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HEAT EXCHANGER SHELVES FOR BETTER TEMPERATURE CONTROL OF FOOD IN OPEN-TYPE DISPLAY CASES

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ABSTRACT

Fresh food and specially meat require to be maintained at an accurate temperature level for good conservation conditions. These accurate levels require small air temperature tolerances. Open-type display cases show very high temperature differences, and even the European standard EN 441 accepts large temperature intervals associated with the defrosting process and what is known of the actual technology level.

A new global design of open-type display case has been realized in order to limit drastically the temperature differences of the products depending on their position on the shelves (from front to rear). A defrosting system without heating up the cooling air has been developed. A good repartition of air on each shelf is achieved by an innovative concept, protected by a patent. The shelf itself is transformed in a heat exchanger, the airflow circulates inside the shelf and is sprayed over the food displayed on the underneath shelf. The design adapts the airflow according to the heat loads received by the food.

A demonstrator of open-type display case has been realized and tested in a climatic room. Experimental results show the different level of temperatures, the air flow circulation and the level of temperature of food. Food can be maintained at a constant temperature ±1.5K.

1. STATE OF THE ART FOR TEMPERATURE CONTROL IN OPEN TYPE DISPLAY CASE

Figure 1 indicates typical variations of temperatures registered in core of products displayed in common vertical fresh food display cases. Those data have been registered during 24 hours and the raise of temperature due to the opening hours of the supermarket can be noticed.

The temperature peaks correspond to defrosting which occurs 4 times a day and where typical raises of temperature are in the range of 2 to 4K. Those thermal events have different impacts depending on the position of the products in the display cases as shown by the 3 curves. Those temperature variations are due to :

- difference in air flows received by the products
- difference in air flow temperatures
- difference in heat loads received by the products.

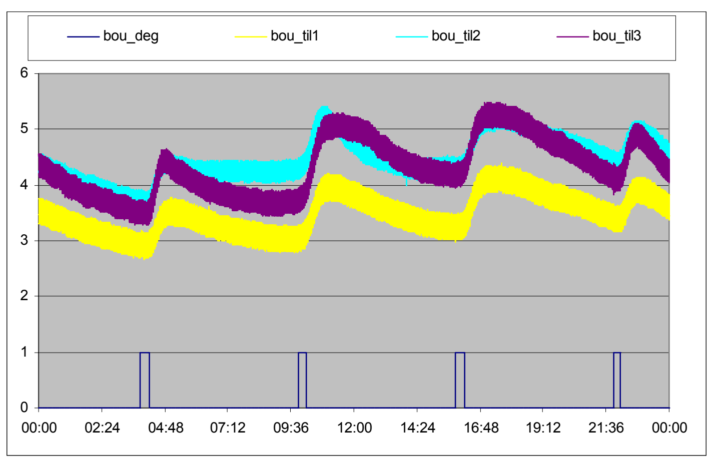


Figure 1 Temperature variations of products inside an open type

display-case

1.1 Temperature Differences of Products Defined by EN 441 Standard

The European standard EN 441 [AFN96] takes into account all those temperature variations as indicated in Figures 2 and 3:

- the temperatures are measured at the core of the fake product
- the mean temperature calculation of the product takes into account the time period integrating the defrosting (Figure 2)
- the temperature differences calculated between 2 products taking into account the mean temperatures as defined previously (Figure 3).

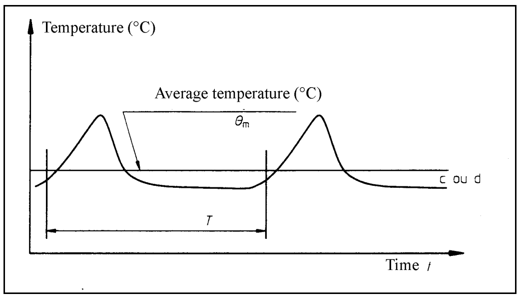


Figure 2 - Reference period of time taken into account for mean temperature calculation [AFN96].

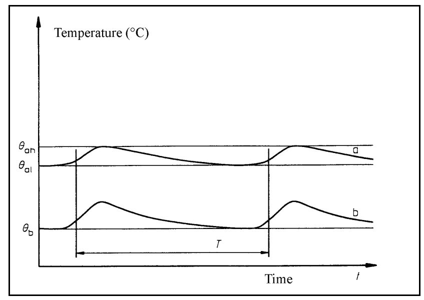


Figure 3 – Temperature differences between 2 products [AFN96].

