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The impact of retrofitting doors on performance of a retail display cabinet

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ABSTRACT

Open fronted retail display cabinets for chilled food are prone to infiltration of warm and moist ambient air. This increases the heat loads on the cabinets, reducing energy efficiency and ability to maintain temperature control. Air curtains are employed to form a barrier to infiltration but are typically limited in their effectiveness. Adding doors can curtail a considerable proportion of the infiltration depending on door opening frequency.

This paper describes ISO23953 test room measurement of the impact of retrofitting doors to a typical open fronted display cabinet. The open fronted cabinet was found to maintain test pack temperatures between 7.4 and -1.0°C (M2 classification with rounding applied) and consume 46.9 kWh.24h^{-1}. Fitting doors to the same cabinet reduced the temperature span to between 3.6 and -1.0°C (M0 classification) and energy consumption to only 51.5% of that used by the open cabinet. Further adjustments were made to raise the maximum pack temperature to a value similar to the open cabinet and the resultant temperature span was between 7.2 and 3.4°C (M2 classification with rounding applied) and energy consumption only 39.4% of that used by the open cabinet.

Key words: Retail display, Temperature control, Energy consumption, Doors, Retrofitting

1. INTRODUCTION

Supermarket energy consumption is widely reported as being comparatively high, with typical energy intensities being almost double those of other buildings (Mukhopadhyay and Haberl, 2014). Published energy consumption indices for supermarkets vary depending on factors such as location and store size. Foster et al (2018) reported a mean specific energy consumption (SEC) of 566 kWh.m^{-2}.year^{-1} based on electrical energy consumption and sales floor area, for one UK retailer. This rose to 759 kWh.m^{-2}.year^{-1} when gas was included. From other studies (van der Sluis et al, 2017 and Tassou et al, 2011) the SEC varied from 407 to 1700 kWh.m^{-2}.year^{-1} based on electrical energy consumption.

The vector for most of this energy is electricity, and consequently supermarkets are the most electricity-intensive type of commercial building. Energy efficiency is therefore increasingly of concern to supermarket owners and facility managers (Lindberg, 2014).

A large proportion of the energy is used for storage and display of refrigerated food, for which refrigeration typically accounts for between 40 and 60% of the total electricity used in supermarkets (e.g. Axell and Lindberg, 2005 and Evans, 2014), with the remainder being split between Heating Ventilation and Air Conditioning (HVAC), food preparation and lighting. As the different systems interact with each other, it is not always easy to calculate and separate the impact of individual factors. Nevertheless, measures which reduce the energy used by the refrigeration system are likely to have the greatest impact on total supermarket energy consumption.

Prepared food and groceries such as meat, dairy, fruit and vegetables make up a large part of the sales of refrigerated food in supermarkets. Such products must be stored and displayed at chilled temperatures as they are perishable and sensitive to temperature abuse. The refrigerated cabinets used for display are often open-fronted, with no physical barrier between the customer and the food. While perceived to be good for customer accessibility and hence sales, open-fronted cabinets allow a large proportion of the refrigerated air to continually spill out and be exchanged with warm store ambient air (Foster and Quarini, 2001). This imposes high heat loads on the supermarket refrigeration systems, increasing their energy consumption.

The exchange of air also has other detrimental effects. Spillage of cold air into the supermarket aisles reduces ambient temperatures in the aisles and can affect customer behaviour, tending to reduce the time they spend in the relatively cold aisles. To counteract this, additional heating is often required, resulting in further increases in energy consumption of the store. Warm moist air entering the cabinets not only imposes heat loads, but also increases the need for defrosting. Temperature control in the cabinets is more difficult, and large temperature differences between different positions in the cabinets are common, as are differences over time resulting from the impact of defrosts. The temperatures of food on display are consequently unstable and often warmer than they should be. In the extreme, food quality and safety can suffer.

Open-fronted cabinets rely on fan-driven air curtains to form a barrier to the exchange of air but not to customers, but they vary in their effectiveness and typically still allow considerable infiltration. A far more effective means of reducing air exchange is to close the front of the cabinets using doors. With adequate seals and correct fitting, doors can eliminate exchange completely, but of course only while they are closed. During loading periods and access by customers, the doors will be opened with varying frequency and for varying durations. The type of doors (sliding versus hinged) also affect air exchange and effectiveness (Orlandi, 2013).

This paper reports the results of ‘before and after’ testing of an open fronted cabinet to which doors were retrofitted by the manufacturer.

