Saving the Bacon: Low-Cost Supermarket Refrigeration Air-Curtain Guiding Vanes - Pilot Results

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ABSTRACT

Open refrigerated display cases for meat, dairy, and produce are among the most energy-intensive electric end uses in supermarkets. Retrofit technologies that optimize the cold-air curtain of existing open cases can reduce cold-air spillage and compressor cycling, improving efficiency and product shelf-life for store owners, while also improving aisle temperature comfort for shoppers.

This pilot study evaluated installations of air-curtain guiding vanes across seven Michigan grocery stores on behalf of DTE Energy to quantify their technical performance, customer experience, and cost-effectiveness. The evaluation team conducted site-level submetering and impact analysis to measure reductions in compressor electricity use. The analysis also examined interactive effects with night covers. Process evaluation interviews with store managers and trade allies found high satisfaction with installation and durability, minimal operational issues, and generally positive perceptions of temperature control and product performance.

Results demonstrated 8.7% refrigeration energy efficiency savings due to air-curtain guiding vanes. With a projected incentive covering half of the incremental cost for installation of the air-curtain enhancements, the aluminum version of the measure is cost-effective with a Utility Cost Test (UCT) at 1.9 and Total Resource Cost (TRC) test at 1.5.[1] Findings highlight how this simple and low-cost retrofit technology reduces refrigeration loads and, by association, store electric bills; this is especially valuable, since the pilot focused on smaller retailers with a higher need for savings. Work is ongoing to add this measure to Michigan's Technical Reference Manual, which will be a first in the nation for this technology.

Introduction

Refrigerated display cabinets with open fronts are widely used in commercial settings, such as supermarkets, convenience stores, and food service establishments, to stock and display refrigerated goods like meat, produce, and dairy. Without doors, these cases rely on an invisible air curtain – a downward flow of cold air across the case opening – to separate the refrigerated interior from ambient store conditions. While the lack of doors provides easy product access and

[1] The Utility Cost Test (UCT) measures cost-effectiveness from the perspective of the utility, comparing the benefits of avoided energy costs to the utility's program costs. The Total Resource Cost Test (TRC) takes a broader societal perspective, comparing total resource benefits — including both participant and utility benefits — to total program and participant costs. A ratio greater than 1.0 indicates the measure is cost-effective under that test. Both tests are standard cost-effectiveness screens used to evaluate demand-side management programs.

enhanced visibility for customers, they also result in significant cold air loss due to the disruption of the air curtain by customer movement, stocking activity, and store airflow, allowing warm air to infiltrate the case and cold air to spill into the aisle (Yuan et al. 2022). The resulting thermal instability drives compressor cycling, temperature instability, and increased refrigeration electricity demand, which is already the largest end use in supermarket buildings (EIA 2018). Improving cold-air retention through low-cost retrofits therefore represents a direct and accessible path to saving energy.

This paper presents findings from a structured field pilot, implemented by ICF and evaluated by Skytop, focused on non-mechanical air curtain enhancement technology – aerodynamically designed vertical "wings" that mount to shelf-edge price-tag displays on open refrigerated cases. The study was conducted across nine Michigan grocery stores and sponsored by DTE Energy. Results are used to support inclusion of this measure in the Michigan Energy Measures Database, which would represent a first-in-the-nation TRM listing for this technology.

Technology Description

The air-curtain guiding vanes evaluated in this study are aerodynamically designed devices – vertical "wings" installed along shelf edges and within the cabinet structure – to optimize the performance of the cold air curtain in open refrigerated display cases. These devices work by guiding airflow more effectively, reducing turbulence, and maintaining a more stable invisible cold air barrier between the refrigerated space and the store environment. By limiting cold air spill into store aisles, the wings help prevent unnecessary refrigeration cycling, thereby reducing compressor runtime and total energy use.

The wings are non-mechanical and constructed from durable materials, available in both aluminum and PVC configurations. They mount to the front of price-tag displays on refrigerated case shelves using clip technology. Installation is straightforward and reversible, with primary effort involving relocating price tags from the original shelf edge to the new price-tag display on the front edge of the measure.

