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TEMPERATURE PREDICTION IN A REFRIGERATED DISPLAY CABINET: DETERMINISTIC AND STOCHASTIC APPROACHES

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Abstract*: The product temperature in the refrigerated display cabinets is very variable and it influences directly the safety and quality of the food products. This variability is due to the type of display cabinet (vertical, horizontal), the position of the product inside the equipment, the fluctuation of the ambient air temperature in the supermarkets (day/night, opening hours, seasons, air conditioning etc.) and the surrounding condition of the display cabinet (in front of another refrigerated display cabinet or in front of grocery products) etc.*
This study proposes a thermal model to predict the load temperature in an open vertical display cabinet in function of two random parameters: ambient temperature in the supermarket and radiation temperature of the surrounding walls. The knowledge of the probability density of these parameters, from field measurements or expert knowledge, allows predicting the variability of the product temperatures inside the display cabinet.

Keywords*: Refrigerated display cabinet, heat transfer, random parameter, product temperature.*

1. Introduction

In France, the consumer spends 62.2% of their food budget in supermarkets and about a half of these foods are presented in display cabinets (Bertrand, 1993). The open front refrigerated display cabinet is the most common method of keeping chilled food at the required temperature and also allowing the customer almost unrestricted access. A survey carried out by our team (Cemagref and ANIA, 2004) showed that 30% of products presented in refrigerated display

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cabinet were subjected to temperature abuse (more than 2°C higher than recommended preservation temperature). Willocx et al (1994) carried out a survey on processed vegetables in Belgian retail display cabinets. This study also showed that retail display cabinets are a critical point in the cold chain. Temperature differences of more than 5°C were measured in the decks. Temperature in one place increases toward the end of the day by 4°C and toward the end of the week by almost 7°C.

In open front display cabinet, the majority of high temperature packs (97%) were located at the front and the largest number (60%) of them was at the front base (Evans et al, 2007). Brimelow (1987) reported temperatures at the rear to be cooler than temperatures at the front of shelves and this was in agreement with the studies of Greer et al (1994) and Gill et al (2003) for a chilled meat case preserved in a vertical display cabinet. The product temperature is influenced by the ambient temperature in supermarket, the lighting (of supermarket and display cabinet), the nature of surface in front of the cabinet (grocery shelves, another cabinet) etc.

A review by Smale et al (2006) brings out the complementary role played by CFD analysis and experimental studies. It demonstrates the ability of CFD to capture temperature critical domains. Although CFD is a powerful simulation tool, its use is limited because of the calculation time (several days for one calculation using more than 1 million cells for loaded equipment).

Several studies have statistically analysed field measurements of product temperature in cold chain [Tolstoy, 1991; Gill et al, 2003a; 2003b; Rosset et al, 2004; Likar & Jevsnik, 2006, Dallaire et al, 2006]. But these studies are not able to evaluate the relative impact of the different sources of variability (product position, ambient air temperature…). In order to overcome this limitation, the present study combines a deterministic thermal model of a display cabinet with a stochastic approach of some sources of variability.

Combined deterministic and stochastic approaches were already applied to domestic refrigerators in our previous work (Laguerre & Flick, 2010). As continuity, this study was carried out to predict the product temperature at various positions in a vertical refrigerated display cabinet. The influence of random parameters such as ambient temperature of supermarket and radiation conditions was studied. The influence of ambient humidity on the product temperature is considered as non significant because of low water content in air (about 0.006 to 0.007 kg water/kg dry air). The condensation is rarely observed on the product in practice. However, the cooling load of the cold production system of the display cabinet is highly influenced by the ambient air humidity because of the condensation and frost formation on the evaporator.