In summary, those calculations smoothen the instantaneous variations that really affect the products. The temperature at the core of products is the one where the variations are the smallest, and the temperature peak during defrosting, which lasts typically 20 to 30 minutes, is smoothen on all the period of time without defrosting. Moreover the EN 441 standard has defined different classes of temperature control as indicated in Table 1. The best temperature control (class M1) implies a 6K mean temperature difference (between +5 and –1°C), which is clearly a significant difference of temperatures.

Table 1 – Temperature classes [AFN94]

Class	Highest temperature of the hottest pack lower or equalt to (°C)	Lowest temperature of the coldest pack lower or equal to (°C)
M1	+5	-1
M2	+7	-1
H	+10	+1

2. GLOBAL DESIGN TO LIMIT RAISE OF TEMPERATURE IN THE PRODUCTS

The global design of the open display case prototype is based on a detailed analysis of thermal loads on a 24-hr period [CLO02]. When accepting the constraint of an open display case, and knowing that more than 80% of thermal loads are due to the opening, the first energy efficient measure is to design an automatic night curtain [PAN00]. The other main efficient designs are shortly presently here below:

- defrosting without blowing air temperature raise
- defrosting by hot refrigerant
- 2 air curtains
- external air curtain cooled at a temperature above 0°C

- new design for air repartition on products.

2.1 Defrosting Without Temperature Change

To limit drastically temperature variations, the first technical concept is to defrost the air coil without affecting the air temperatures. A number of patents [MAE87], [MIL65], [RAY86], [TOS88] addresses this possibility. Basically the design is based on 2 or more air coils, permitting defrosting of one coil without air circulation; during this defrosting period, air is circulating on another air coil to maintain the blowing air temperature at the same level.

On the prototype developed at the laboratory, only the main evaporator 1 operates during the basic cooling mode, while evaporator 2 is inoperative. On the contrary, during defrosting of evaporator 1, evaporator 2 operates in cooling mode. The airflow still circulates over the cold coil through a system of flaps (Figure 4) located upstream and downstream of the coils.

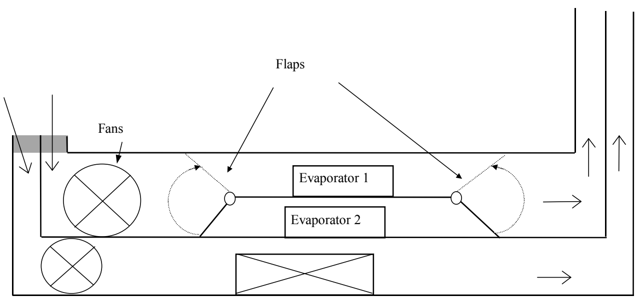


Figure 4 - System of flaps.

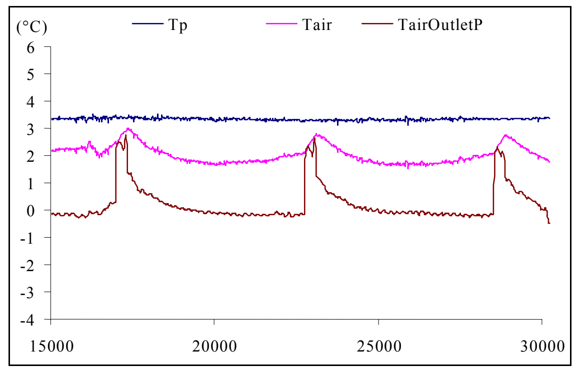
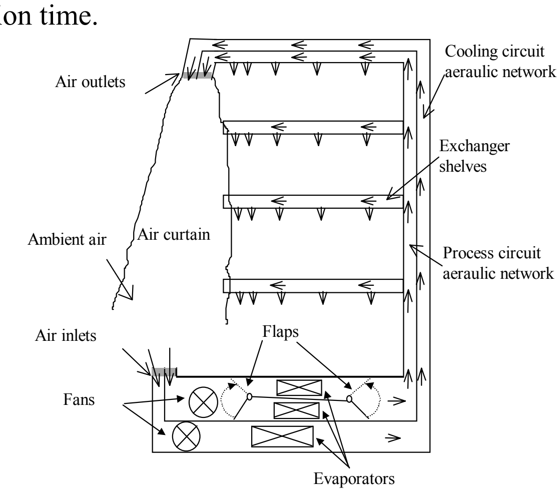


Figure 5 - Product and air temperatures during defrosting by hot liquid.