Figure 1 is an image from a store showing a typical installation. Figure 2 shows computational fluid dynamics still image profiles of a cabinet without and with the enhancement. The image captures the effect of the air-curtain guiding vane on cold air spillage from the refrigerated case into the store aisles.

Figure 1. Typical refrigeration air-curtain guiding vane installation. *Source:* ACR Journal 2019.

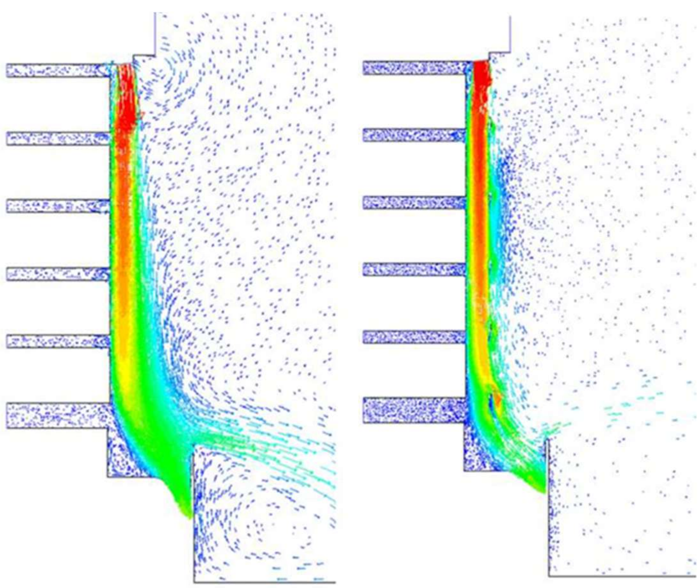

Figure 2. Computational fluid dynamic representation without and with air-curtain guiding vane. *Source:* Yuan et al. 2022.

The technology is compatible with a range of open-fronted display types and can be integrated into new refrigeration systems or retrofitted onto existing cases for commercial and industrial markets, including grocery stores, supermarkets, convenience stores, and food retail outlets in any climate. It is available in sizes typically ranging from 2 feet to 8 feet to match standard cabinet shelf widths, and different models can be applied to flat or tilted shelves. Because the wings clip directly on existing shelf-edge price tag holders and require no electrical work or structural modification, the retrofit is reversible, can be completed in under a day per store, and does not require cases to be taken offline or interrupt customer access.

Literature Review

Several independent studies have demonstrated that optimized air curtain technology can significantly improve efficiency. Findings from laboratory trials indicate that refrigeration electricity consumption can be reduced by up to 31%, depending on factors such as cabinet type, ambient store conditions, and operational settings (EPTA 2016; Yuan et al. 2022). In addition to energy savings, air curtains contribute to better temperature uniformity, enhanced product preservation, and improved comfort in store aisles by reducing the escape of cold air (Brightline 2023).

In situ field tests also show savings, though less than laboratory settings – on the order of 10% due to variations in cabinet age and design, product placement, weather differences pre- and post-installation and stocking and shopping behaviors. Table 1 summarizes findings from available in situ studies, in descending order by savings, including the current pilot.

Table 1. In situ studies: scope and savings

Study	Location	# Stores	% Savings
Smolarek 2024	USA	4	10%
Think-Safe 2016	Australia	2	10%
Williams AE 2017	UK	5	10%
Bailey 2019	UK	1	10%
Skytop 2025	USA	7	8.7%
Brightline 2023	USA	15	0-3%

Prior field studies have generally relied on serial comparisons of baseline and post-installation operation with field metering equipment without controlling for external factors such as ambient weather impacts on refrigeration system efficiency or variations in customer behavior. The Brightline (2023) study found 0-3% energy savings using single-point temperature dataloggers rather than direct energy metering. The current pilot was designed to address both of these limitations and used a stepped-wedge design, which eliminates the need to assume stable external conditions across the baseline and post-installation periods (Duke 2017). Combined with direct rack-level submetering, this approach isolates the measure's contribution from weather, seasonal shopping patterns, and other time-varying drivers.

