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Temperature profiling of open- and closed-doored produce cases in retail grocery stores

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ABSTRACT

Temperature control of produce in the retail environment is essential to reduce food safety risks, maintain quality, and reduce food waste. Previous studies have demonstrated that retrofitting or replacing open display cases doors results in better control of temperature and humidity. However, there are no studies to date that comprehensively evaluate temperature profiles in cases with and without doors in actual retail store environments. Twenty-five open and closed refrigerated display cases in ten retail stores in five states were monitored for temperature and humidity over 9 months. Sensors recorded data every 2 min at eight positions (top, middle, bottom and under the bottom bin, in the front and back locations of each shelf). There were significant differences between open and closed cases, retailers, and sensor position in display cases on temperature and relative humidity ($p < 0.0001$). Seven display cases were retrofitted with doors and, as a result, temperature variations were significantly minimized (p-value < 0.0001). Cases with doors maintained temperatures significantly lower (4.7 °C, p-value < 0.0001) than cases without doors, and the top front position in the cases had both the highest temperature (5.7 °C) and abuse due to high temperature (> 5 °C) for the longest duration (35.7% of total time observed) of allow locations measured. Temperatures and abuse conditions above 5 °C were not significantly different between front and back positions in the cases. The range of temperature and RH variability was reduced following door installation. With changes in display case technology over the past five years, this study provides updated data on operational temperatures in display cases before and after retrofitting with doors. It also provides evidence of the importance of temperature monitoring within display cases to ensure abusive conditions do not persist.

1. Introduction

Approximately half of all food products in retail stores are held in refrigerated display cases (Bertrand, 1993, pp. 54–55; Chaomuang, Flick, & Laguerre, 2017). As of 2010, based on the United States Department of Agriculture's (USDA)'s Economic Research Service estimates, 31% of food waste comes from retail and consumer environments (United States Department of Agriculture, n.d.-a; USDA Office of the Chief Economist, n.d.). In October 2018, the USDA, U.S. Environmental Protection Agency (EPA), and the U.S. Food and Drug Administration (FDA) signed the Winning on Reducing Food Waste Initiative, an interagency agreement to reduce 50% of food loss and waste by 2030 (United States Department of Agriculture, n.d.-b).

The use of refrigerated display cases in retail stores is a common way to extend the shelf-life of food and improve food safety. Retail stores are currently considering the cost:benefit of converting their open refrigerated display cases to closed cases to enhance food quality through improved temperature and humidity control. A study conducted in 2010 on the impact of open vs. closed display cases showed no significant overall impact on sales (Fricke & Becker, 2011). A study in 2017 found that customers understood the benefits of having doors and had a positive perception of having food in closed display cases (Lindberg, Salomonson, Sundström, & Wendin, 2018). The FDA's Food Code states that temperature controlled for safety (TCS) foods must be maintained at temperatures of 41 °F (5 °C) or less during cold storage and display. Studies showed that there was a significant increase in

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food waste, loss of quality, shelf-life reduction, and increased food safety risk in produce kept at temperatures above 5 °C due to increase enzymatic and microbial activity (de Frias, Luo, Zhou, Turner, Millner, & Nou, 2018; Evans, Scarcelli, & Swain, 2007; Kou, Luo, Ingram, Yan, & Jurick, 2014; Luo, He, & McEvoy, 2010; Luo, He, McEvoy, & Conway, 2009; Nunes, Emond, Rauth, Dea, & Chau, 2009; Zeng, Vorst, Brown, Marks, Jeong & Perez-Rodriguez, 2014).

Temperature monitoring studies in the United States, United Kingdom, and France have shown that food displayed in open refrigerated display cases was subjected to temperature abuse, with temperatures ranging from −1 to 16 °C (Derens, Palagos, & Guilpart, 2006; Evans et al., 2007). Luo et al. (2009) observed a 1 log CFU *Escherichia coli* O157:H7 increase after 3 days and increased decay when commercial packages of baby spinach were kept at 12 °C. In a later study, Luo et al. (2010) also observed that bagged lettuce salads stored at 12 °C for 3 days promoted *E. coli* O157:H7 growth by more than 2 log CFU, even though visual quality was still acceptable. E. coli in bagged lettuce salads held below 5 °C survived but had limited growth.