2. METHOD

A production model of an open fronted 2.5 m long chilled retail display cabinet was obtained from its manufacturer. It was installed in an ISO 23953:2015 test room and connected to a remote refrigeration plant running on R448A refrigerant. It was then loaded and tested at Climate Class 3 (25°C and 60% Relative Humidity (RH)) according to the ISO 23953:2015 test standard (ISO, 2015) as shown in Figure 1. The cabinet was tested such that it did not control on set point from a temperature controller, but instead the cabinet received refrigerant all the time and temperature was controlled by setting an appropriate evaporating temperature of refrigerant. As the cabinet was not off-cycling due to thermostatic control, the defrost (off cycle) was set to every hour to avoid icing of the evaporator.

The evaporating temperature was set to achieve the M2 temperature classification (highest temperature of warmest M-pack 7°C, lowest temperature of coldest M-pack -1°C). It was not possible to achieve a lower temperature classification, e.g. M1 (highest M-pack 5°C and lowest M-pack -1°C), due to the wide temperature range of test packs in the cabinet during the test.

Figure 1: Open fronted cabinet.

On completion of the open fronted testing, the manufacturer installed double skinned plastic doors which are typical of the manufacturer's current type of retrofitted doors being installed in supermarkets (see Figure 2). A door opening mechanism was attached to the cabinet in the test room. Prior to the start of the 12 hour period of door opening, each of the four doors was opened once consecutively for 3 minutes. During the 12 hour door opening period, each of the four doors was opened consecutively at 6 minute intervals for 15 seconds.

Initial results with doors identified that the defrost termination temperature for the open cabinet was excessive once doors had been fitted. Being an off-cycle defrost it was found that termination did not occur based on temperature once the doors had been fitted, which meant that the defrost terminated instead on the maximum defrost time setting. This was therefore reduced from 45 minutes to 14 minutes to match the off-cycle duration observed during the open fronted cabinet defrosts.

Figure 2: Cabinet with retrofitted doors.

A first test of the doored cabinet found that the coldest packs reduced to less than -1.0ºC. As this was outside of the M2 classification and below the freezing temperature of the packs, the evaporating temperature was increased by 0.4ºC such that the coldest packs were at the same temperature for both open and closed door tests. As the maximum pack temperature had reduced considerably there was scope to achieve further energy savings, by increasing the evaporating temperature further. A second test was therefore conducted with adjustment of the evaporator saturation temperature to raise the maximum pack temperature to a value similar to that achieved in the open tests, with the aim of maximising the energy savings.

A summary of the settings for the tests is shown below in Table 1.

Table 1. Control settings used in the tests.

Test	Set point	Defrost interval	Maximum defrost time	Mean value of the saturated evaporator temperature during Φ_{run} (θ_{mrun})		
	(°C)	(h)	(mins)	Dew (°C)	Bubble (°C)	Average (°C)
Open	0.8	1	45	-0.6	-6.5	-3.5
Open	0.8	1	45	-1.0	-6.9	-3.9
Doored	0.7	1	14	-0.6	-6.5	-3.5
Doored	0.7	1	14	3.4	-2.4	0.5

3. RESULTS

3.1 Temperature Performance

The maximum and minimum temperatures achieved during the tests are shown in Table 2 below.

Table 2. Temperatures during the tests.

Test	M-pack temperature		Classification
	Max (°C)	Min (°C)	(* with rounding)
Open	7.49	-0.7	M2 *
Open	7.4	-1.0	M2 *
Doored	3.6	-1.0	M0
Doored	7.15	3.39	M2 *

The open fronted cabinet narrowly achieved the temperature classification M2 with rounding to the nearest integer (highest pack 7°C and lowest -1°C), as shown in Figure 3. With doors the cabinet was able to achieve an M0 classification (highest M-pack 4°C and lowest -1°C) as shown in Figure 4. When the maximum temperature was raised back up to that measured in the open cabinet to allow further energy savings, the cabinet achieved M2 classification with a far smaller temperature span between maximum and minimum temperature (see Figure 5).