Methodology

Pilot Design

The pilot recruited 9 supermarkets across the metro Detroit, Michigan area, conducted over 3 phases, each lasting 4 weeks during Fall 2024 through Winter 2025. The pilot divided participants into two groups, five in Group A (reduced to three after two sites removed as explained below) and four in Group B, to compare relative consumption. The pilot used a staggered installation ("stepped-wedge") design with two groups to separate measure impacts from external drivers such as outdoor conditions and store operations. The study period was divided into three four-week monitoring phases:

- Phase 1 (Baseline): No sites have the measure installed.
- Phase 2: Group A receives the measure (treatment); Group B remains unchanged (control).
- Phase 3: Group B receives the measure; Group A continues operating with the measure.

Because both groups operate in the same region over the same calendar periods, external influences are expected to affect both groups similarly within each phase. The methodology therefore estimates savings from site-level phase-to-phase load ratios that are normalized using the corresponding ratio observed in the non-installing group, rather than from raw pre/post changes at a single site.

Participating Stores and Applicability to Broader Grocery Sector

The study participants are ordinary in most respects with the following characteristics:

- Locally owned grocery stores in the metro Detroit, Michigan area
- Small to mid-sized - Gross floor areas 17,000 to 45,000 ft2
- 148-284 linear feet of surveyed refrigerated cabinets.
- Multi-rack refrigeration systems with separate low and mid-temperature racks.
- Older compressor racks and cabinets – many are after-market.
- Similar operating hours from 8 AM to 8 PM seven days per week (+/-1 hour on Sundays).

The mid-sized grocers use equipment similar to large stores. The participant stores were similar in size to the grocery section of big-box retailers with integrated grocery sections. Larger chain grocers are more likely to have doored cabinets, which are not appropriate for this measure. Small grocery and food stores with fewer refrigerated cabinets likely have more stand-alone applications and less-efficient equipment, portending higher savings potential. The hours of operation, approximately 12 hours per day, fall near the middle of the range seen across the broader grocery sector, which spans 24-hour stores at one end and smaller or rural grocers with shorter hours at the other. Therefore, the results of this study are expected to apply to the broader grocery sector. While savings could in principle be scaled proportionally to operating hours for individual sites, the deemed savings value is intended to represent a sector-wide average for program implementation purposes, consistent with standard TRM practice.

The actual pilot implementation closely followed the initial pilot design. However, two sites in Group A were removed from the final analysis due to the following reasons:

1. One site experienced a data metering acquisition failure during the Phase 1 baseline period, that was not discovered until after measure installation.
2. A second site requested measure removal, only days after installation.

The removal of these sites did not materially impact the overall findings, as the remaining study size was sufficient for robust analysis. At a third site, one of two racks that received the measure was not metered due to safety concerns with equipment location.

Field Work – Measure Installation and Submetering

The equipment vendor surveyed each site to determine the appropriate locations and quantities for the shelf-edge measures. Installations, performed by MPH Global, took less than one day at each participant site with minimal disruption to the shopping experience. Installation involved clipping the vertical wings to shelf-edge price tag displays and moving price tags. Six months after installation, all 7 participating sites were revisited, and all still had the measure fully installed. Process evaluation interviews with store managers and trade allies found high satisfaction with installation and durability, minimal operational issues, and generally positive perceptions of temperature control and product performance.

Refrigeration energy data were collected through temporary field metering, completed by Pure Eco, installed at each participating site. Each compressor rack was metered individually using Dent ELITEpro SP power meters, with one meter installed per rack. Meters were installed at the rack electrical panel/feeder so that measured electricity reflected only the load attributable to the targeted rack. Rogowski coils were installed on each electrical phase conductor, and the meters recorded true power and power factor at 15-minute intervals. The metering system logged per-electrical phase measurements as well as three-phase aggregate and average values, which were used to develop average loads for each rack and site.

