



**HAL**  
open science

## Temperature prediction in a refrigerated display cabinet: deterministic and stochastic approaches

Onrawee Laguerre, Evelyne Derens-Bertheau, D. Flick

### ► To cite this version:

Onrawee Laguerre, Evelyne Derens-Bertheau, D. Flick. Temperature prediction in a refrigerated display cabinet: deterministic and stochastic approaches. 11th European Symposium on Statistical Methods for the Food Industry, Feb 2010, Benevento, Italy. p. 111 - p. 120. hal-00583231

**HAL Id: hal-00583231**

**<https://hal.science/hal-00583231>**

Submitted on 5 Apr 2011

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

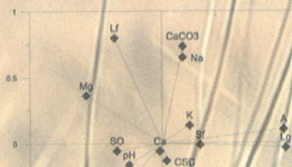
L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



$$(X, Y) = \left( X^j \frac{\partial Y^i}{\partial x^j} - Y^j \frac{\partial X^i}{\partial x^j} \right) \frac{\partial}{\partial x^i}$$

# 11<sup>th</sup> European Symposium on STATISTICAL METHODS FOR THE FOOD INDUSTRY

11<sup>èmes</sup> Journées Européennes  
AGRO-INDUSTRIE ET  
MÉTHODES STATISTIQUES



## BENEVENTO

Italy - Italie

23 - 26 February 2010

23 - 26 Février 2010

Under the auspices of the  
French Statistical Society

Sponsored by the  
Italian Statistical Society

**PROCEEDINGS**

**ACTES**

EDITORE



**TEMPERATURE PREDICTION IN A REFRIGERATED DISPLAY CABINET:  
DETERMINISTIC AND STOCHASTIC APPROACHES  
PREDICTION DE TEMPERATURE DANS UN MEUBLE FRIGORIFIQUE DE  
VENTE: APPROCHES DETERMINISTE ET STOCHASTIQUE**

Onrawee LAGUERRE<sup>1</sup>, Evelyne DERENS<sup>2</sup>, Denis FLICK<sup>3</sup>

<sup>1</sup> Refrigeration Process Engineering, Cemagref, Parc de Tourvoie, BP 44, 92185 Antony, Cedex, France, onrawee.laguerre@cemagref.fr

<sup>2</sup> Refrigeration Process Engineering, Cemagref, Parc de Tourvoie, BP 44, 92185 Antony, Cedex, France, evelyne.derens@cemagref.fr

<sup>3</sup> AgroParisTech, 16 rue Claude Bernard, 75231 Paris Cedex 05, France

**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

**Résumé**

La température du produit dans un meuble frigorifique de vente est très variable et cela influe directement la qualité et la sécurité des aliments. Cette variabilité est due au type de meuble (vertical, horizontal), à la position de produit dans le meuble, aux fluctuations de température ambiante du magasin (nuit/jour, heure d'ouverture, saison, climatisation du magasin etc.) et aux conditions de voisinage du meuble (meuble situé en face d'un autre meuble frigorifique ou en face d'un rayon épicerie).

Cette étude propose un modèle thermique permettant de prédire la température du chargement dans un meuble vertical en fonction de deux paramètres aléatoires: la température ambiante du magasin et la température du rayonnement des parois face au meuble. La connaissance de la loi de distribution de ces paramètres, obtenue par mesures sur terrain or par données d'experts, permet de prédire la variabilité de température du chargement.

**Mots clés:** meuble frigorifique de vente, transfert de chaleur, paramètre aléatoire, température de produit

**Nomenclature**

A	Surface area, m <sup>2</sup>	$\delta$	Infiltration rate, dimensionless
C <sub>p</sub>	Thermal capacity of air, J.kg <sup>-1</sup> .°C <sup>-1</sup>	$\sigma$	Standard deviation
h	Heat transfer coefficient, W.m <sup>-2</sup> .°C <sup>-1</sup>	$\sigma^2$	Variance
m	Mass flow rate of air, kg.s <sup>-1</sup>	$\alpha$	Dimensionless heat transfer
T	Temperature, °C		

## Index

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

### 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 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 radiative conditions was studied.