Nomenclature

A	Surface area, m^2
Cp	Thermal capacity of air, $J.kg^{-1}.°C^{-1}$
h	Heat transfer coefficient, $W.m^{-2}.°C^{-1}$
$\dot{m}$	Mass flow rate of air, $kg.s^{-1}$
T	Temperature, °C
δ	Infiltration rate, dimensionless
σ	Standard deviation
σ^2	Variance
α	Dimensionless heat transfer

Index

a Air
cal Calculated
cv Convection
e External ambient
exp Experimental
int Interaction
r Radiation
th Thermostat

2. Thermal model development

2.1 Description of the loaded display cabinet and heat transfer modes

Figure 1 shows schematically the air circulation and the heat transfers. An air curtain, in which cold air flows downwards, cools the products located in front of the display cabinet. These front products are also submitted to radiation from the surrounding walls. Along the air curtain, there is external air infiltration which leads to increase the air temperature. Near the bottom, a part of the air curtain flows out of the display cabinet. Another part is cooled down through the cold exchanger. A part of this air flows upwards in the rear part of the cabinet to join again the cold air vent and another part flows horizontally through the rear grilles to join the air curtain. The model considers heat exchanges by convection (between air and load), by conduction (between 2 loads located at the same height) and by radiation (between the front loads and the surrounding walls). According to our laboratory and field studies, the front load is warmer than the rear one and the top load is colder than the bottom one. This leads to consider 4 load positions with different temperatures in the model: T_1, T_2, T_3 and T_4.

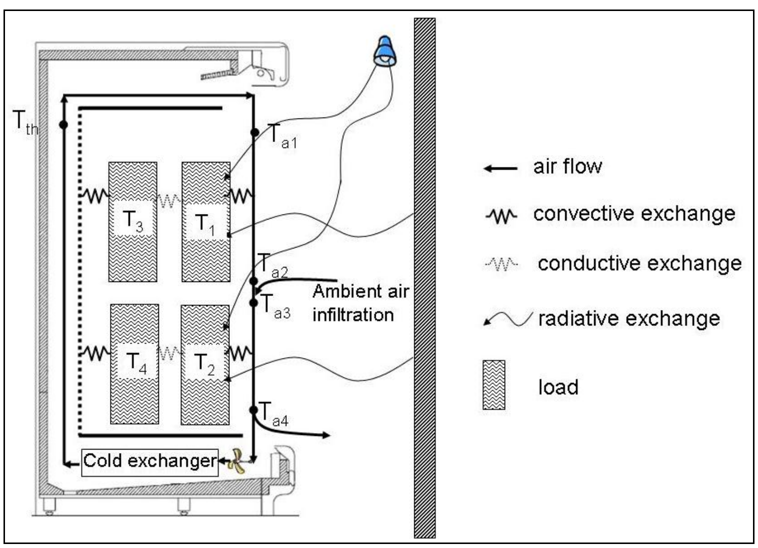


Figure 1. Different heat transfer modes taken into account in an open vertical display cabinet.

2.2 Balance equations

The simplified thermal model is based on steady state heat transfer. This means that all temperatures are constant with respect to time. In practice, the temperatures vary due to several factors: compressor working cycle, defrosting period and night/day period etc.

2.2.1 Heat exchanges between the air curtain and the top front load.

The blown air (temperature T_{a1}, mass flow rate $\dot{m}$), exchanges heat by convection (heat transfer coefficient h_{cv}) with the top front load (temperature T_1). This exchange leads to increases the air temperature form T_{a1} to T_{a2} (Figure 1).

$$\dot{m}.Cp.dT_a = h_{cv}(T_1 - T_a)dA_{cv} \Leftrightarrow \frac{T_{a2} - T_1}{T_{a1} - T_1} = exp\left(\frac{-(hA)_{cv}}{\dot{m}Cp}\right) \Leftrightarrow$$

$$(T_{a2} - T_1) = \alpha_{cv}(T_{a1} - T_1) \Leftrightarrow$$

$$-\alpha_{cv}T_{a1} + T_{a2} + T_1(\alpha_{cv} - 1) = 0 \tag{1}$$

Where $\alpha_{cv} = exp\left(\frac{-(hA)_{cv}}{\dot{m}Cp}\right)$

2.2.2 Infiltration at the mid-height of the display cabinet

After heat exchange with the top front load, this air is mixed with the external air (temperature T_e , flow rate $\dot{m}_e$) because of infiltration. After this mixing, the air temperature increases to T_{a3} and the flow rate to $(\dot{m} + \dot{m}_e)$.