Savings Ratio Calculation

The savings calculation in mathematical terms is as follows: Let $x_{i,p}$ be the average electric load at site i during Phase p, and compute phase-to-phase changes. To focus on how loads changed over the intervals that align with installation timing, define each site's step ratio from one phase to the next:

- Phase 1 → 2 ratio:

$$R_{i,12} = \frac{x_{i,2}}{x_{i,1}}$$

- Phase 2 → 3 ratio:

$$R_{i,23} = \frac{x_{i,3}}{x_{i,2}}$$

These ratios capture how each site's load changes between consecutive phases. If the measure was not installed during the phase change, then the ratio captures external factors only. If the measure was installed during the phase change, then the ratio captures external factors and the effect of the measure. For each installation step, the group that did not change measure status provides an estimate of how external conditions affected loads over that same period.

Site-level savings were calculated comparing each site's step ratio at the installation phase change to the corresponding control ratio. During Phase 1 → Phase 2, only sites in Group A change status (baseline → measure). Group B remains baseline and acts as the control. Comparing the pre/post change for each site in Group A to the pre/post change of the Group B average over the same time window gives a savings factor for each site in Group A as:

$$Savings\ Ratio_{i,A} = 1 - \frac{R_{i,12}}{B_{12}}$$

During Phase 2 → Phase 3, sites in Group B change status (baseline → measure), while Group A is already treated. Here, both groups have the measure in Phase 3, so the relevant comparison is the change from Phase 2 to Phase 3. Group B's change from Phase 2→3 includes external effects plus the new measure. Group A's change from Phase 2→3 reflects external effects under already-treated operation, and thus Group A acts as the control. The ratio isolates the incremental impact of installing the measure at Group B sites. Comparing the pre/post change in Group A to the pre/post change in each site in Group B over the same time window gives a savings factor for each site in Group B as:

$$Savings\ Ratio_{i,B} = 1 - \frac{R_{i,23}}{A_{23}}$$

One Group B participant had partial measure coverage, with approximately 73% of the metered refrigerated cases treated. Because the meter captures both treated and untreated case load, the observed savings at that site are diluted relative to full treatment. To normalize to an equivalent 100% treated basis, savings for that site are adjusted as:

$$Savings\ Ratio_{i,B,adjusted} = \frac{Savings\ Ratio_{i,B}}{F_i}$$

Where F_i is the treated fraction of the metered case population. All other sites had full measure coverage, thus, $F_i = 1.0$, i.e., no adjustment.

Annual Baseline Energy

Baseline energy consumption for each site was modeled as a function of ambient outdoor temperature. Refrigeration energy generally increases with outdoor temperature because warmer ambient air raises condensing temperatures and compressor workload. In very cold weather, refrigerant head pressure controls prevent condensing pressure from dropping below a minimum threshold, maintaining relatively stable base load regardless of how cold it gets. As a result, when daily average energy is plotted against daily average temperature, a clear trend appears with increasing energy use at high temperatures and a flat base load energy use at all lower temperatures. The study baseline data for Detroit includes daily average temperatures between 17 and 69°F, depending on the site, compared to the typical annual spread of roughly 10 to 85°F. Figure 3 shows the plot of one site's data.