In this display case, the air flows on a smaller air coil (evaporator 2) during the defrosting period, which is very short, because defrosting is performed by hot refrigerant getting out of the condenser. The defrosting period is required when 1K raise of temperature is noticed at the blowing port. Defrosting time is between 2 to 3 minutes, which permits to have a small coil for the defrosting period and permits also to perform as many defrostings as necessary. The registered temperatures (Figure 5) at the core of the fake product remains constant while the blowing air raises less than 1K and the air around the defrosting evaporator indicates the small raise of temperature and the fast defrosting operation time.

2.2 Double Curtain With Temperature Control

Two fully independent refrigeration circuits are installed in the display case. One cools the external curtain at a temperature always above 1°C in order to avoid frosting on the evaporator of this external air circuit and permitting also to have a better energy efficiency to separate the internal ambiance of the open display case from the room air. The first curtain is installed in order to limit the introduction of room hot air (25°C). The second curtain is cooled down at the temperature permitting to maintain products at the required level (between 1 and 3°C).



required level (between 1 and 3°C). Figure 6 – The display case

3. HEAT EXCHANGER SHELF

Depending on the position of the product on a given shelf, the heat loads and the received cooling capacity are significantly different. Also the thermal loads received by the different shelves depend on their relative position because the air curtains create blends of room air at 25°C and of blowing air at low temperature, along the air curtain.

3.1 Heat Balance on Products

At night, the external air curtain is stopped and an automated night curtain made of nylon is rolled down permitting major energy savings, and also limiting defrosting. At night the radiative heat transfer on the products is rather limited and so the daylight period is the critical one requiring adequate analysis.

During day operation, the radiative heat transfers between the test room and the products inside the display case include those through the lateral glass panels and the open section. The calculation is performed with the following assumptions:

- the emissivity of the glass panel is equal to 0.95 in the infrared (0.7-10μm);
- the display case is fully filled with products, and the heat radiated through the glass panels is totally transferred to the products located behind the glass panels;
- the products are considered as black bodies;
- the walls of the room are painted grey and their emissivity ε_v is 0.91;
- the temperatures of the products are uniform;
- each wall of the room is defined by its average temperature.

Taking into account those assumptions, Table 2 indicates the heat loads received on the different shelves. Lateral radiative loads shown in Table 2 include both sides. The central and the bottom shelves receive more than 25% of radiative heat loads compared to the 2 others.

Table 2 - Radiative heat transfer during day operation (W)

	Top shelf	Centre shelf	Bottom shelf	Container
Lateral radiative loads	18	29	29	10.8
Open section	94.1	113.9	113.9	108.9
Total (W)	112.1	142.9	142.9	119.7

The total radiative heat loads received by the display case from the test room during day operation is of 517W, which is 4 times higher than during night operation.

3.2 Global Air Distribution For The Two Operating Modes

The air flow distribution shown in Table 3 is calculated on the the following assumptions.

- Air temperature at the evaporator outlet – 3°C.
- Relative humidity at the evaporator outlet 100%.
- Temperature of the products in the display case, about 1°C.

Table 3 - Air flow rate distribution under the two operating conditions

	Night operating conditions			**Day operation**		
	Temperature (°C)	Air flow rate (m^3/h)	Flow rate (%)	Temperature (°C)	Air flow rate (m^3/h)	Flow rate (%)
Ceiling	- 2.8	40	4.3	- 2.8	34	3.4
Upper shelf	- 2.9	70	7.5	- 2.9	62	6.2
Centre shelf	-2.9	73	8	- 2.9	65	6.5
Lower shelf	- 2.9	64	7	- 2.9	39	3.9
Air suction port	- 2.7	673	73.2	- 2.7	800	80

The energy and mass balances calculated on the different shelves and on the internal air curtain indicate that whatever the operating mode (night or day) 73 to 80% of the blown air circulate only along the air curtain, the remaining 20 to 27% are distributed inside the display case on the different shelves. It is consistent with the fact that the major heat load is coming from the opening of the display case.

