Technical article

Air coolers, air flow and temperature distribution in large cold stores

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Main topics:

Large cold stores: Ever larger dimensions of cold stores and automatic storage technology pose new challenges when it comes to selecting and installing air coolers.

Presentation of a study effected in a large cold store in Switzerland and response to the following questions:

- Which type of air cooler is best suited for which cold store?
- How good is the air distribution in large cold stores with an cold air pool and air circulation through thermal activity?
- How large is the potential of energy saving when different air coolers are used?

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Introduction

In the past 60 years, the transportation systems and therefore the technical design of refrigerated warehouses has changed. The first generation of large refrigerated warehouses were multi-floor buildings with a height of 3m to 5m for each floor. Goods were moved around manually and both the freezing and cooling process took place inside the same space. The most basic refrigeration technology was to keep Ammonia circulating inside pipes that were installed on the wall. In the 1960s, with the introduction of forklifts and pallets,the transportation and logistics technology developed fast. The refrigerated warehouses became larger and flatter, and had only 1 floor with a height of 8-12 meters. The typical design to refrigerate such warehouses, where air coolers with finned heat exchangers and fans. With this type of air coolers it became possible to use expansion valves and modern hcfc refrigerants. Furthermore, such air coolers have stable air flows and make it possible to use automated defrosting systems.

Since the 90s, the development of automatic systems for transportation and logistics, required a new design and new placement of air coolers. High-bay storage with automatic transportation systems now reach heights of more than 30 m [100 ft]. The large dimensions and automated storage technology place new demands on the selection and installation of air coolers. The incoming goods normally have storage temperature and shouldn't be frozen. Low cooling capacities in large cold-storage areas result in minimal air circulation rates. Steel or half-timbered beams or storage bay supports may obstruct the air flow under the ceiling. Further restrictions affect system design; for example, air coolers cannot be installed in the operating area of the automatic transportation systems. Such building specifications, as well as requirements for minimizing energy consumption, must be considered in system design.

In recent years, some large refrigerated warehouses have been built in Europe using air distribution without ducts to direct air flow. The cold air flows downwards to the floor, spreads out like a lake of cold air, and rises up to the ceiling as the result of thermal activity within the room before flowing along the underside of the ceiling back to the air cooler. With such an atypical design, several questions come to mind:

- Where does this type of airflow design make sense and what are its limitations?
- Which type of air cooler is the best for different types of refrigerated warehouses?
- How can air flows and temperatures be pre-calculated using a computer simulation?
- How good is the temperature distribution in large refrigerated warehouses using air distribution without air ducts?
- What degree of energy savings can be achieved using these techniques?

In order to find answers to these questions, Güntner made a case study of a large refrigerated warehouse in Switzerland. A computer model was created to simulate conditions in the warehouse. Then, actual temperatures in the warehouse were measured to establish how well the warehouse functions with this airflow pattern, and to what extent the data from the computer simulation corresponds to the measurements.

Different air Cooler Designs in Refrigerated Warehouses
Refrigerated warehouses employ several different types of designs to cool product. (Figure 1)