### 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 ducts 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). Due to our expertise, the model considers 4 load positions with different temperatures:  $T_1$ ,  $T_2$ ,  $T_3$  and  $T_4$ .

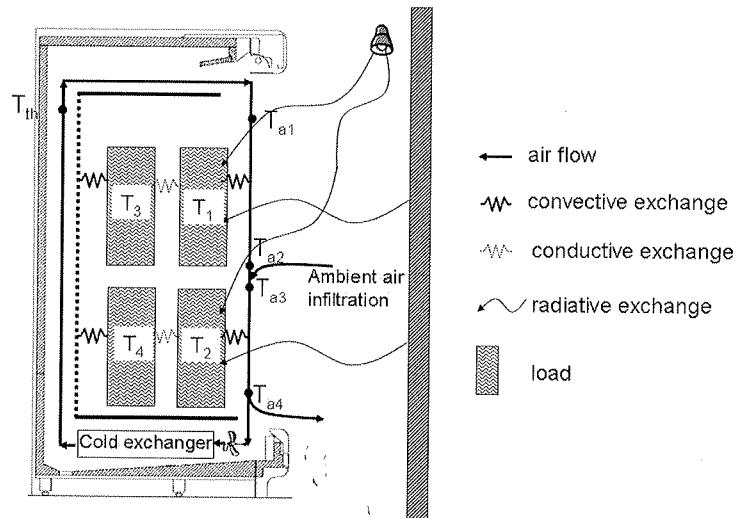


Figure 1: Different heat transfer modes taken into account in an open vertical display cabinet.

## 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 brown 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 from  $T_{a1}$  to  $T_{a2}$  (Figure 1).

$$\dot{m} \cdot C_p \cdot dT_a = h_{cv} (T_1 - T_a) dA_{cv} \Leftrightarrow \ln \frac{T_{a2} - T_1}{T_{a1} - T_1} = \frac{-(hA)_{cv}}{\dot{m}C_p} \Leftrightarrow$$

$$\frac{T_{a2} - T_1}{T_{a1} - T_1} = \exp \frac{-(hA)_{cv}}{\dot{m}C_p} \Leftrightarrow (T_{a2} - T_1) = \alpha_{cv} (T_{a1} - T_1) \Leftrightarrow$$

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

$$\text{Where } \alpha_{cv} = \exp \frac{-(hA)_{cv}}{\dot{m}C_p}$$

### 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  $(\dot{m} + \dot{m}_e)$ .

$$\dot{m}C_pT_{a2} + \dot{m}_e C_p T_e = (\dot{m} + \dot{m}_e)C_p T_{a3} \Leftrightarrow$$

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

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

### 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 radiative 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:

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

$T_{th}$  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.

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:

	0.1456°C	0.1949	0.1831
$a_i =$	0.3572°C	$b_i =$ 0.2929	$c_i =$ 0.1889
	0.0341°C	0.0457	0.0430
	0.0833°C	0.0679	0.0435

### 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 (dimension: 20 cm x 10 cm x 5 cm) 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 ( $0.4^{\circ}\text{C}$ ) from 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.

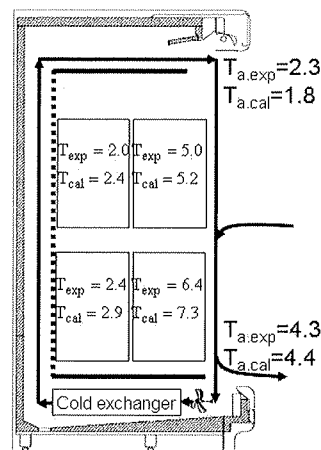


Figure 2: Comparison between experimental and calculated air and load temperatures ( $^{\circ}\text{C}$ ) for the ambient temperature of  $20^{\circ}\text{C}$  and the thermostat temperature of  $1.5^{\circ}\text{C}$ .