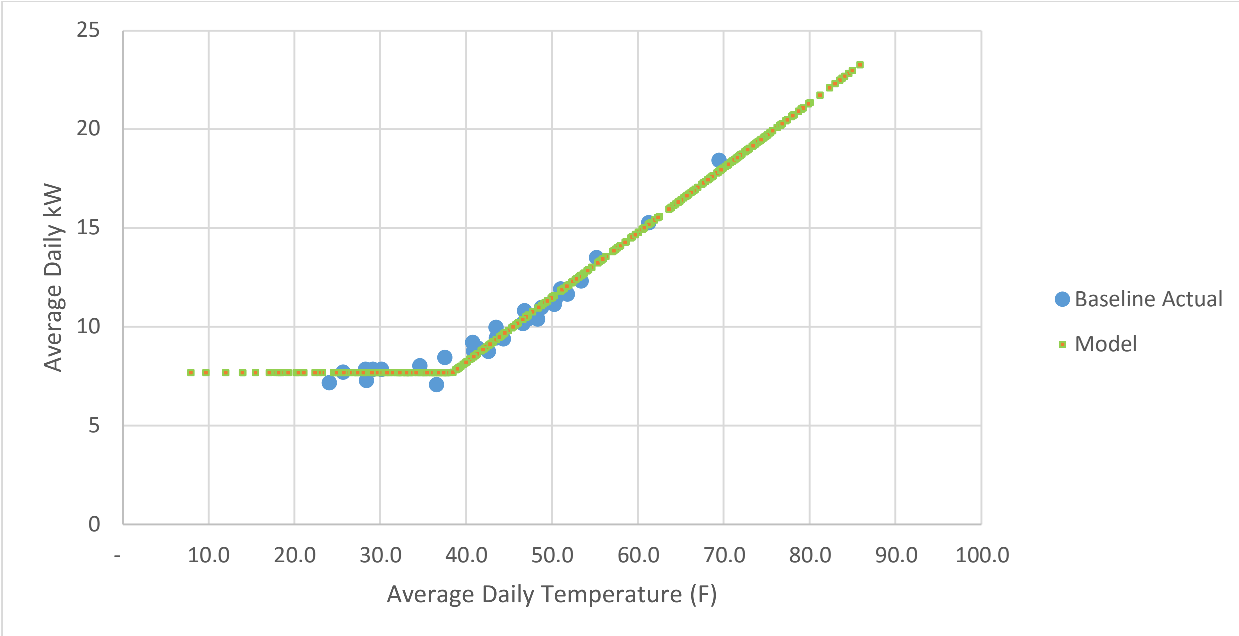

Figure 3. Sample site average daily power correlated to average daily temperature

It is reasonable to extrapolate the average daily power linearly for higher temperatures, and to assume a fixed daily average power of about 7.7 kW for lower temperatures at this site. The correlation, when applied to TMY3 weather data,[2] leads to an estimate of annual average site refrigeration rack energy consumption for the baseline. This process was repeated for all participants to estimate total pilot study annual baseline energy consumption.

Energy savings at each site is the savings ratio multiplied by annual baseline refrigeration rack energy use:

$$Energy\ Savings\left(\frac{kWh}{ft}\right)_i = \frac{Baseline\ Annual\ Energy\ x\ Savings\ Ratio_i}{Feet\ of\ Product\ Installed}$$

Where:

- Baseline Annual Energy is derived from regression of measured energy use and daily temperature
- Savings Ratio = Savings factor vs control group difference observed in the pilot
- Feet of Product Installed = Linear feet of air-curtain guiding vane installed at site

[2] TMY3 (Typical Meteorological Year 3) is a dataset of hourly weather data compiled by the National Renewable Energy Laboratory representing typical long-term climate conditions for locations across the United States. It is widely used in building energy modeling to estimate annual energy performance under representative weather conditions.

Results

Energy Savings

Only seven sites were included in the final analysis, which is a limited number of independent locations for developing a single deemed savings value. However, each site contributed continuous interval refrigeration electricity data across all study phases, and the stepped-wedge design improves internal validity relative to a simple pre/post design by controlling for time-varying external drivers and enables a robust site-specific estimate of phase-to-phase change. The purpose of the deemed value is to represent an expected average value across a mixed market population, not to guarantee savings at every individual site.

Table 2 shows the site-level percent savings results. Results across the seven sites varied, ranging from -3% to 29%, with five of seven sites showing positive savings. This level of variance is expected for open refrigerated display case measures. Savings at any individual site reflect a combination of short-term random variation in stocking behavior and customer traffic and longer-term differences such as rack capacity, cabinet type and condition, refrigeration system vintage and controls, case temperature setpoints, and defrost strategy. For example, field observations indicated that one site had newer racks in better overall condition than several other participating sites, which may have reduced baseline losses and therefore reduced the incremental savings potential from the measure at that location. Therefore, negative savings at individual stores should be interpreted as noise around a positive mean rather than evidence that the measure increases energy use.

Table 2. Site-level annual baseline energy and percent savings results

Site	Modeled annual baseline refrigeration energy (kWh)	% Savings
1	86,776	12%
2	191,498	-1%
3	112,975	6%
4	224,248	7%
5	208,364	29%
6	355,051	-3%
7	164,552	22%
Weighted average	n/a	8.7%

To ensure the deemed value reflects typical market outcomes, the analysis retains all qualifying sites, including low- and no-savings cases, rather than excluding results that reduce the average. In a small sample, site-specific factors as mentioned can cause the portfolio average to be more sensitive to a small number of locations, reinforcing the value of retaining all qualifying sites.