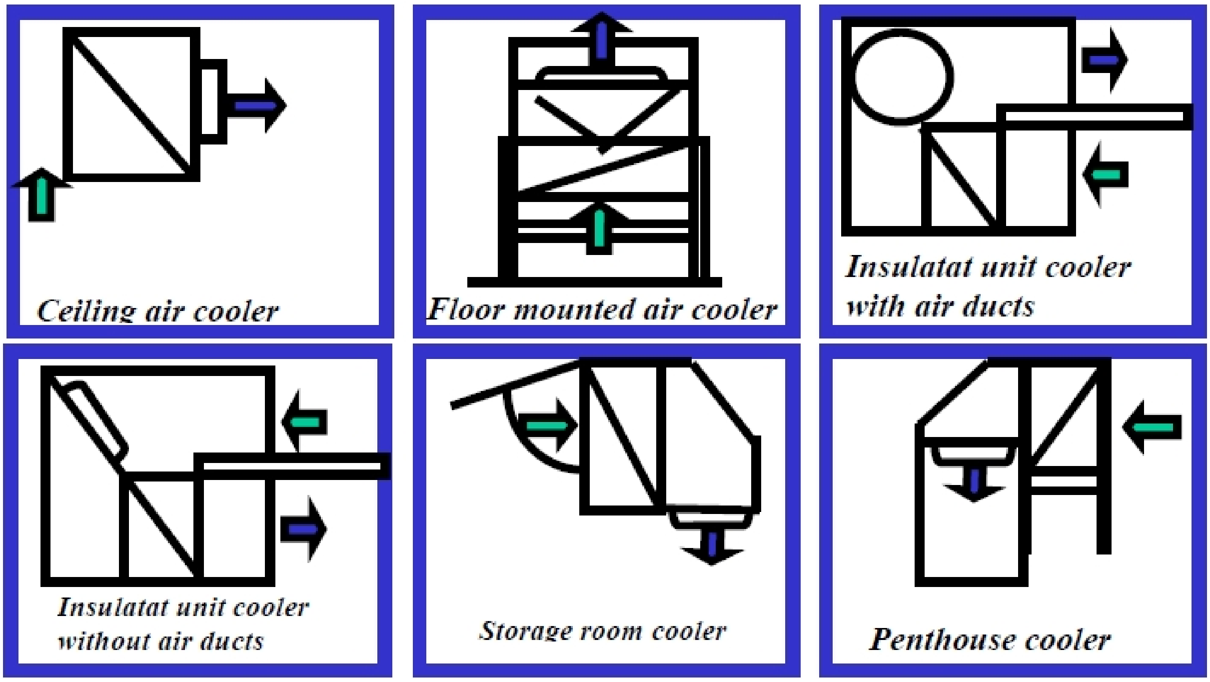

Figure 1. Six types of air coolers

Design 1: Ceiling Air Cooler with Horizontal Air flow
This is an economical design, has short delivery times and is very popular.
That are common coolers for smaller warehouses, but this design has limitations of larger refrigeration warehouses.

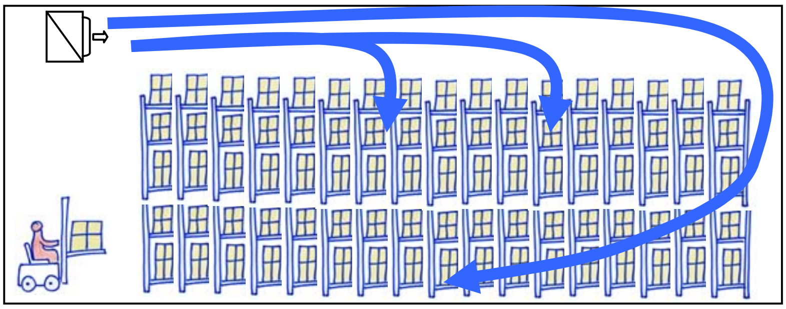

Figure 2. Ceiling air cooler with horizontal air flow

The design requires high-speed fans with high driving power. The air throw from the fans must be at least the length of the room to provide adequate coverage of product. Also, no intrusive girders or lighting fixtures would be permitted in the ceiling area, which is a significant building design limitation. The free space between the goods and the ceiling acts as a distribution plenum, which means that stacking height is limited.

Design 2: Floor-mounted air cooler with air ducts
The floor mounted air coolers with air ducts provide good air distribution even under difficult room conditions because the ducts guide air exactly to where it is needed most.