3.3 Innovative Heat Exchanger Shelves

The heat exchanger shelf design is an innovation protected by the patent [CLOD98]. The heat exchanger shelf consists of a double wall inside which the air circulates from the rear to the front of the display case. The shelf lower wall is perforated to distribute the air on to the products placed on the lower shelf (see Figure 7). Air is supplied through the opening at the rear of the double walls of the shelves in the display case rear vertical panel. Part of the airflow rate passes in the shelf space and is distributed towards to bottom through the perforated plate. The remainder of the main airflow rate is distributed to the other shelves and the air outlet of the display case.

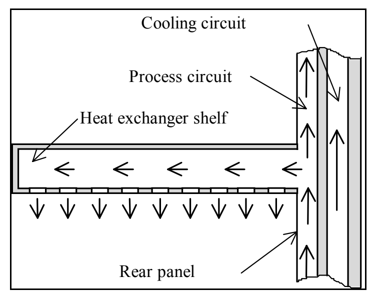


Figure 7 – Heat exchanger shelf

The heat exchanger shelf provides a double thermal transfer: convection for the products on the lower shelf, and conduction for the products on the shelf itself.

3.4 Experimental Results

Tests have been performed to compare (in the same display case) a series of conventional shelves to the new heat exchanger shelves. Figure 8 indicates for the same air blowing temperature, the temperature measured at the core of the products. The difference of temperature is of 4K.

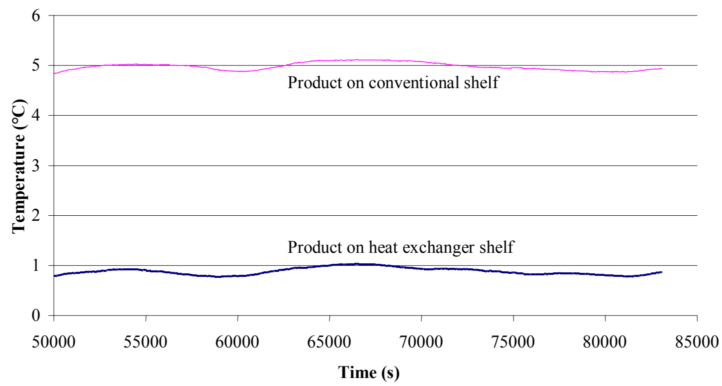


Figure 8 - Effect of the exchanger shelf on the temperature of products

The heat exchanger shelf cools the products faster and maintains the required level of temperature. Additional series of tests have been performed in order to analyze how fast products can be cooled inside the display case when the night curtain is rolled down. As indicated in Table 4, to lower of 1K all the products installed in the display case 9 hours are necessary on conventional shelves and only 6h 20min on heat exchanger shelves.

The temperature difference between the hottest and coldest products is 2.7K with the heat exchanger shelves, whereas it is up to 5.2K with conventional shelves.

Comparing the temperatures of the products displayed on the front and on the rear parts of a given shelf, the difference of temperature between the hottest and the coldest product is of 1.2K for conventional shelf and 0.6K for heat exchanger shelf.

Table 4 - Effect of the heat exchanger shelf

	Time lag for $\Delta T_{product} = 1K$	**$\Delta T^1_{product\ max}$ (K)**	**$\Delta T^2_{product}$ (K)**
Conventional shelves	9 h 00	5.2	1.2
Heat exchanger shelves	6 h 20min	2.7	0.6
Difference	2 h 40min	2.5	0.6

(1) the temperature difference is measured between the hottest and the coldest products taking into account all the products in the display case
(2) the temperature difference between the hottest and the coldest products measured on the same shelf.

In refrigerating display cases, the air is generally distributed to the products through perforations in the rear vertical panel. Circulation is complex and the difference in temperature between the rear and the front of the display case is significant. The heat exchanger shelf air flow optimizes the distribution of the air flow between the front and rear of the shelf through a different number of perforations.

CONCLUSIONS

Open type display cases are used in supermarkets where a large number of consumers make their shopping of fresh food, which is the usual justification of not having doors to separate the internal volume of the display case from the room. A number of research efforts have been accomplished on air curtains, but additional efforts remain in order to avoid large variation of temperature of products. As presented in the paper, depending on the position of the product in the display case, and also depending on the defrosting design, large variations of temperatures are measured on actual display cases.

Effective design are possible to limit drastically these temperature variations. Better temperature control of the products implies defrosting system without air temperature changes and a better repartition of air on the shelves taking into account the different heat loads received depending on the position. Heat exchanger shelves with air distribution realized by the shelf itself permit to provide the required airflow to maintain the products within a small difference of temperature.

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