Additionally, the resulting deemed value is not solely dependent on this field pilot in isolation. It is supported as a “real-world” point within a broader evidence base (see Table 1) showing consistent directional savings across multiple in situ studies.

Total average energy savings (kWh/ft) across all stores results in the final pilot energy savings based on linear feet of installed air curtain wings are presented in Table 3. Coincident peak demand savings were derived using the MEMD refrigeration hourly load shape. This load shape distributes annual energy savings across all 8,760 hours of the year based on the typical operating pattern of commercial refrigeration systems. The coincident peak demand savings represent the portion of savings occurring during the state's defined peak demand period. The Hourly Load Share$_{peak}$ (0.000154) is the fraction of annual energy attributed to the coincident period, and multiplying annual energy savings by this factor yields the coincident peak demand savings in kW.

Table 3. Energy and peak demand savings results

Savings metric	Per linear foot of air-curtain guiding vane installed
Annual electrical energy savings	37.0 kWh
Michigan coincident summer peak demand savings	0.0057 kW

A typical store with 200 feet of treated display case, that installs the pilot-average 2.5 feet of air-curtain guiding vane per case-foot, might expect to save about 18,500 kWh/year, based on the study results.

Interactive Effects with Night Covers

Night covers are an intuitive potential source of interactive effects with enhanced refrigerated cabinet air curtains because both strategies reduce air infiltration and cold-air spillage from open cases. For that reason, night covers were evaluated as a candidate factor that could warrant an adjustment to air-curtain savings when night covers are present and used.

A supplemental field assessment was conducted to document night cover prevalence, condition, and reported usage across the participating stores. Figure 4 presents night cover usage.

Key findings:

- Presence of night covers
  - 73% of the installed air-curtain guiding vanes are on cases with no night covers
  - 27% are on cases with night covers
- Usage of night covers on cases with presence of night covers
  - 92% of night covers are reportedly used 100% of nights
  - 8% of night covers are reportedly used 30% of nights
  - No stores reported night covers that are never used
- Time-weighted night cover presence and usage: 25%
- 4 stores have no night covers or very low usage
- 3 stores have high night cover usage (>74% coverage, reported to be used 100% of nights)

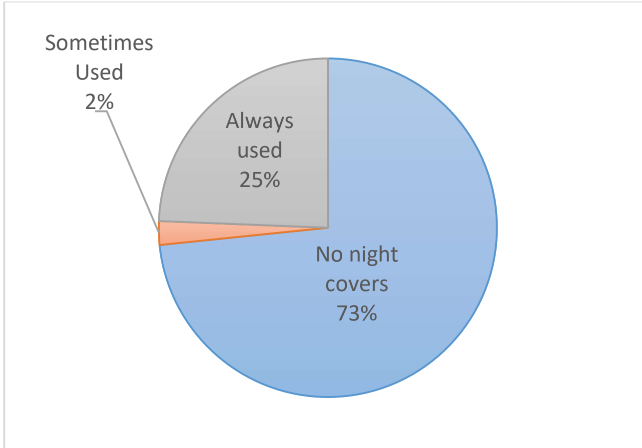

Figure 4. Self-reported night cover usage at participating stores

This distribution indicates the pilot's overall results inherently incorporate both conditions, cases with and without night cover usage, at meaningful shares and similar to the broader market which has approximately 93% of cases without night covers (GDS Associates 2017).

If night covers were suppressing air-curtain savings, one would expect savings to be lower during unoccupied hours, when night covers are typically deployed, compared to occupied hours. The observed data show the opposite. Average relative savings during unoccupied hours (9.6%) were slightly higher than during occupied hours (8.0%), which does not support a suppression effect. This difference is small, however, and given the sample size and site-to-site variability in refrigeration setpoints, compressor controls and vintage, cabinet design, stocking practices, and ambient conditions, the data are insufficient to draw firm conclusions about the night cover interaction.