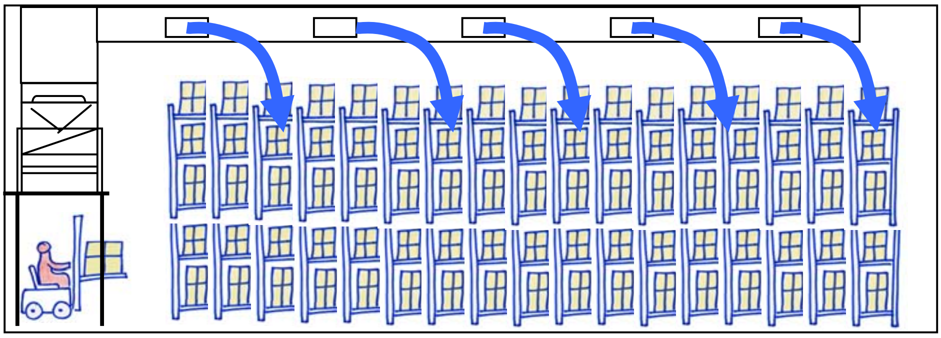

Figure 3. Floor-mounted air cooler with air ducts
Similar to Design 1, the floor mounted air coolers must be installed within the refrigerated space, take up room that could be used for pallets. The air distribution ducts also occupy room within the refrigerated space, further reducing stacking height and storage volume. Constructing the duct system entails higher investment costs. Because the fans must work against external static pressure, they required greater driving power than Design #1, which translates into higher operating costs.

Design 3: Insulated unit cooler with air ducts
This kind of design shares the benefit of Design 2, good air distribution under difficult room conditions. (Figure 4)

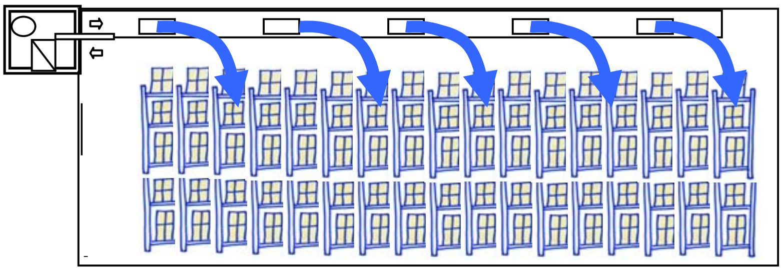

Figure 4. Insulated unit air cooler with air ducts

In this design, the air cooler is located in an insulated room external to the storage area, which enables more pallets to be located within the refrigerated space and enables greater accessibility for servicing. This type of design also exhibits good defrosting characteristics.
As mentioned in the description for Design 2, air distribution duct systems entail loss of refrigerated space and higher investment costs. The external static pressure associated with the ducting entails greater requirements for driving power and higher operating costs.

Design 4: Insulated unit cooler without air ducts
In contrast to design 3, with this type of air coolers, air enters from above and comes out below. There is no air duct, therefore, axial fans without external pressure can be used. This design distributes air to the space via a *cold air lake*. Air circulates by natural convection: as walls and product heats up the cold air, the warmer air rises to the top of the room and flows in a small layer under the ceiling back to the cooler. One note about air circulation supported by thermal activity: this is the optimal type of air circulation for movable bay storage, because the air flows under the storage and rises up between the product.
The cooler is located outside the storage area, it has good defrost characteristics and a better likelihood of obtaining good service.

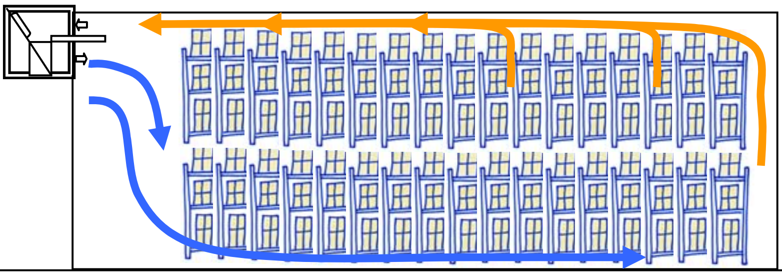

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Figure 5. Insulated unit cooler without ducts

One obvious benefit of not having a duct system is lower investment costs. A side benefit of the cooler not having to work against the air resistance of the ducts is lower drive power required and consequently, lower operating costs. Greater use of available refrigerated space results from the greater allowable stacking height.
This design has a couple limitations and requirements. First, free space must be provided for vertical air circulation between the shelving system and the outer wall. Some space must also be provided for distribution of cold air in front and below the coolers; the maximum recommended ratio of room length to room height is about 3:1.