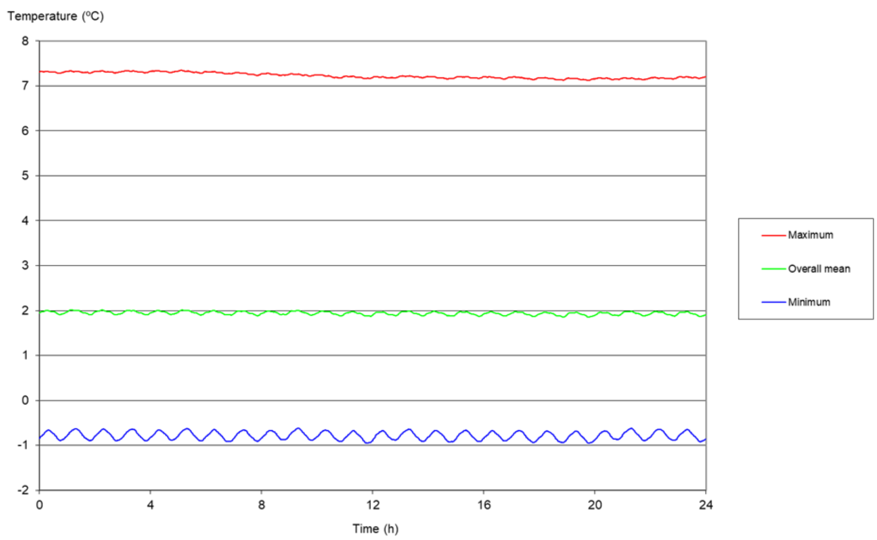

Figure 3: Temperatures achieved during open fronted operation.

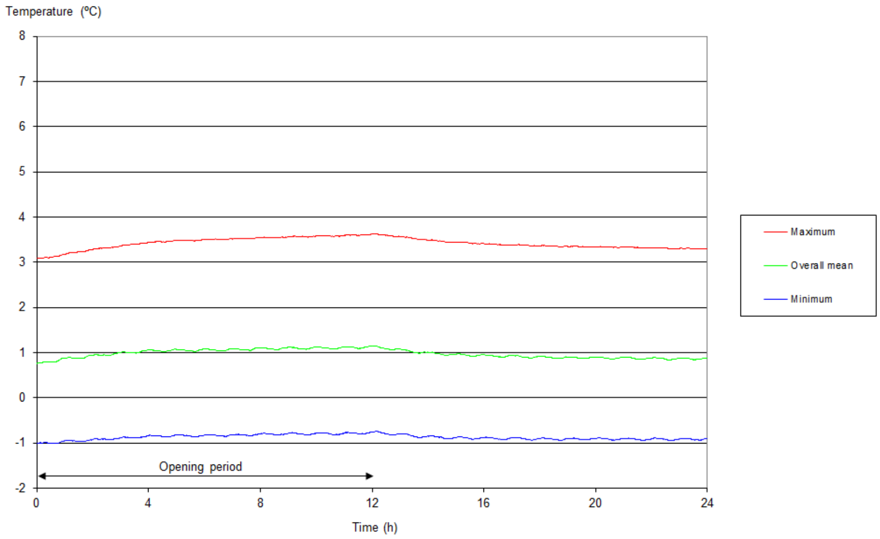

Figure 4: Temperatures achieved with doors added.

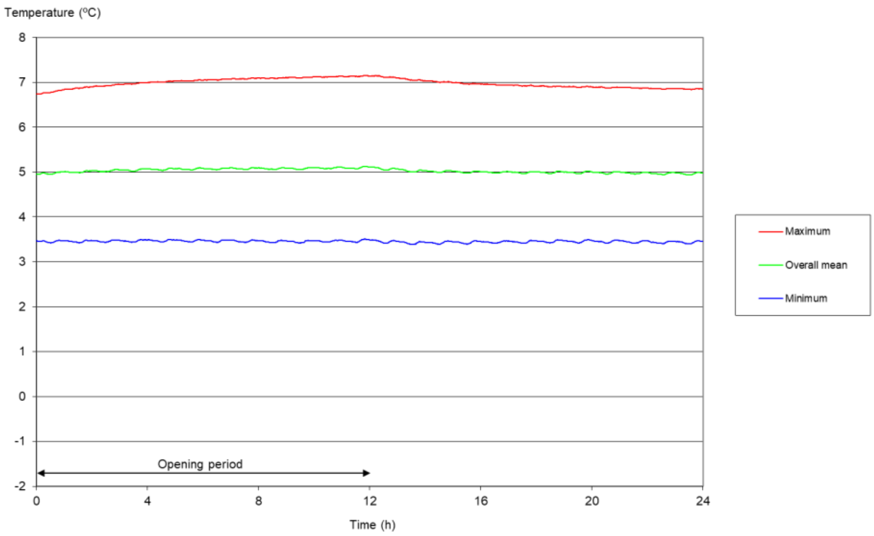

Figure 5: Temperatures achieved with doors after adjustment of maximum temperature.

3.2 Energy Consumption

The energy consumed by the remote refrigeration system and the cabinet during the tests is shown in Table 3 below.

Table 3. Energy consumption during the tests.