#### 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 radiative conditions which surround the display cabinet. The radiative 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 radiative conditions are assumed equiprobable. It is also assumed that the 4 positions of product in a display cabinet are equiprobable.

##### 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  $\bar{T}_e$  is  $22.3^{\circ}\text{C}$  and the standard deviation  $\sigma_e$  is  $1.8^{\circ}\text{C}$ .

##### 4.2. Influence of the variation of radiative 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 radiative temperature is correlated to the ambient air temperature: when grocery shelves are placed oppositely to the refrigerated display cabinet, the radiative temperature is close to that of air. When another display cabinet is placed oppositely, the radiative temperature is averagely  $6^{\circ}\text{C}$  lower than the air temperature.

Two equiprobable radiative conditions [a] and [b] are therefore considered:

[a] condition :  $\bar{T}_e = 22.3^{\circ}\text{C}$ ,  $\sigma_e = 1.8^{\circ}\text{C}$ ,  $T_{th} = 1.5^{\circ}\text{C}$  and  $T_r = T_e$  (grocery shelves located oppositely).

[b] condition :  $\bar{T}_e = 22.3^{\circ}\text{C}$ ,  $\sigma_e = 1.8^{\circ}\text{C}$ ,  $T_{th} = 1.5^{\circ}\text{C}$  and  $T_r = T_e - 6^{\circ}\text{C}$  (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 radiative conditions ( $[a]$  or  $[b]$ ) and for each position (i), the mean load temperature and its standard deviation can be expressed as follows:

$$\bar{T}_{i,a} - T_{th} = a_i + b_i(\bar{T}_e - T_{th}) + c_i(T_r - T_e)_a \quad \text{with } (T_r - T_e)_a = 0^\circ\text{C} \quad (4)$$

$$\bar{T}_{i,b} - T_{th} = a_i + b_i(\bar{T}_e - T_{th}) + c_i(T_r - T_e)_b \quad \text{with } (T_r - T_e)_b = \Delta T_r = -6^\circ\text{C} \quad (5)$$

$$\sigma_{ia}^2 = \sigma_{ib}^2 = b_i^2 \sigma_e^2 \quad (\text{referred as } \sigma_i^2) \quad (6)$$

The results are presented in Figure 4.a and 4.b and discussed in section 5.

### 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 3).

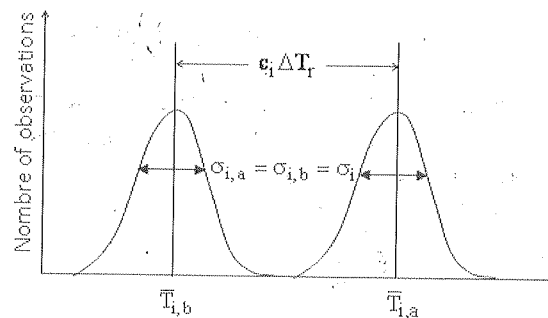


Figure 3: Mixing of 2 normal distributions of the load temperature due to 2 different radiation temperatures.

For each load position, the mean load temperature assuming equiprobable radiative conditions can be calculated as follow:

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

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 radiative conditions.

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

Where  $\sigma_r$  is the standard deviation of  $(T_r - T_e)$ ,  $\sigma_r = |\Delta T_r| / 2 = 3^\circ\text{C}$

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



For the mean value:

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

For the variance:

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

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.

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

## 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 radiative condition [a] (grocery shelves oppositely) are reported in Figure 4.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 radiative condition [b] (display cabinet oppositely) is presented in Figure 4.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 radiative condition is more significant on the front loads (higher value of standard deviation).