Improper product-specific temperature control can result in increased food safety risks and monetary losses for retail companies and customers (Badia-Melis, Mc Carthy, Ruiz-Garcia, Garcia-Hierro, & Robla Villalba, 2018). Low product-specific storage temperatures for produce, after harvest and throughout the cold chain, will extend shelf-life (Brecht, Chau, Fonseca, Oliveira, Silva & Nunes, 2003), but extremely low temperatures can cause chilling injury or freezing damage (Badia-Melis et al., 2018). A recommended minimum temperature of 0 °C in display cases holding temperate fruits and vegetables will maintain quality while maximizing shelf-life (Gast, 2008; Mercier, Villeneuve, Mondor, & Uysal, 2017).

Relative humidity (RH) should also be controlled in display cases as produce stored at too low of a RH will lose weight, wilt, and shrivel (Nunes et al., 2009). This will inevitably render it inedible, increasing food waste and causing economic losses to retail businesses. The optimum relative humidity values for fresh fruits and vegetables is usually recommended as above 90% (Nunes et al., 2009).

At the retail level, temperature and humidity storage conditions for produce are controlled by displaying the products in either closed display cases with doors or open display cases with air curtains. Even though cases are set to appropriate temperatures, actual temperatures inside the display cases may vary and therefore product temperatures can vary. Infiltration of warm air into the display cases causes product at the front of the cases to have a higher temperature. Display case product temperature is also affected by defrost cycles, proximity to lights, and interruptions in air flow (Mercier et al., 2017). Faramarzi, Coburn, and Sarhadian (2002) studied the impact of retrofitting doors to open display cases and estimated a reduction in refrigeration load of 68% while reducing overall temperature in food products by 6 °C.

Since the initiation of this study, refrigeration systems have been improved by manufacturers to reduce energy consumption, increase temperature control, and to comply with legislation as retailers faced the decommissioning of certain refrigerants and refrigeration systems (Navigant Consulting Inc., 2013; Shebik, 2015, p. 3). Work conducted by Navigant Consulting Inc. in collaboration with the U.S. Department Of Energy (DOE), the Better Buildings Alliance, and members of industry found that retrofitting existing open display cases with doors was potentially more cost-effective than completely replacing the cases with closed-door units (Navigant Consulting Inc., 2013). The objectives of this research were to determine the temperature and RH profiles of refrigerated fresh produce held in open vs. closed display cases located in multiple states and with multiple retailers. A total of twenty-five display cases located in ten retail stores, and representing four retailers located in five states, were monitored. Seven of the 25 display cases were retrofitted with doors and data were collected over a 9-month period, both before and after modification.

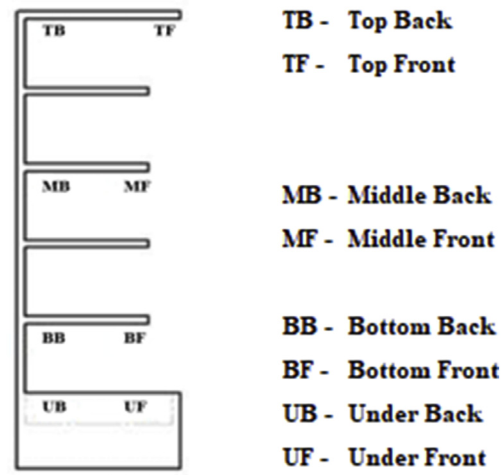

Fig. 1. Side view diagram of a vertical self-service display case showing sensor locations.

2. Materials and methods

This study was conducted in ten retail stores representing four major retailers in five states: California, Florida, New York, Iowa, and Nebraska. Each retailer provided two or three store locations for monitoring based on future plans to retrofit the display cases with doors during the study. Seven stores of three retailers retrofitted their produce display cases with clear glass doors. Between one and four display cases were tagged per store and the cases were used to hold items such as bagged leafy greens, fresh-cut carrots, and containers of fresh-cut fruit, etc. Display cases varied across retailers and within retailers. This study did not control for display case or store design as it hoped to capture the current state of display case efficiency in retailers across the U. S. The vertical refrigerated self-service display cases, both open and fitted with a door, were tagged at 8 locations: at the front and back of the top, middle, and bottom shelves, and under the bottom bin (Fig. 1). The retrofitting process of the display cases was based on the model of the display case and was performed the retailer.

