Manuscript ID: 1206
DOI: 10.18462/iir.icr.2019.XXX

Airflow design in refrigerated retail display cabinets and its impact on food quality

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ABSTRACT

This paper investigates how refrigerated display cabinet airflow design can enhance temperature distribution and potentially reduce food waste. Conventional refrigerated retail cabinets have a single column of cold air from the top to the bottom of the merchandising envelope. By contrast separating the retail space into individual cells, each with its own shorter air-curtain reduces infiltration and improves temperature control.

The quality and safety of bagged salad over an extended display period was evaluated in a conventional and multiple short air-curtain cabinet. At the end of the test period there was a visible difference in cabinet temperature and relative humidity, which had a direct impact on the salad organoleptic quality and microbiological safety. The temperature band was 11.2ºC and 5.4ºC in the conventional and multiple air curtain cabinets respectively, resulting in a higher degree of salad wilting and shrivelling and an increase on total yeast counts on the conventional cabinet.

Keywords: Refrigeration, Food Quality, Retail Display Cabinet, Air Curtain, Temperature Stability

1. INTRODUCTION

Food waste has a considerable environmental and economic impact. According to a study commissioned by the Food and Agriculture Organization of the United Nations about one third of food produced worldwide is wasted, accounting for a total 1.3 billion tonnes (FAO, 2013). It is estimated that the UK retail sector is responsible for 0.25 Mt of food waste every year (WRAP, 2015). An effective cold chain is fundamental to maintain both food safety and quality as refrigeration significantly reduces the rate of growth of pathogens and spoilage organisms and slows down physiological (e.g. ripening), biochemical (e.g. pigmentation) and physical processes (moisture loss) within food products (Gwanpua *et al.*, 2015).

Fresh vegetables are living tissues that undergo respiration and transpiration processes, which dramatically affect product quality and the rate of these processes is greatly affected by temperature. During respiration oxygen is consumed and sugar is converted into CO_2, water and heat energy. The heat of respiration increases with temperature resulting in metabolic changes in composition, texture and colour. Loss of moisture due to transpiration where there is loss of water vapour from the living tissues results in wilting and shrivelling, two obvious signs of lost freshness (ASHRAE, 2006). Leafy vegetables such as iceberg and romaine lettuce, baby leaf lettuce and spinach are particularly sensitive to temperature abuse. It is recommended that fresh leafy vegetables are kept below 5°C at all times throughout the cold chain to ensure food safety. The recommended shelf life for lettuce (iceberg and romaine, chopped, shredded and whole leaf) and spinach (whole and cut leaves) is 6 days (when packaged in air) (FAO/WHO 2008).

A European survey on open refrigerated display cabinets showed that cabinet temperatures range from -2.2 to 12.2°C (EFSA, 2007). Evans *et al.* (2007) further reported that the majority of high temperature abuse (97%) was located at the front of the open-refrigerated display cases (closest to the aisle) and that refrigeration systems and designs of retail displays were not sufficient to keep temperature or humidity within recommended ranges. Furthermore, temperature profiles in commercial retail displays showed large variation depending on location of the products in the displays (Nunes *et al.* 2009). Kou *et al.* (2014) studied the refrigerators temperature profile and its impact on the product quality of baby spinach. They showed that many of the food-products in an open display cabinet are cooled below freezing. This can cause ice-crystal formation and freeze damage of the products. The average temperature differential within the refrigerator was found to be 7.3ºC and many of the products located at the front of the cabinet were not cooled sufficiently.

A common way to distribute cool air in a multi deck display cabinet is through perforated plates in the rear of the cabinet, and in the front of the cabinet is an air curtain. Air is blown out of the back panel between the shelves to cool the load and stabilise the air curtain and enable a lower discharge velocity to be used for the air curtain. Typically the air velocity between the shelves will be 0.05 to 0.4 $m.s^{-1}$, 3 to 5 times less than that of the air curtain (Axell *et al.*, 1999). Significant research has been carried out to determine the ratio of back panel flow to air curtain flow. Gray *et al.* (2008) claims that 70% of the air circulated should be used to supply the curtain and 30% of the flow should be discharged through the back panel for the best results. More recently Wu *et al.* (2013) conducted similar investigations using Computational Fluid Dynamics and experimental techniques, they found that the optimal split was still approximately 70/30.