Test	Refrigeration electrical energy consumption (REC) ($kWh.24h^{-1}$)	Direct electrical energy consumption (DEC) ($kWh.24h^{-1}$)	Total energy consumption (TEC) ($kWh.24h^{-1}$)	Total Display Area (TDA) (m^2)	TEC/TDA ($kWh.24h^{-1}.m^{-2}$)	Percentage relative to highest open energy consumption %
Open	44.59	2.18	46.78	4.39	10.66	99.7
Open	44.75	2.17	46.92	4.39	10.69	100.0
Doored	22.25	2.17	24.42	4.43	5.51	51.5
Doored	16.47	2.20	18.67	4.43	4.22	39.4

Fitting doors reduced the daily energy consumption to 51.5% of the open cabinet consumption while achieving the same minimum pack temperature (-1.0°C) and a greatly reduced maximum temperature. When the maximum temperature was then raised to be close to that of the open cabinet (7.2°C) the daily energy consumption reduced further to 39.4% of the open consumption.

3.3 Comparison With Other Test Laboratory Studies

For cabinets with well-fitted doors, the extent to which infiltration is reduced will depend mainly on the door opening frequency and duration. The door opening regime used in the testing was that defined in the EN23953:2015 test standard for the purposes of evaluating cabinet performance, but this can differ markedly from real-life opening patterns. For the purposes of a more direct comparison with the current results, the following test laboratory studies are therefore more appropriate than results based on in-store trials.

Faramarzi et al, 2002 reported that in laboratory tests, retrofitted glass doors reduced the total cooling load of a display case by 68%, and reduced the refrigerant mass flow by 71% with consequent reduction of compressor power demand by 87%. These tests were however done under slightly different conditions – the standard followed was ANSI/ASHRAE 72-183 with a slightly different climate class (75°F and 55% RH) and a door opening regime of each door opening every 12 minutes for 16 seconds during the whole 24 hour test period. For the door tests, an additional fan was placed such that air was blown into the open doorways to simulate shopper traffic – this would of course reduce the impact of the doors.

Lindberg et al, 2010 compared the performance of cabinets with and without doors in a test laboratory. An open fronted cabinet was initially tested according to the then current ISO standard test method for measurement of performance (EN ISO 23953:2005) in a test room operating at 22°C and 65% RH (Climate Class 2). The cabinet was refrigerated using an indirect propylene glycol system and was operated with night blinds down during a 12 hour night period. Hinged glass doors were then fitted and the cabinet was re-tested under 2 door opening regimes (the standard 10 or increased shopper simulation of 30 openings per hour of 6 seconds duration for 12 hours). Both the standard and increased opening frequency differ from that in ISO 23953: 2015 as used in the current tests. When tested with doors, additional lighting was added to the cabinet (3x 28W). To maintain the same temperature classification for the cabinet it was possible to increase the inlet heat exchanger temperature by 10 K when doors were fitted. Adding the doors reduced heat extraction by between 61 and 66% during the day and by between 46 and 53% at night.

In another laboratory study, Atilio de Frias et al, 2015 reported comparison of a cabinet holding packaged baby spinach, first open and then closed with retrofitted doors. Ambient conditions were 21°C +/-3°C and 60–70% RH. Closed cabinet product temperatures were greater than 5°C for only 1% of the four-day test period, compared with 24% for the open cabinet. The range between maximum and minimum temperatures was also reduced by up to 6 K, and at the same time daily energy consumption was 69% lower. Interestingly it was reported that energy consumption was the same for the doored cabinet when the doors were kept closed as it was when they were opened according to ASHRAE standard 72-2014, with each door being opened sequentially and fully opened 6 times per hour for 6 seconds for a period of 8 hours.

4. DISCUSSION AND CONCLUSIONS

The reported series of tests confirmed the findings of previous studies that adding doors to open fronted retail display cabinets is an effective way to improve temperature control and at the same time reduce energy consumption. Doors can be added at the production stage or retrofitted in most existing retail installations which currently have open cabinets. The findings help to reinforce initiatives adopted by some but not all retail operators.

The temperature results suggest that in practice there may be different operating strategies when retrofitting doors. Lower and more uniform temperatures can be achieved to improve food safety and quality retention and possibly lead to less food waste, at the same time as reasonable reductions in energy consumption. Alternatively, similar (but more uniform) maximum temperatures can be achieved with even greater reductions in energy consumption.

The average evaporator temperature increased to above 0ºC in the doored test at the higher temperature. This provides an opportunity to run the cabinet without the need for defrosts. In this test the refrigerant had 5.9ºC glide, therefore, even though the average temperature was 0.5ºC, the entrance to the evaporator would have been at -2.4ºC (bubble point). If a refrigerant without glide was used, it may have been possible to run the cabinet without the need for defrosts.

5. ACKNOWLEDGEMENTS

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