Design 5: Storage room cooler
Design 5, a storage room cooler, is similar to Design 4 in that a "lake" of cold air is supplied to the floor without the use of ducts, and warmed air convects up through the product stacks to the top of the room, and then returns to the cooler. (Figure 6) It has all the financial benefits of a channel-less system.

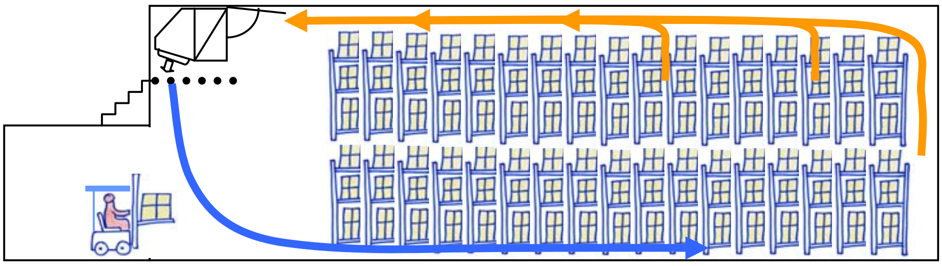

Figure 6. Storage room cooler

This design needs no air throw, so the fan may operate at a low speed. This design yields a high utilization of storage volume and greater stacking heights. This is the ideal air distribution for a mobile shelving system.
This design has similar limitations and requirements to Design 4. Free space must be provided for vertical air circulation between the shelving system and the outer wall. Some space must also be provided for distribution of cold air below the coolers; the maximum recommended ratio of room length to room height is about 3:1. This design also requires a service platform for the cooler. In cases of low room height, a draft can be felt beneath the coolers.

Design 6: Penthouse cooler
With a penthouse cooler design, the air cooler is located outside the storage area on the roof, permitting high space utilization. (Figure 7) This design provides good accessibility for service; no service personnel need enter the refrigerated warehouse. Pipes and valves are routed above the roof. Air coolers can be replaced as needed without a structural change in the building. Expansion of the warehouse is possible without changing the cooling system.

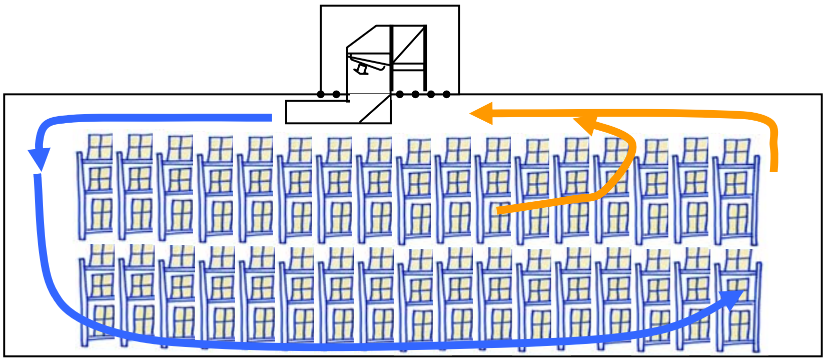

Figure 7. Penthouse cooler

To prevent a short circuit of air a system of short air ducts is necessary. Fans need external pressure capabillities for the air ducts, on the order of about 65 Pa [0.23" H_2O] of external static pressure.