$$\dot{m}CpT_{a2} + \dot{m}_eCpT_e = (\dot{m} + \dot{m}_e)CpT_{a3} \Leftrightarrow$$

$$T_{a2} - (1 + \delta)T_{a3} = -\delta T_e \tag{2}$$

$\delta = \frac{\dot{m}_e}{\dot{m}}$ = infiltration rate

2.2.3 General equations

The same reasoning was used to develop the other heat balance equations which take into account heat transfer between the air and the loads at other positions (by convection), between 2 loads located at the same height (by conduction and radiation), between the front load and the walls located oppositely (by radiation) and due to lighting. The mean temperature of these walls (floor, ceiling, shelves, supermarket walls etc.), which exchange heat by radiation with the front load, is called radiation temperature (T_r). The obtained set of equations which involves different air and load temperature in function of T_e and T_r is linear. Solving of these linear equations allows expressing the 4 load temperatures: T_i (i index of load position, see Figure 1) as follows:

$$(T_i - T_{th}) = a_i + b_i(T_e - T_{th}) + c_i(T_r - T_e) \tag{3}$$

T_{th} called thermostat temperature is defined as the air temperature near to the thermostat. Its value is fixed by the manufacturer for a given type of display cabinet. In fact, there are small periodic temperature fluctuations due to regulation, but there are neglected here.

An estimation of the heat transfer coefficients by conduction, convection and radiation leads to establish the values of a_i, b_i and c_i as shown below:

$$\mathbf{a_i} = \begin{bmatrix} \mathbf{0.1456°C} \\ \mathbf{0.3572°C} \\ \mathbf{0.0341°C} \\ \mathbf{0.0833°C} \end{bmatrix} \qquad \mathbf{b_i} = \begin{bmatrix} \mathbf{0.1949} \\ \mathbf{0.2929} \\ \mathbf{0.0457} \\ \mathbf{0.0679} \end{bmatrix} \qquad \mathbf{c_i} = \begin{bmatrix} \mathbf{0.1831} \\ \mathbf{0.1889} \\ \mathbf{0.0430} \\ \mathbf{0.0435} \end{bmatrix}$$

3. Validation of the thermal model

The thermal model was firstly validated by comparing the load temperatures with the experimental values obtained for a display cabinet placed in a laboratory test room (ambient temperature controlled at 20°C). The vertical open display cabinet was loaded by packages of test product made of methylcellulose (dimensions: 200 mm x 100 mm x 50 mm) and the thermostat temperature was fixed at 1.5°C. At each of the 4 load position, the core temperatures of 6 packages were measured by thermocouples every minute until the steady state was reached (after 24h). Then, the average temperature was calculated over 3h of steady state period. Figure 2 shows a comparison between the experimental and predicted load temperatures (calculated by the eq. 3), a good agreement was obtained (max. difference 0.9°C). It can be observed that for the 2 front loads, the experimental temperature increases from the top (5.0°C) to the bottom (6.4°C). This can be explained by the increase of the air curtain temperature during the downward flow due to infiltration of external air at 20°C. The front load temperature are higher than the air curtain temperature because of the heat exchanges by radiation between the front loads and the surfaces located in front of the display cabinet. For the 2 loads of the same height, the temperature of the front load is higher than that located at the rear. This is due to the convective exchange between the rear loads and the air which is cooled down by the cold exchanger and flows then upward in the back of the cabinet. For the 2 rear loads, the temperature decreases slightly (0.4°C) form the bottom to the top. This is due to the heat exchange by conduction which is more significant between the 2 loads located at the bottom (higher temperature difference) than those located at the top.