The air curtain of an open display refrigerator is a turbulent plane jet of air that seals the refrigerated retail space from the ambient air. The momentum created by the air curtain provides a non-physical barrier against heat and moisture, while facilitating easy access for customers. The amount of heat and mass transfer across the air-curtain is directly affected by the initial velocity, turbulence intensity and the length of air-curtain and width of the jet (Pitchers *et al.* 2018). The best performing air-curtain will be one with the minimum required velocity to completely seal the product space. An air-curtain with an initial velocity that is too slow will not have sufficient momentum to seal against the ambient air and will allow excessive heat and moisture to infiltrate into the cabinet. An air-curtain that has an initial velocity that is much higher than required will experience an increased amount of viscous mixing between the still ambient air and the fast turbulent jet of air; this process of viscous mixing is referred to as entrainment.

Shorter air-curtains will require less minimum velocity to seal against the ambient air and will thus entrain much less heat and moisture into the cabinet resulting in a reduction in the refrigerated energy consumption. If short air curtains were to be utilized, a stable air curtain can be created using a slow velocity and so the problematic back panel flow can be eliminated. The elimination of back panel flow will then enable better temperature control independently of cabinet loading (Hammond *et al.* 2016).

Short air curtain technology works by dividing the refrigerated display area into separate airflow managed cells with short, stable air columns. Each cell has its own air curtain, which is more efficient than the full height air curtain on a conventional retail display refrigerator. The net result is less pressure on the air curtain of each cell, reduced entrainment rates, and a substantial reduction in cold air spillage from the cabinet (Wood, 2013). As a result, energy efficiency and product temperature control is improved.

This paper investigates how cabinet airflow design can enhance temperature distribution and potentially reduce food waste. In order to achieve this, the quality and safety of bagged salad over an extended display period was evaluated in both a conventional refrigerated retail cabinet and cabinet with multiple short air-curtains.

2. MATERIALS AND METHODS

The cabinet tests described in this paper were carried out at Adande's test facility in Lowestoft. All Adande test chambers comply with the ISO 23953:2015 specifications. Ambient and product temperatures were recorded using PT100 temperature probes with an accuracy of ±0.2ºC, readings were recorded every 15s. Relative humidity was recorded using humidity sensors with an accuracy of ±3%, readings were recorded every 60s.

The ambient conditions in the test rooms were controlled to climate class 3 (25°C, 60% relative humidity) and measured in front of each cabinet following the ISO 23953-2:2015. Cabinet A (multiple air curtain technology) was set up in test room 1 and cabinet B (conventional single air curtain) was set up in test room 3.
Each cabinet was loaded with bagged salad in the following locations: top shelf left (6 bags), middle shelf centre (6 bags), bottom shelf right (6 bags). The salad bowls were placed in the following locations: top shelf right (6 bowls), middle shelf centre (6 bowls), bottom shelf left (6 bowls). The intermediate shelves had 7 bags/bowls for microbiological samples (one replicate per day). The remaining space was filled with test packages. Measurement packages were placed in the top, middle and bottom shelves at the front and back of each shelf to give an indication of product temperature. The m-packs and test packs have the same thermal properties as lean beef.
Dataloggers were placed on the centre of top, middle and bottom shelves to record cabinet air temperature and relative humidity over the 7-day display period.
Figures 1 and 2 show the multiple air curtain technology (cabinet A) and conventional cabinet (cabinet B) loading respectively.

Figure 1: Cabinet A

Figure 2: Cabinet B

The baby leaf salad bags and house salad bowls displayed in both cabinets were photographed at the beginning of the trial (day 0) and days 5 and 7 to monitor product appearance.
The baby leaf salad bags contained baby iceberg lettuce; baby spinach and red Batavia, whilst the house salad bowls contained a mix of crisp iceberg and romaine lettuce, cherry tomatoes, cucumber, red onion and radish. An organoleptic assessment of the salad bags/bowls was carried out on day 7 following the food scoring system illustrated in Figure 3.