Display case temperature and RH were measured using FlashLink BLE (Bluetooth Low Energy) reusable temperature or temperature and RH data loggers (models 40900 and 40901, respectively, DeltaTrak, Pleasanton, CA). All data loggers had an accuracy of ± 0.4 °C from −10 °C to 60 °C and a resolution of 0.01 °C. The loggers with RH function had an accuracy of ± 6% RH max (between 20% and 80% RH - non-condensing from −10 °C to 60 °C), ± 4% RH typical (over recommended range), with a resolution of 0.03% RH. The sensors were installed under or on the side of the shelves using double-sided tape and were set to record temperature and humidity values at 2-min intervals.

3. Statistical analysis

Sensors were identified with the position, case, city, and restart code. Data were analyzed before and after retrofitting the cases with doors. Variables analyzed were temperature, RH, percent of time above 5 °C (abuse due to high temperature), and percent of time below 0 °C (abuse due to low temperature), using SAS ver. 9.4 (SAS Institute, Cary, NC). Analysis of variance was also used to establish differences between open and closed display cases by position and retailer, with the case effect nested within retailer. Data were paired and compared before and after retrofitting with doors using Tukey's HSD and Bonferroni's Correction, for retailer and sensor location effects. Data for temperature, RH, and percent abuse due to high temperature (> 5 °C) met assumptions of ANOVA. Data for percent abuse due to low temperature (< 0 °C) were log transformed in order to meet assumptions of ANOVA

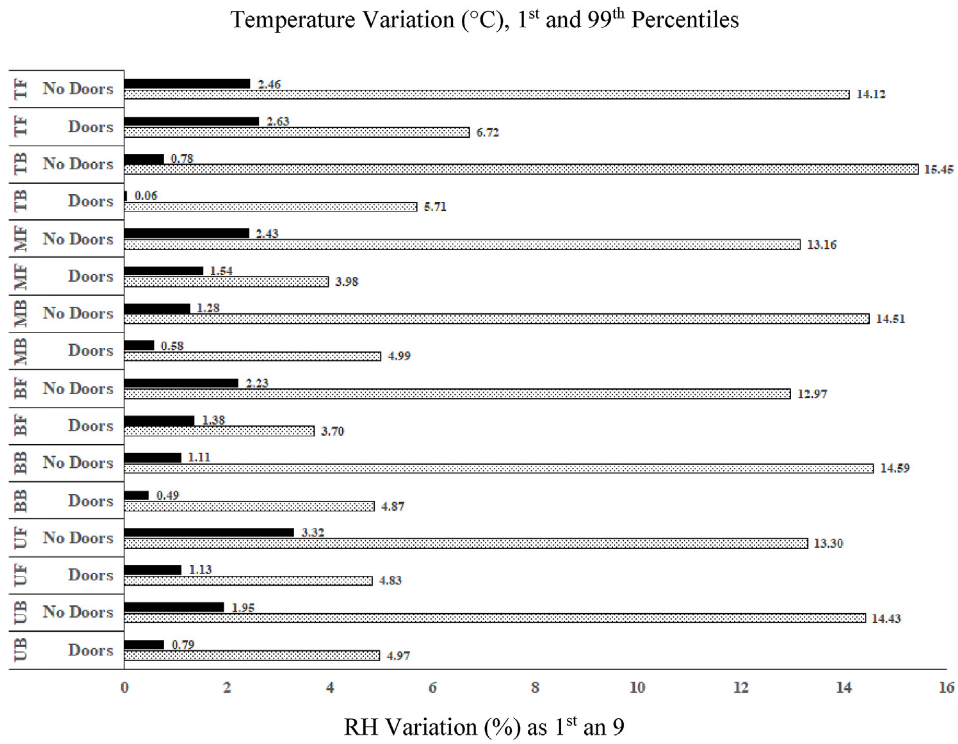

Fig. 2. Temperature variation (°C) 1st and 99th percentiles. Display-case sensor position: TF = top, front; TB = Top, back; MF = Middle, Front, MB = Middle, Back; BF = Bottom, Front, BB = Bottom, Back; UF = Under (bin), Front; UB = Under (bin), Back.