Trends in Refrigerated Warehouses and Logistical Storage

As mentioned above, refrigerated warehouses are becoming ever-bigger and ever-higher. Compared with historical designs, they are operating with relatively little cooling capacity for large volumes of space and with low air circulation rates. Automatic transportation systems now permit high bay storage. Further, mobile shelving optimizes use of space and is becoming increasingly popular. The result is a net savings in energy and investment costs.

Energy costs are crucial for the economic efficiency of a refrigerated warehouse. That is why it is very important for every refrigerated warehouse to use the optimum design concept. As mentioned above, energy costs can be reduced two ways if fans with low driving power are installed. Not only is the direct power consumption of the fans lower, but the refrigeration energy required to offset the heat generated by each fan is also reduced.

In recent years, large refrigerated warehouses in Europe have been built using designs in which the cold air from the coolers is routed directly to the floor. It spreads out like a lake, rises as the result of thermal activity and flows under the ceiling back to the air cooler. With this type of air flow, it is possible to install low-speed fans with low driving power. The investment costs for air channels are saved as well as the operating costs.

Refrigerated warehouses with automatic transportation systems are often suitable for this type of air flow. How do the air currents in this type of refrigerated warehouse behave and how even is the temperature distribution? An existing refrigerated warehouse in Switzerland of this type was studied to answer this question. Results from the study are presented in the following section.

Case Study

The operator of the warehouse is Migros Verteilbetrieb Neuendorf AG. The warehouse provides logistical high bay storage with fixed shelving for 25,800 pallets. The space is comprised of four cooling rooms. (Figure 8) Two of the rooms are 14 m [46 ft] wide, and the other two are 18 m [59 ft] wide; all rooms are 83 m long x 32 m high [277 ft x 107 ft]. The stacking height is 29 m [95 ft], enough for about 14 pallets. Goods are maintained at -28°C [-18°F].

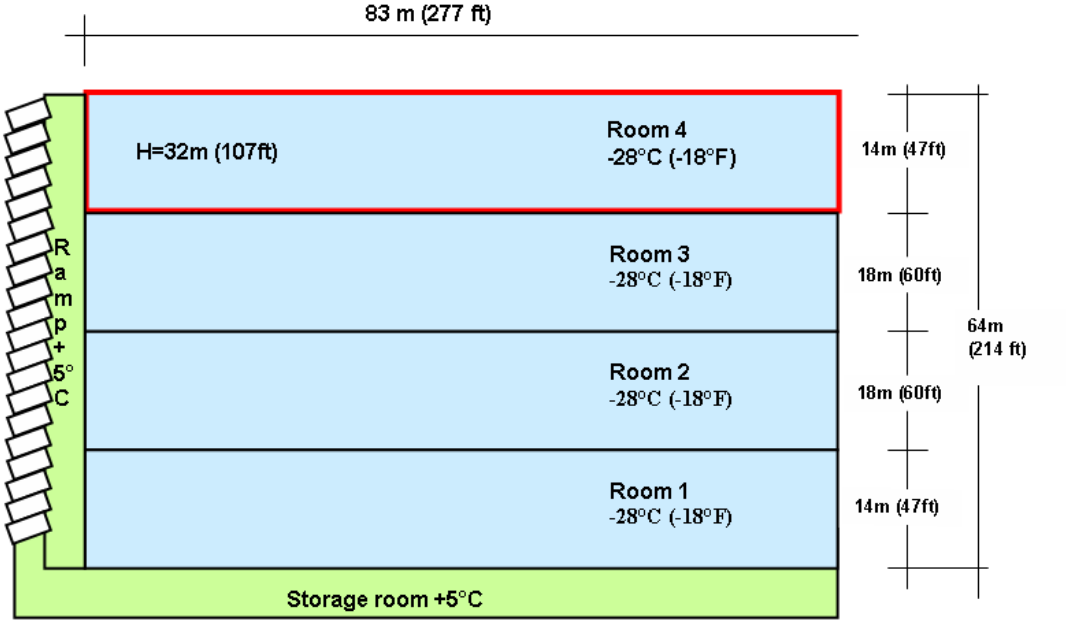

Figure 8. Warehouse in case study

The cooling capacity required is 447 kW [127 TR]. The ammonia refrigeration plant consists of 3 rotary screws and 1 reciprocating compressor; sufficient capacity was installed (1074 kW [300 TR]) to allow 10 hours operating time only in the night. Twelve air coolers were installed, 3 per room, each having a capacity of 91 kW [26 TR]. Each cooler has 3 fans that draw 1.4 kW each in electric power. The total air quantity delivered is 52,600 m³/h [30,960 cfm].