Degree and Direction of Difference from Target

	Not Acceptable Quality	Significant Difference	Marginal	Slight Diference	Equal to TARGET	Slight Diference	Marginal	Significant Difference	Not Acceptable Quality
Sensory Score	1	2	3	4	5	6	7	8	9
%QI	0%	25%	60%	85%	100%	85%	60%	25%	0%

Figure 3: Nine-point bipolar food scoring system

A salad bag/bowl were taken from each cabinet everyday during the trial period and delivered to a local laboratory for microbiological testing i.e. measurement of yeasts, moulds and total viable counts (incubated at 30°C for 48 h).

3. RESULTS

3.1 Temperature stability

Table 1 shows a comparison of the air temperature and relative humidity in both cabinets.

Table 1: Average air temperature and relative humidity in cabinets A and B

Probe location	Air Temperature (°C)		Relative Humidity (%)	
	Cabinet A	Cabinet B	Cabinet A	Cabinet B
Top Shelf Left	4.02	5.06	79.76	80.90
Middle Shelf Centre	2.60	7.98	89.06	79.61
Bottom Shelf Right	3.71	11.52	87.99	68.69

The air temperature in the multiple air curtain cabinet (cabinet A) was on average 1 to 7.5°C cooler than the conventional cabinet (cabinet B) and the relative humidity was 9% higher in cabinet A. Figures 4 and 5 show the measurement packs temperature during the test in cabinets A and B respectively.

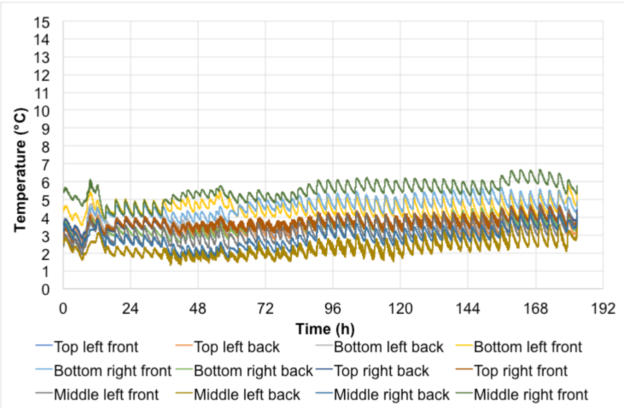

Figure 4: Temperature stability in cabinet A

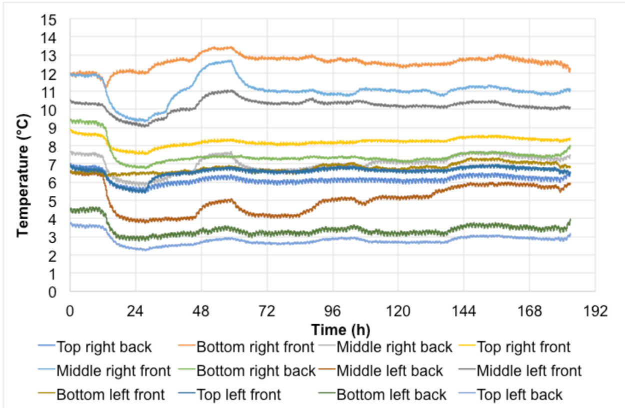

Figure 5: Temperature stability in cabinet B

As can be seen in Figure 4 the product temperature in the cabinet A was controlled within a tight band throughout the trial period and the average packs temperature was 3.71°C. The temperature in the conventional cabinet B was considerably wider compared to cabinet A with temperatures between 2.23°C and 13.46°C. The average packs temperature was 7.28°C in cabinet B.

3.2 Baby leaf salad bags quality

Figures 6 and 7 show the baby leaf salad on day 5, the last day of the use by date.

Figure 6: Day 5 - Baby leaf salad

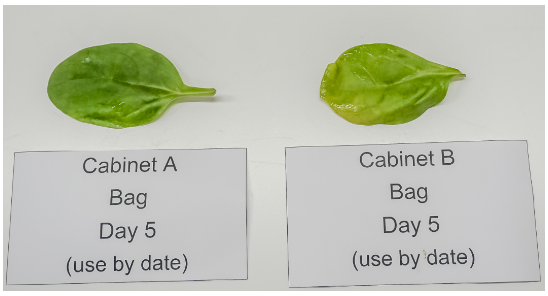

Figure 7: Spinach from cabinets A and B

There was a higher degree of shrivelling in the baby leaf salad displayed in the conventional cabinet compared to the multiple air curtain cabinet on day 5. The spinach displayed in the conventional cabinet had turned yellow and there was moisture at the surface of the leaf, the spinach displayed in th cabinet A was still green on the last day of its use by date.
Figures 8 and 9 show the baby leaf salad on day 7, two days after the use by date.