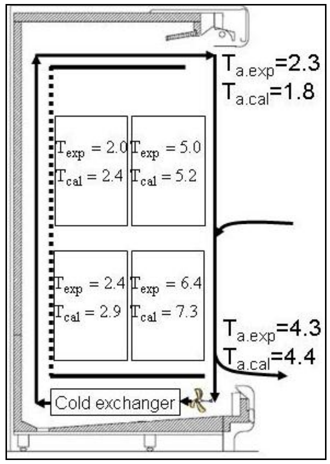


Figure 2. Comparison between experimental and calculated air and load temperatures (°C) for the ambient temperature of 20°C and the thermostat temperature of 1.5°C.

4. Combination of deterministic and stochastic approaches

Once, the simplified thermal model was validated, it was combined with a stochastic approach by considering 2 random parameters: variation of ambient air temperature in the supermarkets and the variation of radiation conditions which surround the display cabinet. The radiation conditions depend on the nature of the surfaces located in front of the display cabinet: cabinet located in front of another cabinet, cabinet located in front of grocery shelves. These 2 radiation conditions are assumed equally probable. It is also assumed that the 4 positions of product in a display cabinet are equally probable.

4.1 Influence of the variation of ambient temperature in supermarket on the variation of load temperature.

A normal distribution was fitted to the survey data of ambient temperature in 8 supermarkets in USA (measurement for 12 months, Rosario and Howell, 2001). This study showed that the mean air temperature in the supermarkets $\overline{T}_e$ is 22.3°C and the standard deviation σ_e is 1.8°C.

4.2 Influence of the variation of radiation conditions on the variation of load temperature.

The surrounding walls temperature strongly influences the temperature of the load located at the front of a display cabinet due to radiation. However, as our knowledge, there was no field measurement of the surrounding walls temperature. From expert knowledge [Gac & Gautherin, 1987], it appears that the radiation temperature is correlated to the ambient air temperature: when grocery shelves are placed opposite the refrigerated display cabinet, the radiation temperature is close to that of air. When another display cabinet is placed oppositely, the radiation temperature is averagely 6°C lower than the air temperature.
Two equally probable radiation conditions (*a*) and (*b*) are therefore considered:

a. condition : $\overline{T}_e$= 22.3°C, σ_e= 1.8°C, T_{th} = 1.5°C and $T_r = T_e$ (grocery shelves located oppositely).

b. condition : $\overline{T}_e$ = 22.3°C, σ_e = 1.8°C, T_{th} = 1.5°C and $T_r = T_e - 6°C$ (a display cabinet located oppositely).

It appears that the T_e and T_r are correlated and T_{th} can be chosen as a reference temperature. Therefore, T_e-T_{th} and T_r-T_e are rather used as independent parameters.

For the 2 radiation conditions (*a* or *b*) and for each position (i), the mean load temperature and its standard deviation can be expressed as follows:

$$\overline{T}_{i,a} - T_{th} = a_i + b_i\left(\overline{T}_e - T_{th}\right).+c_i.\left(T_r - T_e\right)_a \; with \; \left(T_r - T_e\right)_a = 0°C \tag{4}$$

$$\overline{T}_{i,b} - T_{th} = a_i + b_i\left(\overline{T}_e - T_{th}\right).+c_i.\left(T_r - T_e\right)_b \; with \; \left(T_r - T_e\right)_b = \Delta T_r = -6°C \tag{5}$$

$$\sigma_{ia}^2 = \sigma_{ib}^2 = b_i^2\sigma_e^2 \;\; (refered \;\; as \;\; \sigma_i^2) \tag{6}$$

The results are presented in Figure 3.a and 3.b and discussed in section5.

