primary of the acidity levels (pH) of the products was conducted. The experiments showed that almost all products placed on the heat pipe shelves, after 20 days of experiments, had almost the same pH values, even 20 days beyond their expiration date.

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Keywords: Heat pipe refrigeration shelves; open display cabinets; food preservation

* Corresponding author. Tel.: +44-18952-67805; fax: +44-1895-269777.
E-mail address: hussam.jouhara@brunel.ac.uk

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1. Introduction

Retail food outlets are among the largest consumers of electric energy in the UK. Their energy consumption is estimated around 2,000 kWh/m2/year, depending on the sales area of the store, the business practices, the store configuration, the shopping activity and the equipment used in-store for preserving and displaying food products [1]. It is essential to note that almost half percent of that energy is consumed by refrigeration equipment only, while the rest is consumed by other supporting systems (air-condition, etc.).

The most common type of refrigerators used in supermarkets and retail stores worldwide is vertical open type display cabinets. This type of cabinet is equipped with a recirculating air curtain that acts as an aero-thermodynamic barrier between the inside domain of the cabinet and the external environment, allowing at the same time the display of the food products without imposing any physical restrictions between them and the consumers. However, the heat conduction between the food products and the shelves, in the conventional design of the cabinets is relatively poor, causing the inefficient cooling of food products in sites where the products are in direct contact with the shelf. In addition, they often show large temperature variations and significant temperature rises during defrost cycles.

The legislation of UK Government, in compliance with ISO 23953:2005 states that all foodstuffs shall be maintained at a temperature below 5°C [2]. However, existing cabinet designs are not capable of maintaining minimum temperatures without causing localized freezing somewhere in the cabinet. Studies of Consumer's Association have showed that 70% of foodstuffs in retail display cabinets are stored at temperatures above 8°C, while 60% of the products are maintained at a temperature of 10°C or more [3]. Therefore, the improvement of refrigeration systems is crucial.

The way that refrigeration works is by preventing or retarding the deterioration, spoilage and growth of pathogens in the food. However, the ultimate goal of refrigeration systems is not only to secure the edibility of foodstuff, but to preserve the food products at the peak of their quality, regarding their appearance, odour, taste and vitamin content, as any detectable changes of any of these factors reduces the commercial value of the product and entails economic loss.

2. Open display cabinets performance and food spoilage

Over the years a lot of research has been conducted investigating the performance of retail food cabinets regarding their ability to maintain the quality of products. Gill et al. studied the effects of temperature and aging of packs of beef displayed in multi-shelf retail cabinets [4]. They showed that in general older packages of beef were cooler than newer, packages at the back of shelves were cooler than packs placed at the fronts and packages on intermediate shelves were cooler that the packs of top or bottom shelves. Evans et al. evaluated the performance of open front display cabinets and they noticed that the majority (97%) of maximum temperature packs are located at the front and the largest number of them (60%) are placed at the front of the base of the cabinet [5]. The conventional design of refrigeration cabinets provides poor heat conduction between food products and shelves, resulting insufficient and not uniform cooling of the core temperatures of the food. According to research food temperatures in the same cabinet can vary between up to 10°C [6].

Maidment et al. succeed to address the design malfunctions of display cabinets by a new approach. They showed that better heat transfer rates between the food product and the shelf can be achieved, by positioning the product in direct contact with a cold base [7]. In this way the efficiency of the cabinet is improved, its energy consumption is reduced and the food quality and safety are enhanced. Some years later Maidment et al. simulated the application of a superconductive heat pipe shelf in a retail cabinet [7]. Later on, Wang et al. continued the work of Maidment et al., by implementing Phase Changing Materials (PCMs) into the structure of the heat pipe shelf for better heat transfer [7]. Lu et al. conducted a comparison between the conventional shelves used on the display cabinets, a new structure of heat pipes shelves and the heat pipes shelves combined with appropriate PCMs [8]. They found that only the incorporation of the heat pipe self in the refrigerator was able to reduce the food core temperatures by 3 to 5.5°C compared to the conventional shelf's design, while the shelf with both heat pipes and PCMs managed to lower the food temperature fluctuations during the defrost cycles by 1.5°C and improve the overall uniformity of the food temperature distributions; however the heat pipe shelves showed no contribution in reducing the cabinet's energy consumption.