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Computer Simulation of the Warehouse

Diagrams of Calculated Areas

In the model, the air velocity and temperature distribution in all specified horizontal, longitudinal, and transverse sections are calculated. (Figure 9) The following examples illustrate use of these parameters.

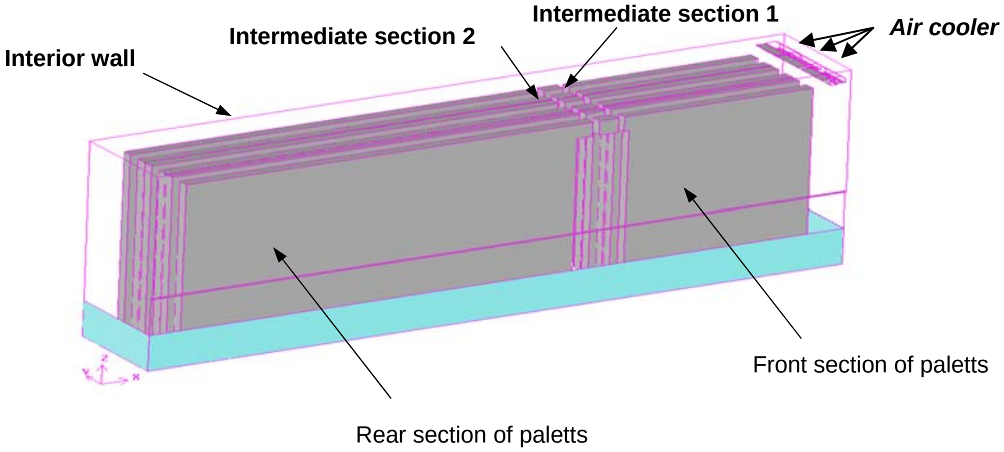
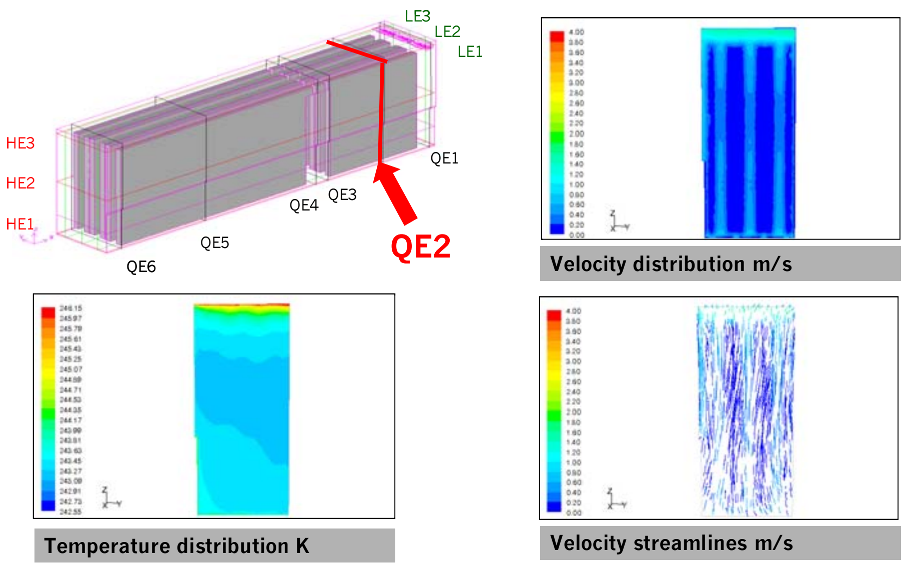


Figure 9. Some sections used in the model

Example: Transverse section QE2



In this transverse section, note the distinct air speed down the length of the room as air flows from the air coolers to the opposite side of the room. (Figure 10) Some of the warmed air flows upward, forms a thin layer under the ceiling and flows back to the coolers.