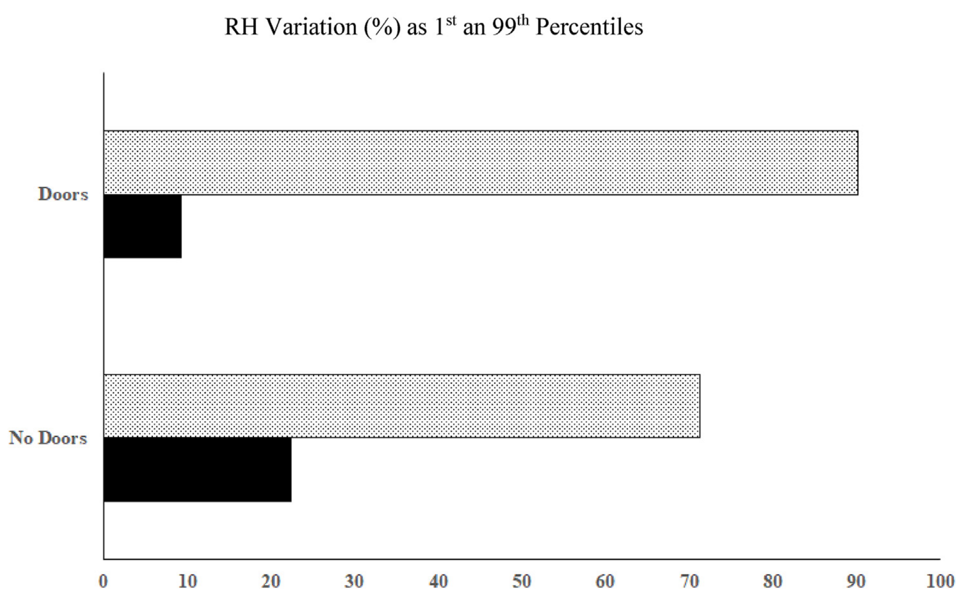

Fig. 3. RH variation (%) as 1st and 99th percentiles.

Table 1
Mean values for temperature and performance parameters of display cases for the main effects of before and after retrofitting with doors.

Doors	Temperature (°C)	Percentage of Time > 5 °C (%)	Percentage of Time < 0 °C (%)	Relative Humidity (%)
No Door	7.3	41.0	0.001	79.5
With Door	2.6	6.3	0.019	95.7
Std. Error	0.2	1.6	N/A	0.8
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

and then back transformed median values were reported. In order to assess the range of temperature and RH values, the 1st and 99th percentiles were computed rather than the 0 and 100th percentiles before and after doors were retrofitted (Figs. 2 and 3). These values were more representative of an expected range because the outliers, especially the maximum values were artificially high due to situations (e.g. maintenance) not related to the normal operation of the cases.

4. Results and discussion

Avoiding temperature abuse, both high (> 5 °C) and low (< 0 °C), while maintaining a high humidity level (above 90%) during retail display is critical to maintaining food safety and food quality. The temperature for display cases retrofitted with doors decreased by 4.7 °C –compared to open display cases (Table 1 and Fig. 2) – resulting in a beneficial temperature below the FDA recommended upper storage limit of 5 °C. Abuse due to high temperature was also reduced by 34.7% when the display cases were fitted with doors. It is imperative to keep produce at a constant low temperature as *Listeria monocytogenes* and *E. coli* O157:H7 have caused many produce-related health problems and research has shown that these pathogens have the ability to grow under refrigerated conditions (Evans et al., 2007; Kou et al., 2014; Nunes et al., 2009; Zeng et al., 2014). Walker et al. studied three strains of *L. monocytogenes* and found generation times as low as 13 h at 5 °C but up to 131 h at 0 °C (Walker, Archer, & Banks, 1990). Francis et al. also found that both *L. monocytogenes* and *E. coli* O157:H7 can increase up to 2.5 log CFU/g on shredded lettuce over a 12-day storage period, depending on the strain (Francis & O'Beirne, 2001). Zeng et al. observed up to 3 log CFU/g growth of *E. coli* O157:H7 and *L. monocytogenes* on romaine lettuce when temperature abuse was up to 16 °C, but no pathogen growth when the lettuce was kept below 4 °C (Zeng et al., 2014).