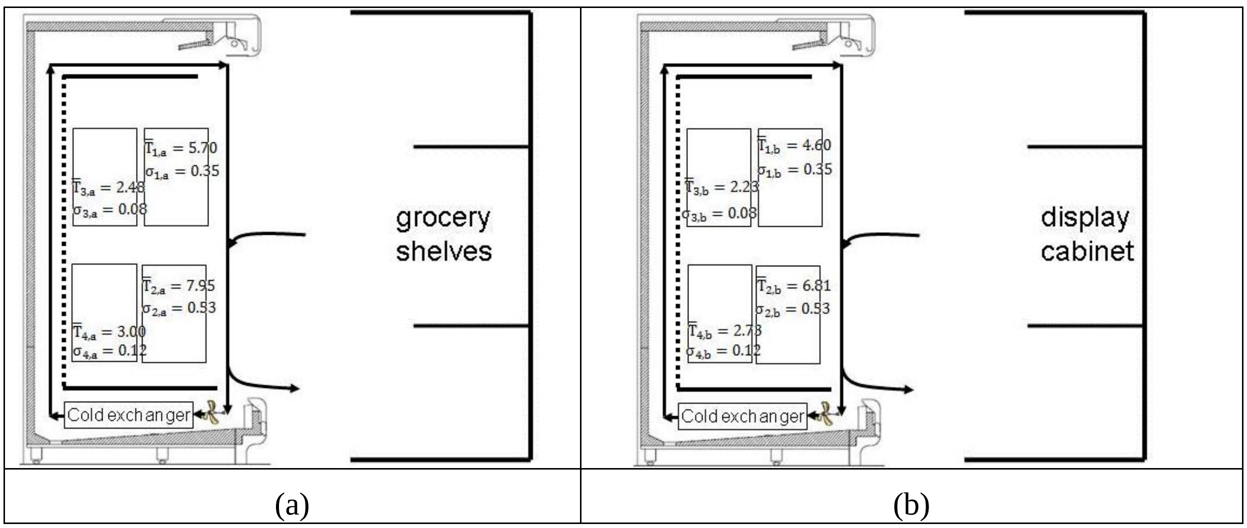


Figure 3 : Load temperature and standard deviation for $T_{th} = 1.5°C$

a. $\overline{T}_e = 22.3°C, \sigma_e = 1.8°C, T_r - T_e = 0°C$ **(called (a) condition),**

b. $\overline{T}_e = 22.3°C, \sigma_e = 1.8°C, T_r - T_e = -6°C$ **(called (b)condition).**

4.3 Combined influence of the variation of ambient temperature in supermarket and the radiation temperature.

At a given load position, the combined influence of the variation of these 2 random parameters is the result of the mixing of 2 normal distributions with the same variance (Figure 4).

For each load position, the mean load temperature assuming equally probable radiation conditions can be calculated as follow:

$$\bar{T}_{i,\, a+b} = \left(\frac{\bar{T}_{i,\, a} + \bar{T}_{i,\, b}}{2} \right) \tag{7}$$

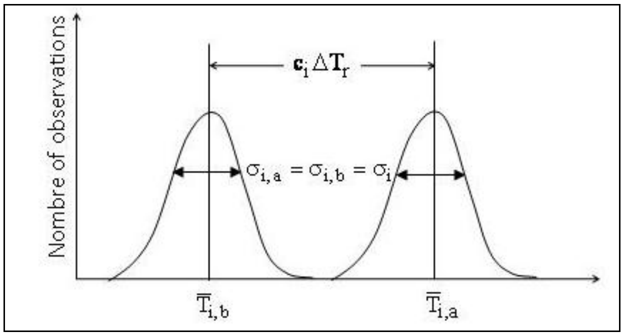


Figure 4. Mixing of 2 normal distributions of the load temperature due to 2 different radiation temperatures.

The variance of the load temperature is the sum of the one due to the variation of the ambient temperature and the one due to the variation of radiation conditions.

$$\sigma^2_{i,\, a+b} = \underbrace{b_i^2 . \sigma_e^2}_{\text{due to variability of } T_e} + \underbrace{c_i^2 . \sigma_r^2}_{\text{due to variability of radiative conditions}} = \frac{\sigma^2_{i,a} + \sigma^2_{i,b}}{2} + \frac{\left(\bar{T}_{i,a} - \bar{T}_{i,b}\right)^2}{4} \tag{8}$$