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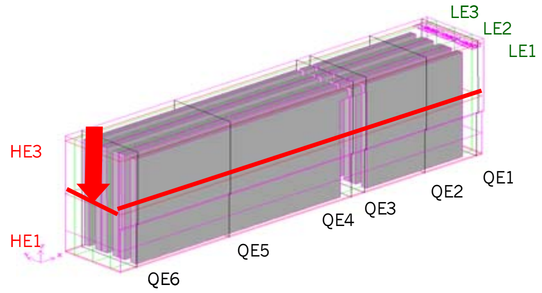
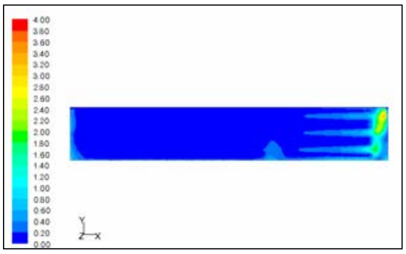
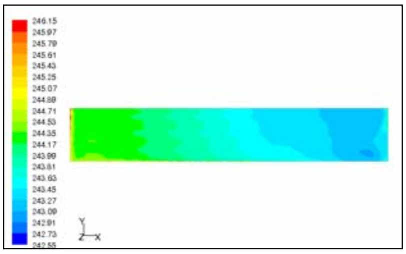
Example: Horizontal section HE6

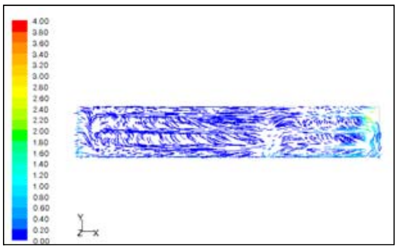




Velocity distribution m/s



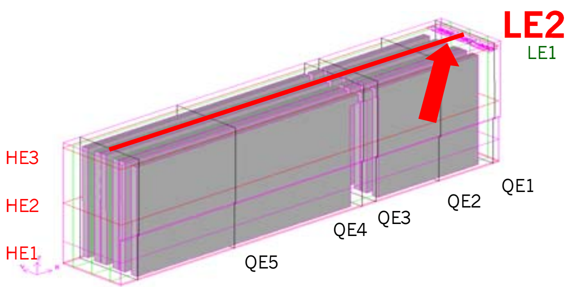
Temperature distribution K

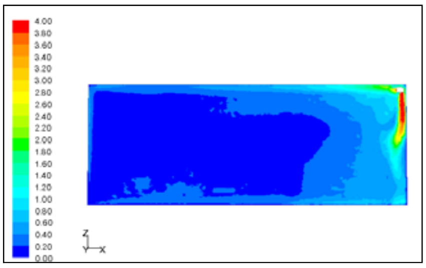


Velocity streamlines m/s

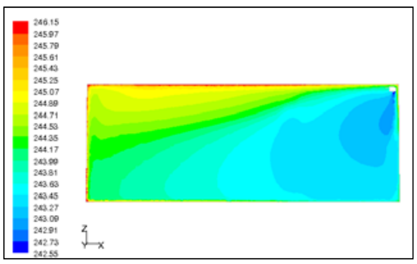
The air speed in the section reduces after approximately 20 m [65 ft]. (Figure 11) The cold air flows down the section to the end of the room. At the outer walls, warmer air convects upward. The temperature difference over the length of the room is about 1.4 K [2.5°F] in this section.