Figure 8: Day 7 – Baby leaf salad in bags

Figure 9: Day 7 – Baby leaf salad leaves

On day 7 there was visible cellular breakdown on the red Batavia stored in the conventional cabinet demonstrated by the red tinged water accumulated in the bag (see Figure 8).

3.3 House salad bowls quality

Figures 10 and 11 show the house salad on day 5, one day after the use by date.

Figure 10: Day 5 - House salad

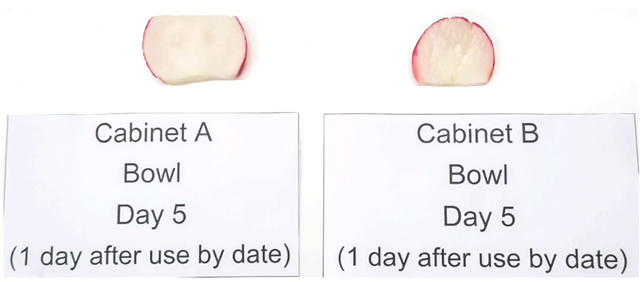

Figure 11: Radish from cabinets A and B

The house salad in cabinet B was very wet, lacked body and the radish was dry. Figures 12 and 13 show the salad on day 7.

Figure 12: Day 7 - House salad

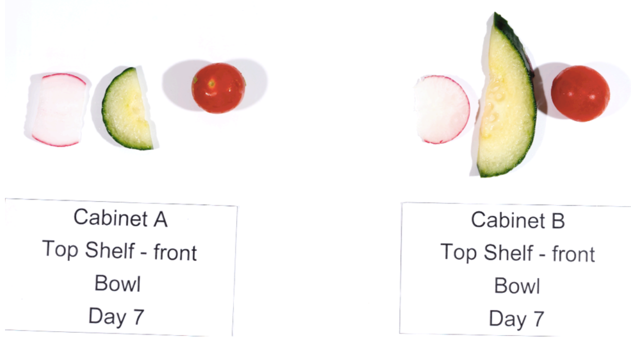

Figure 13: Radish, cucumber and tomato

There was significantly more volume on the house salad displayed in the cabinet A compared to the salad displayed in the conventional cabinet B after 7 days. Cabinet A had crip lettuce and cucumber, firm tomatoes and a clean aroma, whilst the conventional cabinet had limp lettuce, soft slimy cucumber, soft tomatoes and a musty green earthy aroma.

3.4 Organoleptic assessment

Figures 14 and 15 show the baby leaf salad overall finished quality score after a day 7 display period in cabinets A and B respectively. The back diamonds indicate the m-package temperature in each shelf location.