Where σ_r is the standard deviation of $(T_r - T_e)$, $\sigma_r = |\Delta T_r| / 2 = 3°C$

The combine influence of ambient temperature and radiation condition variability on the entire load temperature without distinction of positions can be calculated as follow:
For the mean value:

$$\bar{T}_{a+b} = \frac{1}{2} \frac{\sum_{i=1}^{4} \bar{T}_{i,\, a}}{4} + \frac{1}{2} \frac{\sum_{i=1}^{4} \bar{T}_{i,\, b}}{4} \tag{9}$$

For the variance:

$$\begin{aligned} \sigma^2_{a+b} &= \frac{1}{2} \frac{\sum_{i=1}^{4} \sigma^2_{i,\, a}}{4} + \frac{1}{2} \frac{\sum_{i=1}^{4} \sigma^2_{i,\, b}}{4} + \frac{1}{2} \frac{\sum_{i=1}^{4} \left(\bar{T}_{i,a} - \bar{T}_{a+b}\right)^2}{4} + \frac{1}{2} \frac{\sum_{i=1}^{4} \left(\bar{T}_{i,b} - \bar{T}_{a+b}\right)^2}{4} = \\ &= \frac{\sum_{i=1}^{4} \sigma_i^2}{4} + \frac{1}{2} \frac{\sum_{i=1}^{4} \left(\bar{T}_{i,a} - \bar{T}_{a+b}\right)^2}{4} + \frac{1}{2} \frac{\sum_{i=1}^{4} \left(\bar{T}_{i,b} - \bar{T}_{a+b}\right)^2}{4} \end{aligned} \tag{10}$$

since $\sigma_{i,a} = \sigma_{i,b} = \sigma_i$.

The calculated variance value was interpreted as the sum of 4 terms reflecting the weight of each variability source and interactions between them.

$$\sigma_{a+b}^2 = \underbrace{\frac{\sum_{i=1}^{4} b_i^2 \sigma_e^2}{4}}_{\substack{\text{mean influence}\\\text{of ambient}\\\text{temperature}\\\text{variability}}} + \underbrace{\frac{\sum_{i=1}^{4} c_i^2 \sigma_r^2}{4}}_{\substack{\text{mean influence}\\\text{of radiative}\\\text{condition}\\\text{variability}}} + \underbrace{\frac{\sum_{i=1}^{4} \left(\bar{T}_{i,a+b} - \bar{T}_{a+b}\right)^2}{4}}_{\substack{\text{mean influence}\\\text{of position}\\\text{variability}}} + \underbrace{\sigma_{\text{int}}^2}_{\substack{\text{interaction}\\\text{term}}} \quad (11)$$

5. Results and discussion

5.1 Influence of the variation of the ambient temperature in supermarket

The mean load temperature and its standard deviation for the radiation condition (*a*) (grocery shelves oppositely) are reported in Figure 3.a. The same trends as those shown in Figure 2 were obtained: front loads warmer than rear loads and top loads cooler than bottom loads. The influence of the ambient temperature variability is more noticeable on the front loads compared to that of the rear loads (higher value of standard deviation).

5.2 Influence of the variation of radiation temperature

The result of radiation condition (*b*) (display cabinet oppositely) is presented in Figure 3.b. The same trends as observed previously were obtained but the mean load temperature decreases for every position while the standard deviation is the same. This temperature decrease is more noticeable for the front loads (1.1°C) than for the rear loads (0.3°C) whatever the height. This can be explained by the radiation between the front loads and the surrounding surfaces which is higher when grocery shelves are placed oppositely than when another display cabinet is there. Like the result shown on Figure 4a, the influence of the radiation condition is more significant on the front loads (higher value of standard deviation).