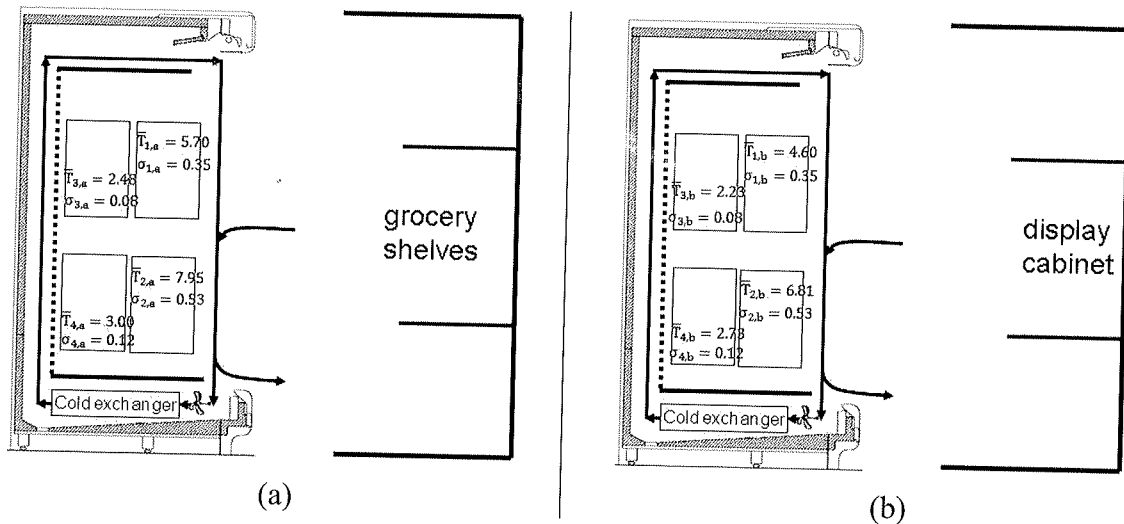


Figure 4 : Load temperature and standard deviation for  $T_{th} = 1.5^{\circ}\text{C}$

(a)  $\bar{T}_e = 22.3^{\circ}\text{C}$ ,  $\sigma_e = 1.8^{\circ}\text{C}$ ,  $T_r - T_e = 0^{\circ}\text{C}$  (called [a] condition),

(b)  $\bar{T}_e = 22.3^{\circ}\text{C}$ ,  $\sigma_e = 1.8^{\circ}\text{C}$ ,  $T_r - T_e = -6^{\circ}\text{C}$  (called [b] condition).

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

The combined influence of the ambient temperature and the radiative conditions is presented in Figure 5. For each position, the mean value is intermediated between those obtained in radiative 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  $4.44^{\circ}\text{C}$  (standard deviation 2.07 and variance 4.267). This variance is the result of the variability of several parameters: ambient temperature of supermarkets, radiative conditions and load position.

