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ABSTRACT

Due to the importance of the heat generated by the respiratory activity of cheeses, temperature control in pallets is a major industrial issue in order to preserve food safety and quality.
Experiments were conducted on platforms in order to evaluate the influence of the palletization and the level of ventilation on the temperature variability within cheese pallets.
Platform ventilation plays a primary role, both on the level of temperatures and on their homogeneity within the pallets. Pallets placed in well-ventilated areas always have lower temperatures (ex: Tmax 5.2°C) than those placed in poorly ventilated areas (ex: Tmax 7.6°C). Palletization has also a significant impact on the cooling efficiency and temperature uniformity of products within the pallet. The presence of a chimney in the pallet pattern, the headspace above the products, the vented area and the alignment of the holes seem to promote a better cooling (lower product temperature of 1 to 1.5°C).
Keywords: cheese, heat generating product, on-site temperature, core temperature, platform, experimental data.

1. INTRODUCTION

Temperature is the most important parameter influencing the quality of products (Defraeye et al. 2015, Ambaw et al. 2016). However, uniform cooling is difficult to achieve in practice.
One of the reasons of the temperature heterogeneity in a cold room is the over-ventilation in areas near the refrigerating unit with temperature close to the blowing temperature and the under-ventilation in the areas far from the refrigeration unit causing locally hot spots within the pallet (Moureh et al. 2009). Alvarez and Flick (1999) explained the heterogeneity of cooling principally by the increase in air temperature and the variation of heat transfer coefficient as a function of position along the airflow paths.
Some products like cheeses generate heat via the metabolism of micro-organisms resulting in greater temperature heterogeneity within the load. Moreover, heat of respiration of food products increases with the temperature (Thompson 1996). For example, the heat of respiration of coriander, green beans and red beet is 4 to 5 times higher at 30°C than at 10°C (Waghmare et al. 2013). At 0°C, the respiration rate of mushrooms is three times lower than at 10°C (Zhang et al. 2018). Products at the edge of a pallet are better cooled and therefore give off less heat than products at the core of the pallet (Moureh and Derens 2000).
Many authors have studied cooling heterogeneities in a stack of products, with numerical studies (Delele et al. 2008, Dehghannya et al. 2011, Defraeye et al. 2013, Delele et al. 2013, Ambaw et al. 2017) and experimental laboratory studies (Alvarez & Flick 1999, Moureh & Flick 2004, Tapsoba et al. 2007, Merai et al. 2018). However, most of the articles relate only to a part of a pallet (a few cardboards). Duret et al. (2014) studied the air speed, heat transfer and mass loss of four apple pallets in a cold room. They observed that the temperature of the products is strongly correlated with the air speed.
Experimental studies in the laboratory allow a better understanding of the physical phenomena under controlled conditions. However, they do not reflect the whole diversity of situations encountered in practice. Measurements under real industrial conditions are therefore essential to complete the experimental and

numerical laboratory approaches. Derens-Bertheau et al. (2015) carried out temperature measurements of products (sliced ham) from the production plant to domestic consumption in France in comparison with other countries. The study clearly shows the heterogeneity of temperature in different steps of the cold chain.
Wu et al. (2018) carried out temperature measurements in a cold room during the pre-cooling of 40 citrus palettes (lemon, mandarin, orange). Different parameters were taken into account: the position of the pallets, the design of the boxes, the size of the products. However, during the cooling phase, a high air speed results in greater temperature uniformity than during the storage phase (Wu et al. 2018). These two studies focused on products that give off a negligible amount of heat (ham, citrus) which is not the case for cheeses. The aim of the study presented here is to assess temperature heterogeneities within pallets of cheese stored in two different platforms. Different parameters were taken into account: the local level of ventilation related to pallet position in the platform, the type of palletization and the position of the product in the pallet. Temperature profiles under actual operating conditions of the platforms were acquired to identify representative configurations for laboratory studies (Pham et al. 2019).

2. MATERIALS AND METHODS

In order to retrieve data on temperature evolutions of products stored within pallet, experiments were carried out in situ on two platforms under different storage conditions. . On platform 1, the pallets are stored on one level, while the pallets are stored on four levels on platform 2 (Fig. 1).