In contrast to the reduction in abusive high temperatures (> 5 °C), incidents when the temperature fell below 0 °C increased 0.018% when display cases were retrofitted with doors (Table 1). Lower temperatures reduce microbial growth (Francis & O'Beirne, 2001; Zeng et al., 2014), however, they may cause chilling damage of or freezing damage to specific products (Badia-Melis et al., 2018). Freezing injury breaks plant cells accelerating spoilage of leafy greens (Steele, 2004). The reported highest freezing points of Bibb, Boston, Iceberg and Romaine lettuce range from just −0.39 to −0.17 °C (Whiteman, 1957). Physical freezing conditions of leafy-green packaged products were observed by researchers while collecting data. Thus, it is critical to adjust (increase) case thermostats to avoid low temperature abuse after case retrofitting with doors.

RH increased by 16.2%–95.7% after the display cases were retrofitted, compared to the detrimental 79.5% RH for cases without doors (Table 1). The observed RH is significantly higher in cases with doors, which should lead to an improvement in quality and shelf-life of both unpackaged and packaged produce (e.g., strawberries held in clamshells) displayed in cases with doors (Fig. 3).

Retailers have different designs and technologies incorporated into their display cases and corresponding refrigeration systems, and maintenance can affect the performance of these systems (Mota-Babiloni et al., 2015). There were significant differences between retailers in the performance of their display cases (Table 2). The display cases maintained by retailer 4 had a significantly higher temperature, % abuse due to high temperature, and lower relative humidity, before and after retrofitting with doors, compared to retailers 2 and 3. Retailer 4 failed to maintain TCS food products at temperatures < 5 °C more than 84% of the time before retrofitting, but this was reduced to 14.2% of the time after doors were installed. The temperature and RH characteristics of display cases maintained by retailers 2 and 3 were also significantly improved when the cases were retrofitted. This provides evidence that if a retailer has a display case that maintains product at abusive temperatures, retrofitting may be the solution to achieving proper temperature control.

The display cases of retailers 2, 3, and 4 decreased both in temperature and percentage of time at high temperature (> 5 °C) when retrofitted with doors (Table 2). In contrast, the percentage of time product experienced abuse due to low temperature (< 0 °C) increased for retailers 2 and 4 but decreased for retailer 3 after retrofitting. Relative humidity increased in all cases when doors were installed. Other studies have also found that products displayed in open refrigerated display cases may be subjected to abusive temperatures and that closed display cases have more homogeneous temperature profiles (Atilio de Frias, Luo, Kou, Zhou, & Wang, 2015; de Frias et al., 2018; Lindberg et al., 2018; Mercier et al., 2017). Faramarzi et al. found that open refrigerated display cases are more vulnerable to infiltration of warm air from the environment (Faramarzi et al., 2002).

There were differences in temperature at the various positions monitored within the display cases (Table 3). The top front position experienced the highest temperatures, highest percentage of time at temperatures > 5 °C, and showed little improvement when the cases were retrofitted with doors. After retrofitting, the average temperature reduction by position was 4.7°C, with the top front position experiencing less improvement, reducing only 2.4°C. High temperature abuse was reduced on average 34.7% after retrofitting, with the top front position having the lowest reduction of 9.6%. Analyses of temperature and time abuse due to high temperatures indicated no difference (p-values > 0.05) when comparing the average of all values from front positions in the cases with the average of all values from the back

Table 3
Mean values for performance parameters of display cases compared by sensor (datalogger) position, before and after retrofitting with doors. There was no significant interaction by retailer and sensor position.