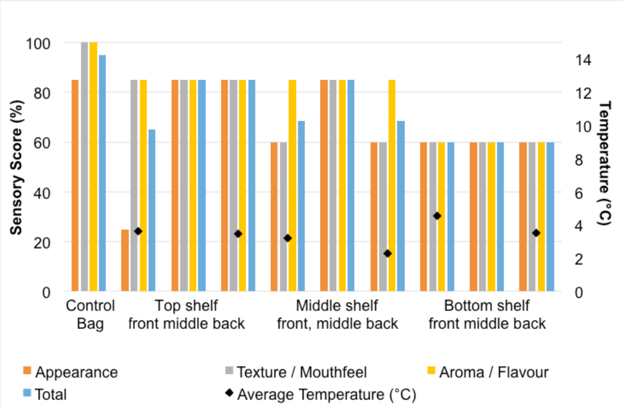

Figure 14: Organoleptic assessment: cabinet A

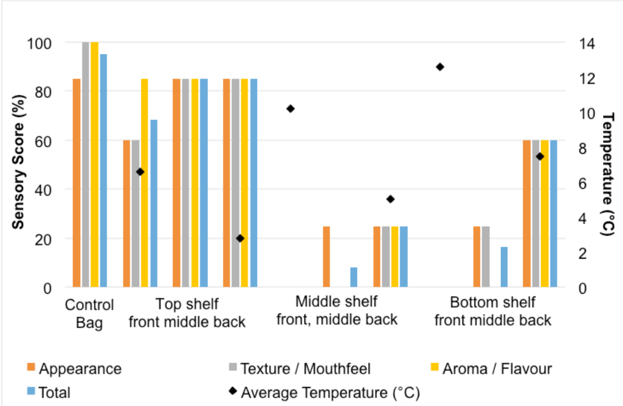

Figure 15: Organoleptic assessment: cabinet B

The total quality score (appearance, texture and flavour/aroma) of the baby leaf salad in cabinet A was equal to or above 60%, which indicates a marginal difference from target. The only case where the appearance was rated low (25%) was on the top front shelf bag, which was the warmest point in the cabinet.
As can be seen in Figure 15 the baby leaf salad overall quality in the conventional cabinet was rated above 60% in the top shelf which had an average air temperature of 5.06°C. However, the middle and bottom shelves show a considerable deterioration in quality on day 7 with a score of 25% in some positions within the selves, which indicates a significant difference from target. The average air temperature in the middle and bottom shelves was 7.98°C and 11.52°C respectively. Similar results were obtained for the house bowls salads: overall quality score for the salad displayed in cabinet A was 68% compared to 44% on cabinet B.

3.5 Microbiological tests

Figures 16 and 17 show the total viable counts (incubated at 30°C for 48 h) and the yeast growth in the samples of baby leaf salad displayed in both cabinets.

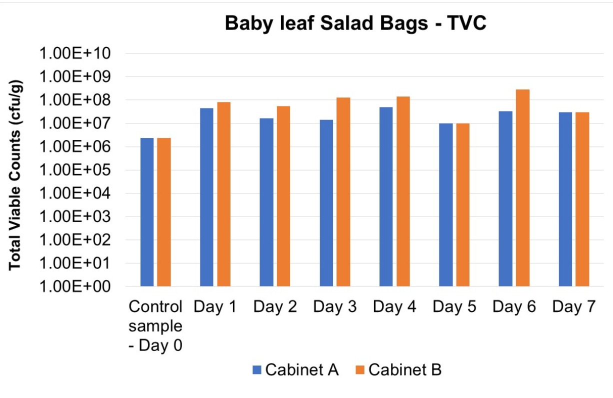

Figure 16: Total viable counts in baby leaf salad

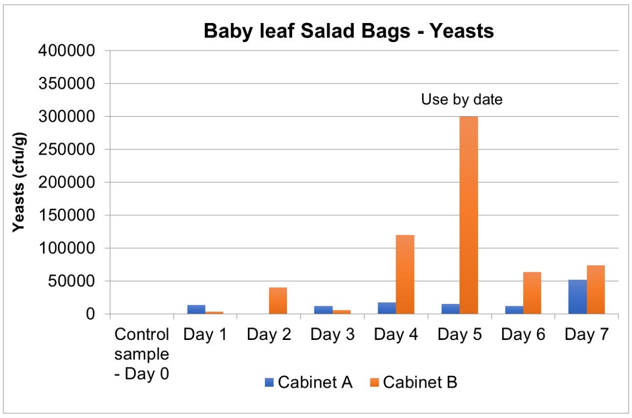

Figure 17: Yeast count in baby leaf salad

As can be seen in Figure 16 the total viable counts (TVC) were consistently higher in the baby leaf salad bags stored in the conventional cabinet compared to the multiple air curtain cabinet. The highest TVC in cabinet A was 5.0 x 10^7 cfu/g compared to 2.8 x 10^8 cfu/g in cabinet B.
Figure 17 shows a substantial difference on the total yeast count between the multiple air curtain and conventional cabinet. By day 5 (use by date) there was 1.6 x 10^4 cfu/g in cabinet A compared to 3.0 x 10^5 cfu/g in cabinet B (the yeast count was 18.8 times higher in cabinet B). Figures 18 and 19 show the total viable counts and the yeast growth in the samples of the House salad displayed in cabinets A and B.