5.3. Combined influence of the variation of ambient and radiation temperatures.

The combined influence of the ambient temperature and the radiation conditions is presented in Figure 5. For each position, the mean value is intermediated between those obtained in radiation conditions (*a*) and (*b*). The standard deviation is higher due to the combined influence.
For the entire load (without distinction of position), mean temperature is 4.44°C (standard deviation 2.07 and variance 4.267). This variance is the result of the variability of several parameters: ambient temperature of supermarkets, radiation conditions and load position.
Table 1 shows the importance of each influence (ambient temperature and radiation conditions) on the variance of the load temperature at the 4 positions. As observed previously, the combined influence is more significant on the front load than on the rear load (higher variance values at the positions 1 and 2). The most critical position is that of the bottom front load: mean temperature and total variance values are the highest. The influence of ambient temperature variability and radiation condition variability are almost the same at this position. For the top front load, the influence of ambient temperature variability is lower because the air curtain temperature is not yet increased due to ambient air infiltration.
Table 2 shows the importance of each influence (ambient temperature, radiation conditions and load position) on the variance of the entire load temperature. It can be observed that the influence

of the load position is the most important compared to that of the ambient temperature and the radiation conditions.

Table 1. Combined influence of ambient temperature in supermarkets and radiation conditions on the variance of load temperature.

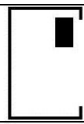
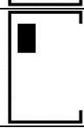
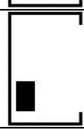
Position	Load temperature (°C)	Variance due to ambient temperature	Variance due to radiation conditions	Total variance
1 	5.15	0.123	0.302	0.425
		28.9%	71.1%	100%
2 	7.38	0.278	0.321	0.599
		46.4%	53.6%	100%
3 	2.36	0.007	0.017	0.023
		29.2%	70.8%	100%
4 	2.87	0.015	0.017	0.032
		46.9%	53.1%	100%

Table 2. Combined influence of ambient temperature in supermarkets, radiation conditions, load position and interaction of these 3 parameters on the variance of load temperature.

Variance due to variability of ambient temperature	Variance due to variability of radiation conditions	Variance due to variability of load position	Variance due to interaction term	Total variance
0.106	0.164	3.981	0.016	4.267
2.5%	3.8%	93.3%	0.4%	100%

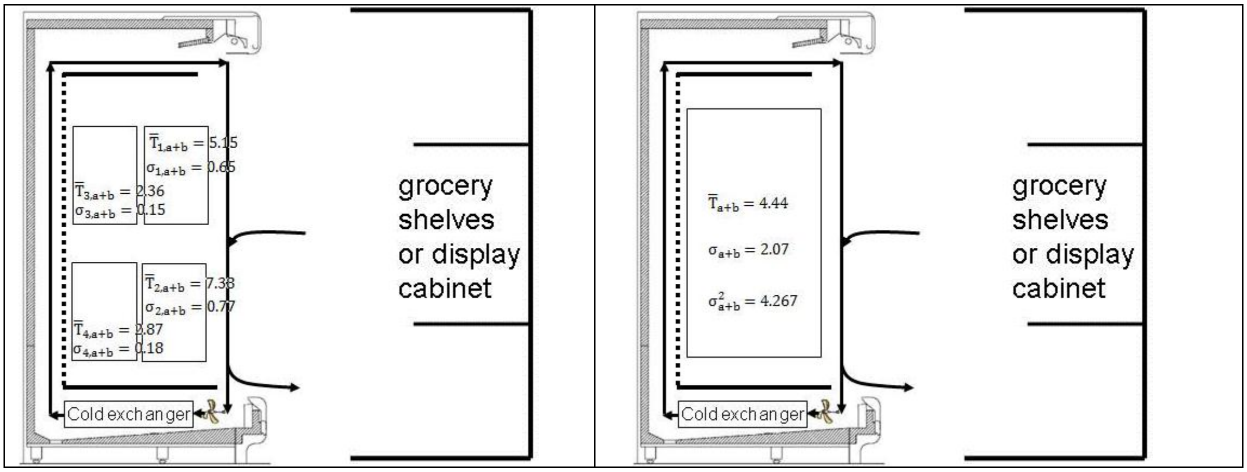


Figure 5: Load temperature and standard deviation due to the combined influence of the ambient temperature and radiation conditions ((*a*) and (*b*) conditions) Left-with position distinction, Right-without position distinction.