Positions	Temperature (°C)		Percentage of Time > 5 °C	
	No Door	Door	No Door	Door
Bottom Back	6.5	1.7	35.1	1.6
Bottom Front	7.6	2.4	40.8	1.2
Middle Back	6.7	1.8	35.6	1.9
Middle Front	7.6	2.6	38.5	2.0
Top Back	6.5	1.8	34.7	2.3
Top Front	8.1	5.7	45.3	35.7
Under Back	7.2	2.2	36.6	2.6
Under Front	8.6	2.5	61.4	2.8
Standard Error	0.3	0.3	3.1	3.1
p-value	< 0.0001		< 0.0001	

Table 2
Mean values for performance parameters of display cases compared by retailer, before and after retrofitting with doors. There was no significant retailer by sensor position interaction.

Retailer	Door	Temperature (°C)	Percentage of Time > 5 °C	Percentage of Time < 0 °C	Relative Humidity (%)
Retailer 2	**No Door**	3.8	17.7	0.000	94.2
	Door	1.7	1.5	0.142	99.7
	Std Error	0.4	2.9	[a]	1.5
Retailer 3	**No Door**	3.7	21.2	0.008	93.5
	Door	2.7	3.1	0.002	99.6
	Std Error	0.3	2.4	[a]	1.3
Retailer 4	**No Door**	14.5	84.1	0.000	50.7
	Door	3.4	14.2	0.018	87.8
	Std Error	0.4	2.9	[a]	1.5
p-value		< 0.0001	< 0.0001	< 0.0001	< 0.0001

[a] Standard error for percent time < 0 °C is not reported because the statistical model was log transformed to meet ANOVA assumptions, and therefore this value was not calculated.

Table 4
Means with (standard errors) of the 1st and 99th temperature (°C) percentiles for display cases compared by sensor (datalogger) position, before and after retrofitting with doors. The 'difference' between before and after display case doors were installed is also presented.

Sensor location	Temperature (°C) Percentiles		
		1	99
Top Front	**No Doors**	2.46 (0.37)	16.58 (3.58)
	Doors	2.63 (0.99)	9.35 (1.95)
	Difference	0.18 (1.13)	−7.23 (3.35)
Top Back	**No Doors**	0.78 (0.45)	16.23 (3.60)
	Doors	0.06 (0.32)	5.77 (0.24)
	Difference	−0.72 (0.58)	−10.47 (3.41)
Middle Front	**No Doors**	2.43 (0.33)	15.59 (3.70)
	Doors	1.54 (0.36)	5.52 (0.25)
	Difference	−0.89 (0.56)	−10.07 (3.56)
Middle Back	**No Doors**	1.28 (0.48)	15.79 (3.63)
	Doors	0.58 (0.36)	5.57 (0.24)
	Difference	−0.69 (0.68)	−10.22 (3.46)
Bottom Front	**No Doors**	2.23 (0.4)	15.20 (3.57)
	Doors	1.38 (0.37)	5.08 (0.23)
	Difference	−0.85 (0.99)	−10.12 (3.42)
Bottom Back	**No Doors**	1.11 (0.51)	15.70 (3.76)
	Doors	0.49 (0.38)	5.36 (0.20)
	Difference	−0.61 (0.72)	−10.34 (3.56)
Under Front	**No Doors**	3.32 (0.39)	16.62 (3.29)
	Doors	1.13 (0.34)	5.96 (0.24)
	Difference	−2.19 (0.57)	−10.67 (3.09)
Under Back	**No Doors**	1.95 (0.26)	16.38 (3.56)
	Doors	0.79 (0.41)	5.76 (0.25)
	Difference	−1.16 (0.31)	−10.62 (3.33)

positions. However, studies by Laguerre, Hoang, Osswald, and Flick (2012), Evans et al. (2007), Zeng et al. (2014), de Frias et al. (2018), and Kou et al. (2014) found significant differences between the front and back locations of retail display cases.

There was no effect of sensor position in open or closed display cases on the length of time when temperature fell below 0 ℃ (p-value = 0.8997; data not shown). The range of temperatures showed a non-significant decrease of 0.87 ℃ and 1.14 ℃ over all the sensor positions for the 1st percentile after retrofitting the doors (Table 4). However, temperature ranges decreased significantly – 9.97 ℃ at the 99th percentile – after retrofitting. There was no difference among sensor positions for the difference between the 1st and 99th percentiles. However, there was a 9.10 ℃ (± 2.02) difference between these percentiles, which was significantly different from zero, and which was indicative of reduced variability after door installation.