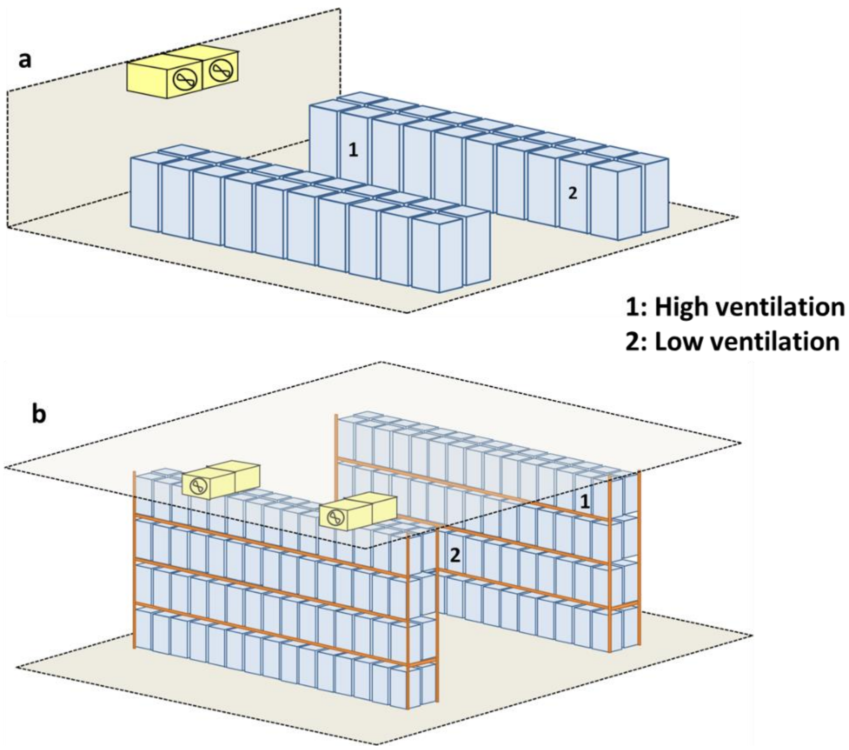

Figure 1: Locations of the instrumented pallets: a) platform 1; (b) platform 2

On the two platforms, 4 or 6 pallets were similarly instrumented:

- 3 layers of cardboard per pallet: bottom, mid-height, top,
- 6 products per layer, i.e. 18 product temperature measurements per pallet.

The core temperatures of the products were measured by recorders with external probes (Testo 171, 175T3 and 176 T3, thermocouples T; +/-0.5 °C, range -35 °C +60 °C, calibrated at -5 °C, 0 °C, 10 °C, 20 °C and 30 °C). Two parameters were studied, the type of palletization and the level of ventilation:

- Level of ventilation: two levels of ventilation have been chosen, so two area; high ventilated (area 1, i.e. 0.6-0.8 ms-1) and low ventilated (area 2, i.e. 0.2-0.4 ms-1). Air velocity measurements were acquired with hot wire and fan type anemometer (Testo 435-2).

- Type of palletization: in each area (level of ventilation), different pallets were placed to be compared. For platform 1 (P1): two pallets have been chosen per area, named A and B. For platform 2 (P2), three pallets have been chosen per area, named M (with 2 chimneys), N (identical to pallet M but without chimneys) and O. The characteristics of the different palletizations are shown in Table 2 and Fig. 2. The palletized products were goat cheese and camembert.

Table 2. Geometric characteristics of the pallets

	Platform 1 (P1)		Platform 2 (P2)		
	Pallet A	Pallet B	Pallet M	Pallet N	Pallet O
External dimensions of a cardboard (mm)	450 x 239 x 63	345 x 235 x 56	290 x 200 x 92	290 x 200 x 92	596 X 264 X 147
Number of layers per pallet	23	15	14	14	9
Number of boxes per layer	7	8	14	16	6
Number of products per box	15	8	12	12	30
Type of product	Goat cheese 200g	Goat cheese 300g	Camembert 125g	Camembert 125g	Camembert 250g
Air thickness (mm) above the products	19	3	12	12	25
Chimney	Yes	Yes	Yes	No	No