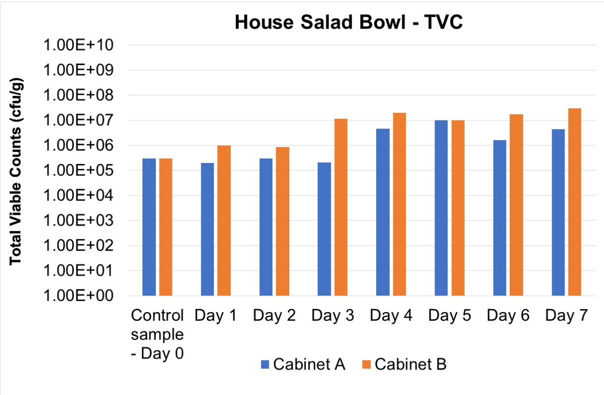

Figure 18: Total viable counts in House salad

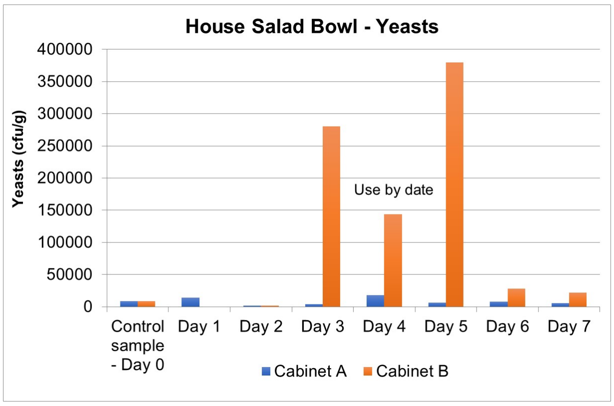

Figure 19: Yeast count in House salad

Again, the total viable counts in the house salad bowls were consistently higher in cabinet B compared to cabinet A. By day 3 (one day before the use by date) the total yeast on the salad displayed in the conventional cabinet was 70 times higher than on cabinet A, 2.8 x 10^5 cfu/g and 4.0 x 10^3 cfu/g respectively.

4. CONCLUSIONS

The multiple air curtain technology showed a significant improvement on temperature stability compared to a conventional single air curtain cabinet with temperature spans of 5.4ºC and 11.2ºC respectively. The relative humidity was also 9% higher on the multiple air curtain cabinet.
There was a significant difference in salad quality at the end of the display period in both cabinets. By day 5, which was the use by date for the baby leaf salad there was a higher degree of wilting and shrivelling in the lettuce and spinach displayed in the conventional cabinet compared to the multiple air curtain cabinet. The spinach in the conventional cabinet was yellow and moisture pooled at its surface indicating a clear loss in freshness. The house salad displayed for 5 days in the conventional cabinet was very wet and was lacking body compared to the one displayed in the multiple air curtain cabinet, which only showed slight leaf damage.
By day 7, two days after the use by date for the baby leaf salad and three days for the house salad there was a more pronounced difference in quality between vegetables displayed on both cabinets. Cellular breakdown on the red Batavia lettuce tinged the water red on the bags stored in the conventional cabinet, which did not occur on the multiple air curtain cabinet. The baby leaf salad displayed in the middle and bottom shelves of the conventional cabinet scored below 25% in the organoleptic assessment showing a clear deterioration in quality, which is directly correlated to the higher average storage temperature of 7.98ºC and 11.52ºC respectively. The baby leaf salad in the multiple air curtain cabinet was rated equal or above 60% in all shelves.
The house salad displayed on the multiple air curtain cabinet generally had more volume and less leaf damage compared to the conventional cabinet. The overall house salad quality was rated at 68% in the cabinet A and 44% in cabinet B.
The total viable counts in the baby leaf and house salad were consistently higher in the conventional cabinet. The total yeast count was 70 times higher on the house salad displayed in the conventional cabinet one day before its use by date.
Overall the test results show a clear difference on salad quality and microbiological safety between the multiple air curtain and conventional cabinet, which can be correlated to the storage

temperature within each cabinet. Additional testing is required to determine if the multiple air curtain technology can increase the shelf life of leafy vegetables by one extra day.

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