Example: Longitudinal section LE2

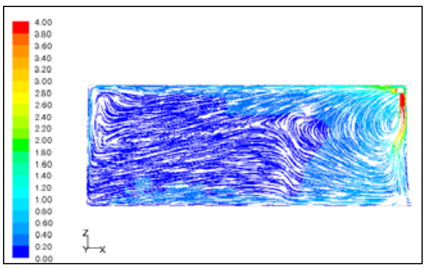




Velocity distribution m/s



Temperature distribution K



Velocity streamlines m/s

The graphic representation of the air convection shows that only a part of the air flows back to the cooler after about 20 m [65 ft] of room length. (Figure 12) Most of the air flows all the way down the length of the room to the opposite outer wall, rises, and flows under the ceiling back to the air coolers. In the area of the outer wall and ceiling, a thin dividing layer with warmer air is visible.

Simulation Results

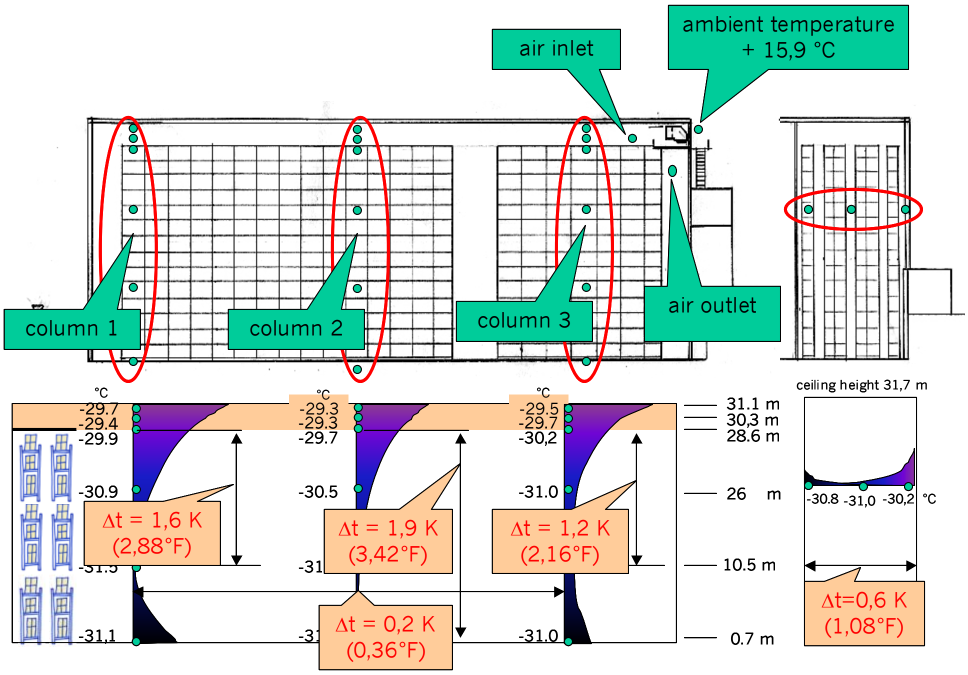
The temperature variation calculated over the length in the region of the pallets was as follows:

- At the floor 1.3 K [2.3°F]
- At the middle section 1.8 K [3.2°F]
- At the upper section 2.0 K [3.6°F]

The warmest air temperature in the product area was below –28°C.

Temperature Measurements

Temperatures measurement were over a period of 7 days. They are stated as mean values below.



Results of the measurements

Over the entire volume contained by the pallet stack, the maximum temperature difference measured between the coldest and the warmest point was 1.9 K [3.4°F]. At all points, the temperature was below –28°C [-18°F] and thus in the target range.

Summary

With an air circulation rate of 4.2 room volumes per hour and natural air convection supported by thermal activity, an even temperature distribution can be achieved in refrigerated warehouse rooms. The computer simulation of the flow pattern and temperature conditions provides a good basis for assessing the subsequent functioning of a refrigerated warehouse.