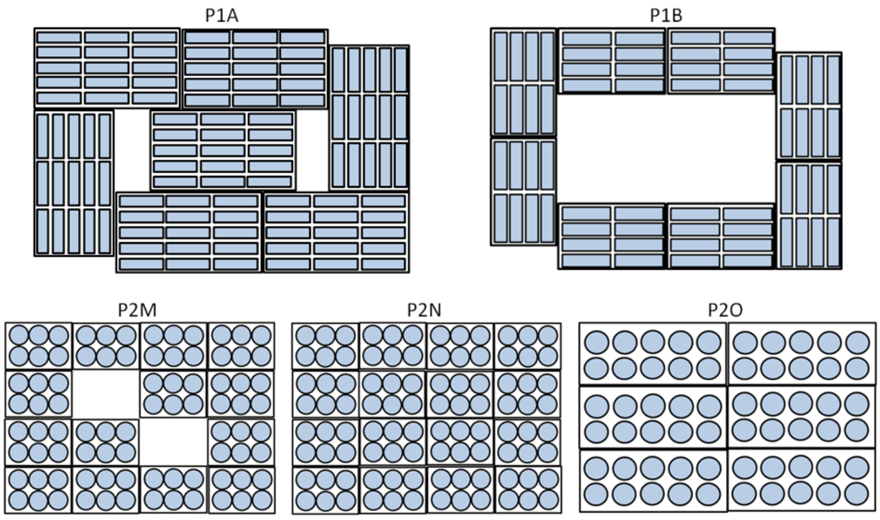

Figure 2: The different types of instrumented pallets (top view)

3. RESULTS AND DISCUSSION

Fig. 3 shows examples of temperature evolution within a pallet during cooling and stabilization phases in the platform. To make comparisons within a pallet and between different pallets, only the stabilized product temperatures will be considered thereafter. As it can be seen, the thermal stabilisation occurred within almost two days storage. Stabilized temperatures ranged from 0.3°C to 2.5 °C for an average upstream air temperature of the pallet of 0.9°C (+/-1°C, fluctuations due to on/off cycle of the refrigeration unit).
The products located at the edge of the pallet are more sensitive to air temperature variations of the platform.