6. Conclusions

This study was carried out to analyse the influence of 3 random parameters (ambient air temperature in supermarkets, radiation conditions and load position) on the load temperature in a refrigerated display cabinet. The load position has the most influence compared to the ambient temperature and the radiation conditions.
This kind of deterministic-stochastic model could also be developed for other refrigerating equipment such as vehicle, domestic refrigerator etc. These models can then be linked and completed by a predictive microbial model to develop a risk evaluation tool along the cold chain. In the future, the model developed for the display cabinet and domestic refrigerator will be linked together allowing the prediction of product temperature evolution in the 2 equipments which are critical points in the cold chain.

References

[1]. Brimelow, C.J.B. (1987). Temperature and Time-Temperature Surveys of Chilled Foods in the UK, in: Paper at COST 91 bis mid-term seminar in Clermont Ferrand.
[2]. Cemagref and ANIA (2004). La chaine du froid du fabricant au consommateur: résultats de l'audit ANIA/Cemagref. *Revue Générale du Froid*, 1042, 29-36.
[3]. Dallaire, R., LeBlanc, D.I., Tranchant, C.C., Vasseur, L., Delaquis, P. and Beaulieu, C. (2006). Monitoring the microbial populations and temperatures of fresh broccoli from harvest to retail display. *Journal of Food Protection*, 69, 1118-1125.
[4]. Evans, J.A., Scarcelli, S. and Swain, M.V.L. (2007). Temperature and energy performance of refrigerated retail display and commercial catering cabinets under test conditions. *International Journal of Refrigeration*, 30, 398-408.
[5]. Gac, A. and Gautherin, W. (1987). *Le Froid dans les Magasins de Vente de Denrées Périssables*, pyc Edition, Paris.

[6]. Greer, G.G., Gill, C.O. and Dilts, B.D. (1994). Evaluation of the bacteriological consequences of the temperature regimes experienced by fresh chilled meat during retail display. *Food Research International*, 27, 371-377.

[7]. Gill, C.O., Jones, T., Rahn, K., Campbell, S., LeBlanc, D.I., Holley, R.A. and Starke, R. (2003a). The temperatures and ages of boxed beef packed and distributed in Canada. *Meat Science*, 60, 401-410.

[8]. Gill, C.O., Jones, T., Houde, A., LeBlanc, D.I., Rahn, K., Holley, R.A. and Starke, R. (2003b). The temperatures and ages of packs of beef displayed in multi-shelf retail cabinets. *Food Control*, 14, 145-151.

[9]. Laguerre, O. and Flick, D. (2010). Temperature prediction in domestic refrigerator: association of deterministic and stochastic approaches. *International Journal of Refrigeration*, 33, 41-51.

[10]. Likar, K. and Jevsnik, M. (2006). Cold chain maintaining in food trade. *Food Control*, 17, 108-113.

[11]. Rosario, L. and Howell, R.H. (2001). Relative humidity and temperature measurements and predictions in supermarkets. *Trans. ASHRAE*, 107, 415-423.

[12]. Rosset, P., Cornu, M., Noël, V; Morelli, E. and Poumeyrol, G. (2004). Time-temperature profiles of chilled ready-to-eat foods in school catering and probabilistic analysis of *Listeria monocytogenes* growth. *International Journal of Food Microbiology*, 96, 49-59.

[13]. Tolstoy, A. (1991). Practical monitoring of the cold chain. *International Journal of Food Microbiology*, 13, 225-230.

[14]. Smale, N.J., Moureh, J. and Cortella, G. (2006). A review of numerical models of airflow in refrigerated food applications. *International Journal Refrigeration*, 29, 911-930.

[15]. Willocx, F., Hendrick, M. & Tobback, P., (1994). A preliminary survey into the temperature conditions and residence time distribution of minimally processed MAP vegetables in Belgian retail display cabinets. *International Journal of Refrigeration*, 17, 436-444.