Discussion and Conclusion

This pilot study demonstrates that refrigerated cabinet air-curtain guiding vanes can deliver meaningful energy savings in commercial grocery settings. The 8.7% savings observed across seven stores is consistent with prior in situ studies and falls within the expected range for field applications. The stepped-wedge study design with direct submetering provides a robust basis for a deemed savings value by controlling for external factors including weather and seasonal shopping patterns.

The measure life is estimated at 10 years for aluminum air-curtain guiding vanes and 5 years for PVC. Air curtain systems are passive devices with no moving parts, and because they do not require routine interaction by shoppers or employees, they are not subject to the handling and wear mechanisms that typically limit measure persistence for other refrigerated cabinet measures. When installed as intended, they do not materially interfere with normal shopping, stocking, or cabinet cleaning activities.

The air-curtain guiding vane is a simple, low-cost, and minimally disruptive retrofit that delivers measurable energy savings to grocery retailers. With an estimated measure cost of $13 per linear foot installed (either material; equipment and labor), no anticipated recurring costs, and a projected program incentive of $6.50 per foot covering half of the incremental cost, the aluminum version of the measure clears cost-effectiveness thresholds with a utility cost test of 1.9 and a total resource cost test of 1.5. The PVC version passes UCT at 1.0, but not TRC at 0.8

No relevant codes or standards currently govern this technology, though it aligns with best practices for refrigeration efficiency. The findings support ongoing work to add this measure to the Michigan Energy Measures Database, which would represent a first-in-the-nation TRM listing for air-curtain guiding vanes.

Several limitations of this study should be acknowledged. The analysis draws on seven stores in a single metropolitan area operating during fall and winter months, and the pilot stores are predominantly small to medium, independently owned grocers with older equipment. These constraints are inherent to an initial field pilot and warrant some caution in extrapolating the precise savings estimate to other contexts. That said, they do not undermine the core finding that the measure delivers meaningful savings. The air-curtain guiding vane works by a physical mechanism, stabilizing airflow at the case opening, that is not specific to climate, geography, or store ownership type. The fall and winter monitoring period, while not capturing peak summer condensing loads, does capture the base load conditions that dominate annual energy use for most of the year. And the older, less efficient equipment in the pilot stores, if anything, represents a conservative estimate. The stepped-wedge design controls for most within-study variability. The results are consistent with the broader body of in situ evidence in Table 1, spanning multiple countries and store types, which reinforces confidence in the directional finding even where the precise savings estimate may vary. Replication across additional climate zones, store types, and seasons would strengthen confidence in the deemed savings value and support its broader adoption in TRM programs nationally.

The analysis of night cover interactions was inconclusive at this sample size. Future studies with larger sample sizes and more controlled night cover conditions would help determine whether a savings adjustment is warranted for sites with high night cover usage.

Implications and Recommendations

Ongoing Evaluation, Measurement, and Verification (EM&V) efforts should focus on:

- Assessing the impact of outdoor temperature on energy savings across a broader range of climate conditions.
- Assessing measure lifetime through continued monitoring of system performance.
- Evaluating the in-service rate (IRAF) to determine the long-term adoption and persistence of the measure.
- Assessing whether case setpoints can be raised following installation, since reduced infiltration of ambient store air may permit higher setpoints and greater savings.
- Evaluating the measure’s applicability to stand-alone cases with self-contained condensers, which may exhibit higher baseline energy intensity due to less efficient equipment and therefore represent an opportunity for equal or greater savings.

The measure appears broadly applicable to any open refrigerated display case, regardless of store ownership type. While the pilot participants were independently owned stores, the refrigeration equipment used is similar to that found in large chain stores and big-box retailers with grocery sections. Chain grocers are more likely to have doored cabinets and thus may not be the primary eligible population, but convenience store and small to mid-sized independent grocers represent a significant and underserved segment that is well-matched to this technology.

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Disclosure

AI-assisted tools used: Claude
Used for: Organizing and proofreading
Extent: Organizing content from previously written white paper to fit ACEEE format, proofreading, checking formatting, and light editing.
Human review: The authors reviewed and verified all content, calculations, and citations.