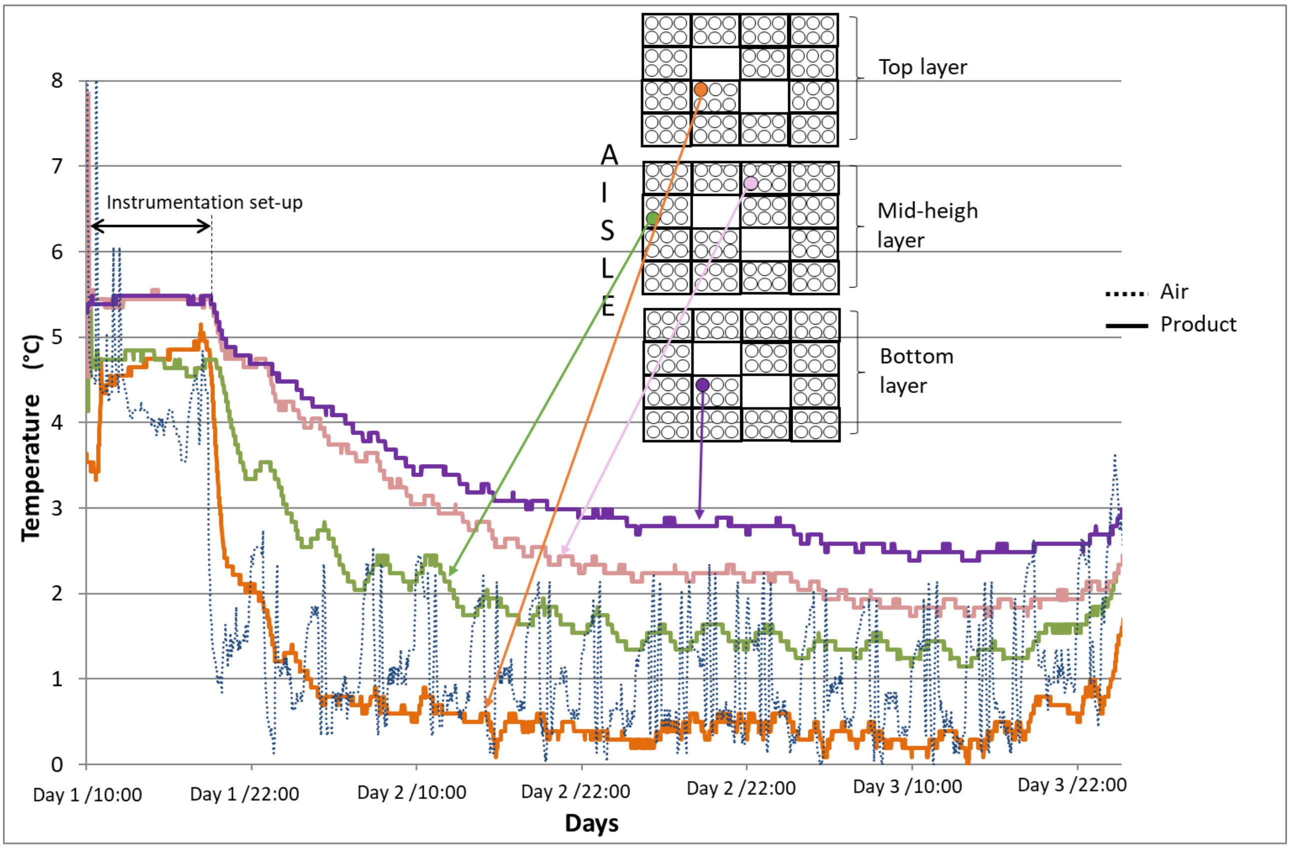

Figure 3: Examples of temperature evolution in the high ventilated pallet M ($P2M_1$)

Fig. 4 shows the stabilized temperatures within the three layers of cardboard in the pallet "O": top, mid-height and bottom.

For all the layers and ventilation levels, the warmest products are located in the middle region due to the weakness of the airflow in the core of the pallet; the longer distance of the product is from the edge, the higher its temperature.

In the high ventilated case, the mid-height layer is the warmest, while in the low ventilated case, the warmest is the top layer. This difference can be explained by the fact that when the forced convection is high, the main airflow generated by the refrigerating unit dominates the top of the pallet implying lower product temperature. On the contrary, for low ventilated case, natural convection become dominant, resulting in an upward airflow with an increasing temperature from the bottom to the top, due to the heat exchange with the products.

A large temperature difference between the two ventilated cases can be observed for all products positions, the maximum temperature of 5.2°C in the high ventilated case and 7.6°C in the low ventilated case. This difference can also be explained by the surrounding air temperature near to the studied pallets (Tair = 0.9°C for high ventilated case and 2.6°C for low ventilated case) which were located at different distances from the refrigeration unit.