The RH ranges increased significantly after door retrofitting – 18.9% for the 1st percentile– though an increase of 5.9% for the 99th percentile was not significant (Table 5). The RH varied 22.4% between the 1st and 99th percentiles before retrofitting and 9.4% after retrofitting, a difference of 13% which was indicative of reduced RH variability after retrofitting. Since RH was measured at only three positions per display case (top front, middle front, and middle back), an analysis by sensor position was not performed.

Overall, the location of the shelves in the display cases affected both the temperature and duration of abuse due to high temperature (p-values < 0.0001) but did not affect low temperature or the length of low temperature abuse (p-value = 0.9980). In open display cases, the area under the bottom bin was at a higher temperature (> 5 ℃), and this higher temperature occurred for a longer period, than at other locations in the cases, but once the cases were retrofitted with doors, the top shelf was warmest with higher temperatures occurring for a longer overall time than at other locations in the cases (Table 6).

Table 5
Means with (standard errors) of the 1st, 5th, 95th, and 99th relative humidity (%) percentiles before and after doors were installed on the display cases. The means represent an overall average for the display cases in which they were measured as not all positions within the case were measured.

Relative Humidity (%) Percentiles		
Doors	1	99
No Doors	71.3 (6.6)	93.7 (6.3)
Doors	90.1 (4.7)	99.5 (0.5)
Difference	18.9 (6.5)	5.9 (6.4)

Table 6
Values for performance parameters of display cases compared by grouping sensors according to display-case shelf before and after retrofitting with doors.

Shelf	Temperature (°C)		Percentage of Time > 5 °C	
	No Door	Door	No Door	Door
Bottom	7.0	2.1	37.9	1.4
Middle	7.1	2.2	37.0	2.0
Top	7.3	3.7	40.0	19.0
Under	7.9	2.3	49.0	2.7
Standard Error	0.3	0.3	2.4	2.4
p-value	< 0.0001		< 0.0001	

Evans et al. (2007) found that there were significant technological differences between display case designs that impact performance and therefore temperature control. Technological modifications from display case manufacturers in order to comply with the Department of Energy and EPA refrigerant regulations caused changes in refrigeration systems due to the delisting of refrigerants (Shebik, 2015, p. 3). Retailer-specific technological modifications to improve control and reduce energy costs may have affected overall case performance, but this would have to be evaluated in future research.

5. Conclusions

Retrofitting open refrigerated display cases with doors improved case ambient conditions, reduced case temperatures, increased case RH, and reduced temperature and RH variability within the cases. However, the benefits of retrofitting display cases with doors varied among retailers. All retailer displays experienced a decrease in temperature, had less time that product was subject to temperatures > 5 ℃, had a higher case RH, and experienced less fluctuation in temperature and RH when the cases were retrofitted with doors. Food safety evaluations of display cases provide useful and needed information to the retail business and scientific community to better understand the current status of the cold chain. Additional evaluation on overall energy consumption of open vs closed display cases at retail stores will provide additional useful information to continue to improve case performance.

Credit authorship

Ana Lorena Monge Brenes: Software, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization **Wyatt Brown:** Methodology, Validation, Investigation, Resources, Writing - Review & Editing, Visualization, Supervision, Project administration **Scott Steinmaus:** Software, Validation, Formal analysis, Writing - Review & Editing, Visualization, **Jeffrey K. Brecht:** Methodology, Validation, Investigation, Resources, Data Curation, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition **Yurui Xie:** Validation,

Investigation, Writing - Review & Editing, Visualization **Ellen R. Bornhorst:** Validation, Investigation, Writing - Review & Editing, Visualization **Yaguang Luo:** Conceptualization, Methodology, Software, Validation, Resources, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition **Bin Zhou:** Validation, Investigation, Data Curation, Writing - Review & Editing, Visualization **Angela Shaw:** Conceptualization, Validation, Resources, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition **Keith Vorst:** Conceptualization, Methodology, Software, Validation, Resources, Data Curation, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition

Declaration of competing interest

All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report.

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