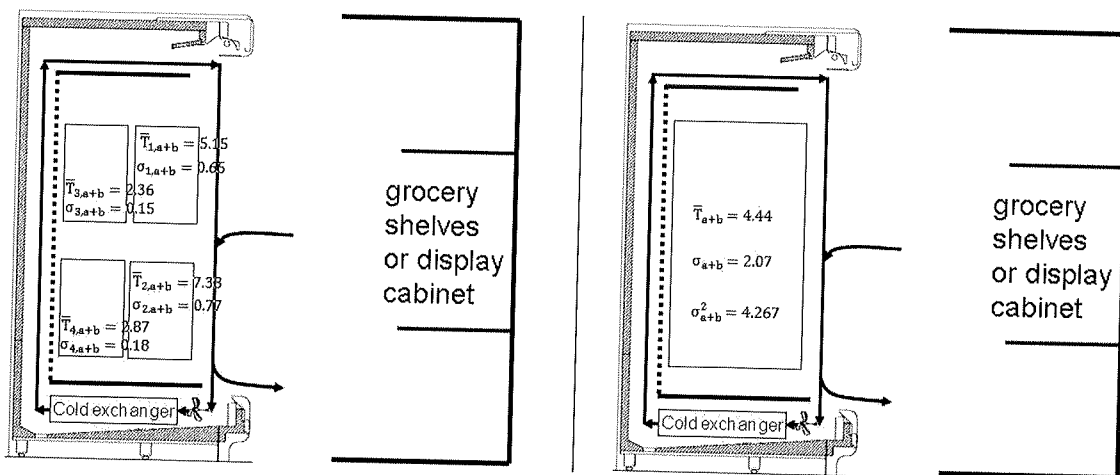


Figure 5 : Load temperature and standard deviation due to the combined influence of the ambient temperature and radiative conditions ([a] and [b] conditions) Left-with position distinction, Right-without position distinction.

Table 1 shows the importance of each influence (ambient temperature and radiative 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 radiative 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.


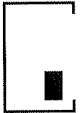

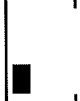
Position	Load temperature (°C)	Variance due to ambient temperature	Variance due to radiative conditions	Total variance
1 	5.15	0.123	0.302	0.425
		28.9%	71.1%	100%
2 	7.38	0.278	0.321	0.599
		46.4%	53.6%	100%
3 	2.36	0.007	0.017	0.023
		29.2%	70.8%	100%
4 	2.87	0.015	0.017	0.032
		46.9%	53.1%	100%

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

Table 2 shows the importance of each influence (ambient temperature, radiative 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 radiative conditions.

Variance due to variability of ambient temperature	Variance due to variability of radiative 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%

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

## 6. Conclusion

This study was carried out to analyse the influence of 3 random parameters (ambient air temperature in supermarkets, radiative 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 radiative 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

- 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.
- Cemagref & ANIA, (2004). La chaîne du froid du fabricant au consommateur: résultats de l'audit ANIA/Cemagref. *Revue Générale du Froid*, 1042, 29-36.
- Dallaire, R., LeBlanc, D.I., Tranchant, C.C., Vasseur, L., Delaquis, P., Beaulieu, C., (2006). Monitoring the microbial populations and temperatures of fresh broccoli from harvest to retail display, *Journal of Food Protection*, 69 (5), 1118-1125.
- Evans, J.A., Scarcelli, S. & 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.
- Gac, A. & Gautherin, W. (1987). *Le Froid dans les Magasins de Vente de Denrées Périssables*, pyc Edition, Paris.
- Greer, G.G., Gill, C.O. & 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 (4), 371-377.
- Gill, C.O., Jones, T., Rahn, K., Campbell, S., LeBlanc, D.I., Holley, R.A. & Starke, R. (2003a). The temperatures and ages of boxed beef packed and distributed in Canada, *Meat Science*, 60, 401-410.
- Gill, C.O., Jones, T., Houde, A., LeBlanc, D.I., Rahn, K., Holley, R.A., Starke, R. (2003b). The temperatures and ages of packs of beef displayed in multi-shelf retail cabinets, *Food Control*, 14, 145-151.
- Laguerre, O. & Flick, D. (2010). Temperature prediction in domestic refrigerator: association of deterministic and stochastic approaches, *International Journal of Refrigeration*, 33, 41-51.
- Likar, K. & Jevsnik, M. (2006). Cold chain maintaining in food trade, *Food Control*, 17, 108-113.
- Rosario, L. & Howell, R.H. (2001). Relative humidity and temperature measurements and predictions in supermarkets, *Trans. ASHRAE*, 107(2), 415-423.
- Rosset, P., Cornu, M., Noël, V; Morelli, E. & 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.
- Tolstoy, A. (1991). Practical monitoring of the cold chain, *International Journal of Food Microbiology*, 13, 225-230.
- Smale, N.J., Moureh, J. & Cortella, G. (2006). A review of numerical models of airflow in refrigerated food applications, *International Journal Refrigeration*, 29(6), 911-930.
- 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(7), 436-444.