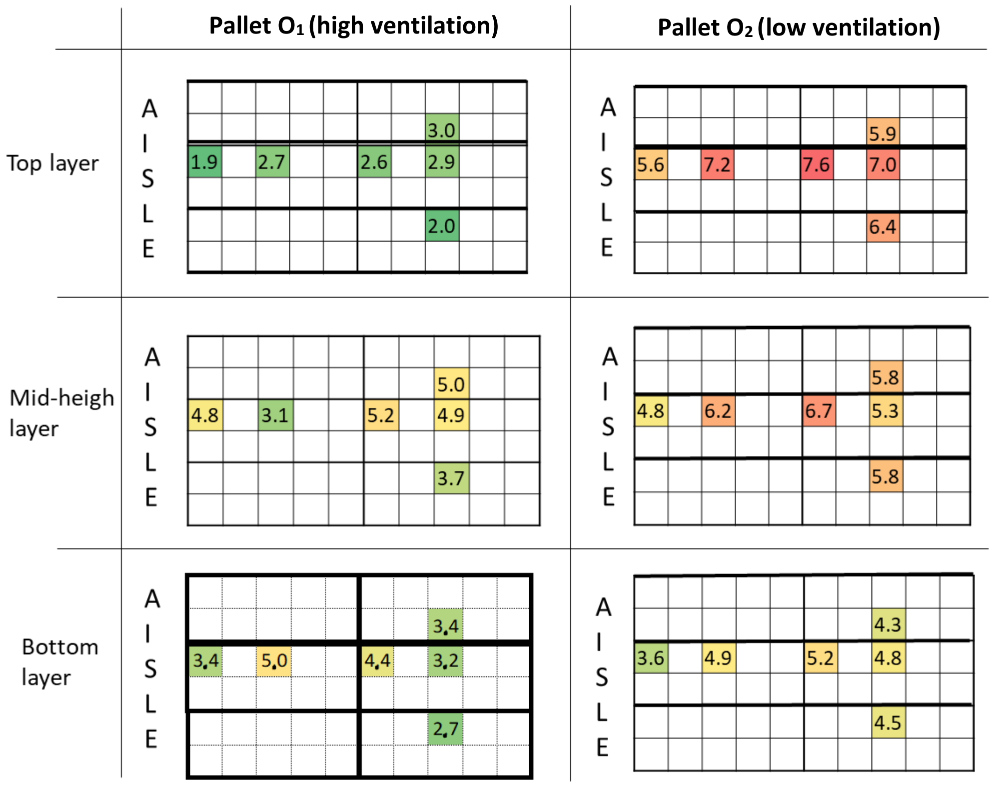

Figure 4 : Stabilized product temperatures in palette O in the two ventilation cases (P2O₁ et P2O₂)

Table 3 presents all the results obtained on the two platforms. The temperature levels increase within the same pallet when moving from a high ventilated place (1) to a low ventilated place (2), whatever the type of pallet (A, B, M, N or O).
In platform 1 (floor storage, only one level of pallets), the maximal temperatures are located in the mid-height layer of the related pallets (Table 3). But for storage on several levels (platform 2), the maximal temperatures are located at the top layer especially for low ventilated areas where natural convection predominates implying an upward flow within the related pallets.

Table 3: Stabilized product temperatures on pallets for platforms 1 and 2
***PIX$_j$: I represents the platform 1 or 2, X represents the type of palletization (A B M N or O), j represents the ventilation level (j=1 high level, j=2 low level)**

	Pallet PIX$_j$*	Tav pdt (°C)	Tmin / Tmax pdt (°C)	Tmax – Tmin pdt (°C)	Layer Tmax pdt
Plateform 1 (P1)	P1A$_1$	3,1	2,6 / 3,7	1,1	mid-height
	P1A$_2$	3,4	2,2 / 4,2	2,0	mid-height
	P1B$_1$	4,1	3,0 / 5,4	2,4	mid-height
	P1B$_2$	4,8	3,3 / 7,3	4,0	mid-height
Plateform 2 (P2)	P2M$_1$	1,6	0,3 /2,5	2,2	Bottom and mid-height
	P2M$_2$	3,7	2,7 / 5,0	2,3	top
	P2N$_1$	1,8	0,6 / 3,2	2,6	Bottom and mid-height
	P2N$_2$	4,6	2,8 / 6,6	3,8	top
	P2O$_1$	3,6	1,9 / 5,2	3,3	Bottom and mid-height
	P2O$_2$	5,6	3,6/ 7,6	4,0	top

3.1. Effect of ventilation

To estimate the effect of ventilation on the product temperature of the five pallets tested in the two platforms, a variance analysis was carried out taking into account all the instrumented products.

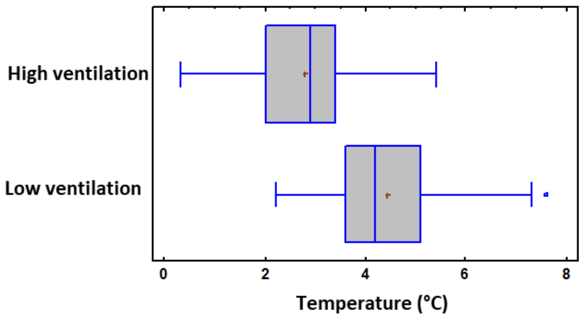

Figure 5 : Boxplot showing the average temperatures and temperature dispersion depending on the ventilation

This variance analysis highlights a statistically significant difference in the confidence level of 95% of the mean temperatures between the products of high ventilated pallets and those of low ventilated pallets (Fig. 5). Indeed, the temperatures of high ventilated products vary from 0.3°C to 5.4°C with an average temperature of 2.8°C, while temperatures of low ventilated products vary from 2.2°C to 7.6°C with an average temperature of 4.4°C.

3.2. Effect of palletization

Figures 6 show the effect of palletization on the temperature dispersion within a pallet depending of ventilation level, for the platform 2. Concerning the effect of a chimney, it is good to notice that pallets M and N are almost identical excepting that M is with a chimney, while N is without. For a given ventilation level, the maximum product temperature is lower for palletization with chimney than palletization without chimney.

This could be explained by the effect of natural convection that could be induced within the chimney. This extra convection could increase the internal ventilation and thus improve the temperature homogeneity within the pallet.

This confirms the beneficial effect of the palletization with chimneys.

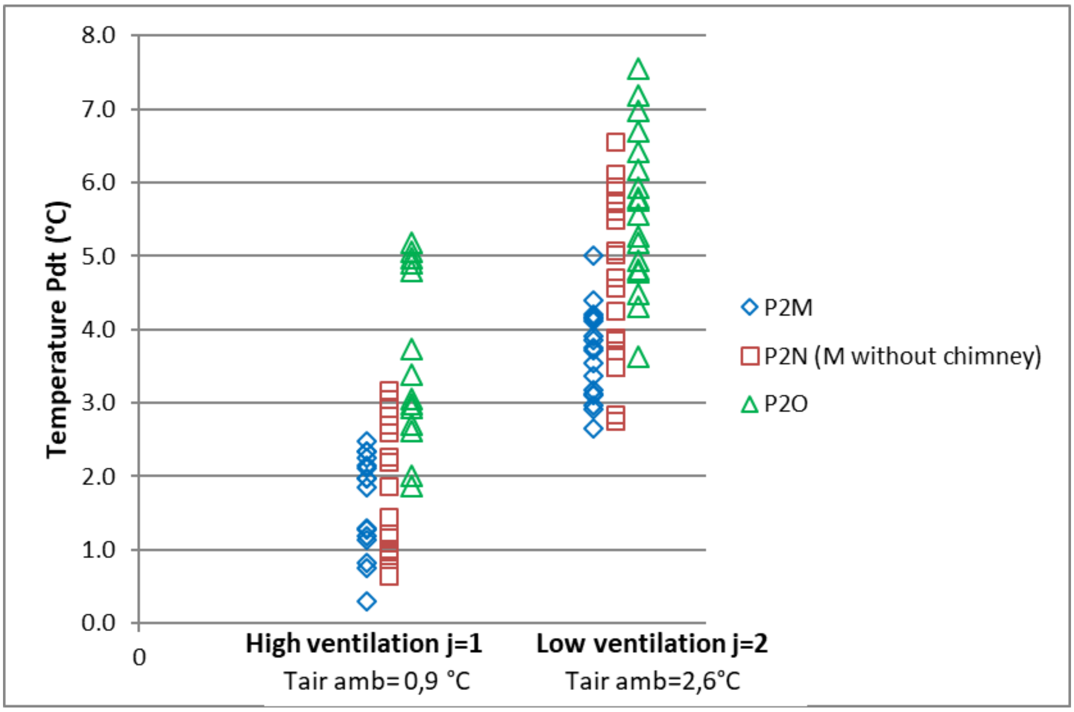

Figure 6 : Effect of palletization on the dispersion of product temperatures as a function of ventilation (Platform 2)

In addition, the comparison of N and O pallets, both without chimney, shows the importance of packaging and palletization stacking patterns as well as the design of vented cardboard boxes on the control of product temperatures. The spacing between the cheeses, which is directly connected to mass per unit area, plays a positive effect on internal air circulation within a pallet. However, internal air circulation depends closely on air fluxes entering the boxes, which in turn depends on the area and the alignment of holes between two successive boxes. Therefore, the no alignment of holes between two successive boxes in pallet O (Figure not shown for confidential reasons) represents a limiting factor for internal air circulation and could explain the higher temperatures of this pallet when comparing to pallet N. In addition, the higher area of holes of pallet N could also improve internal air circulation for this pallet in comparison to pallet O.

4. CONCLUSIONS

Heterogeneities of temperatures, more or less important, are always observed within pallets. Depending on the palletization mode, air cools down the products differently. The presence of a chimney seems to have a positive effect on cooling, although other factors are involved in palletization (openwork area, alignment of orifices, filling rate, packaging, etc.).

The external ventilation around the pallets plays a determining role, as well on the level of the temperatures as on their homogeneity. Pallets placed in the most ventilated locations always have lower temperatures than those located in low ventilated locations.

For the platform with only one level of pallets (P1), the warmest products are always located in the median layer of the pallets. In the case of multi-level storage (P2), two trends were observed depending on the level of ventilation. In a high ventilated place, we observe the same trend on platform 1. On the other hand, in a low ventilated place, the warmest product is located on the top layer because the main flow then comes from bottom to top.

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