Energy Saving at Coldstore Doorways by Means of Specialist Air Curtains

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ABSTRACT

Energy analysis reveals that the Air Change Load at doorways has a large impact on overall refrigeration heat loads. Air Change reduction be achieved by a variety of means but at open doorways, air separation technology, a derivative of air curtains, comes into play. Air separation technology is introduced and explained. At sub-zero cold store entrances, demisting is one of the components of the technology described. This requires heat input and occurs within the cold side of a cold store doorway. This may sound counter intuitive. If available, waste heat of refrigeration can be employed in the demisting process thereby cutting running costs of the air separation installation. Applications in the cold chain are described. Case studies will demonstrate its effectiveness.

Keywords: Coldstores, Doorways, Air Change, Energy Efficiency, Air Separation.

1. INTRODUCTION

"To maximise efficiency attention needs to be paid to the following: minimising the need for refrigeration and reducing the cooling load. This is the most important first step – a system cannot be considered efficient if the cooling load is unnecessary." IOR Policy[1] lists this item above four other priorities.

As a technical case study, presented here is an "off the shelf" and well-established technology for reducing energy demand at cold stores or frozen and chilled food manufacturing. Because of the significant contribution Air Change or Infiltration makes to the overall heat loads, its reduction has long been a topic considered by the IOR and an aim of cold store designers/operators. Infiltration, as a carrier of moisture, leads to unwanted frost build-up. "Why is it some cold stores maintain temperature with very little problem of frost and ice formations, yet others turn into ice palaces within a few weeks of start up?" (Boast, 2003). This question was put, together with some thorough answers to IOR members in 2003. 18 years on, it is still a valid question to ask.

Logically, the first step to reducing Air Change is to minimise the time that coldstore doorways are open. However, a busy coldstore facility is characterised by frequently used doorways not closed ones. High density storage racking systems and automation plus a good turnover dictate a trend towards larger throughput via the openings available. High frequency door usage, even with fast acting doors, can result in an aggregate door open period of over 1000 hours per year. At this threshold, the benefits of applying specialist air curtains/air-separation technology to reduce the coldstore's cooling load can be cost-effectively considered.

By also reducing humidity transfer, effective air separation will address hazardous ice formation on floors and ceilings near the doorway. Instead of fog, clear visibility at the open doorway reduces the possibility of collisions. Better traction and visibility improve logistics speed and efficiency. Avoidance of air-locks allows for smooth-running unhindered and safe movement of goods, improving reliability and overall ROI at the facility.

2. SPECIALIST AIR CURTAINS, AN OPPORTUNITY FOR HEAT LOAD REDUCTION

2.1. Heat load reduction at doorways in context

The main components of heat loads that a coldstore must contend with are:
(a) Insulation or fabric heat gains
(b) Air change heat gains

(c) Personnel and equipment loads
(d) Lighting loads
(e) Product loads
(f) Fresh produce respiration loads
(g) Glycol pump loads if applicable
(IOR, 2016)

The influence of water vapour on the air change heat gains is understood and calculation methods available. (Cleland, 2012). It is the difference in enthalpy of the air masses and the quantity of air exchanged (Air Change) that determine the load. "The air volume entering per hour must be carefully assessed by discussing the use of the store with the operational management." (IoR, 2016). Case studies have investigated these loads at existing facilities enabling their proportions to be assessed. One early study reported that after transmission loads and the fixed loads (fans) "The other major heat load on the rooms was from infiltration." (Evans 2008). One can therefore expect great benefits by paying attention to the possibilities of reducing air transfer, particularly if it is heavily moisture laden.

2.2. Infiltration and moisture ingress at doorways and available means of its reduction

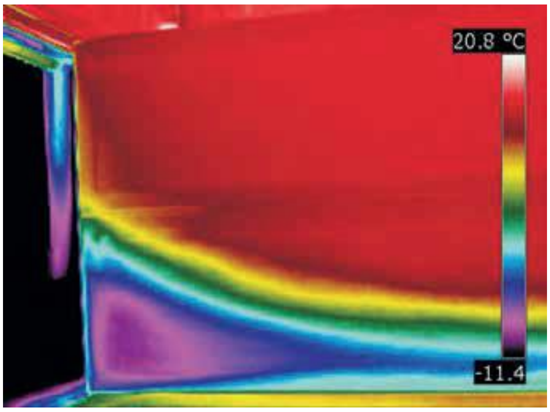


Figure. 1 Thermal image outside an open cold store doorway, REWE Russeina, Germany

Using thermal imaging (here at REWE Russeina, Germany) the cold air spillage and the warm air entering the coldstore at high level becomes clearly visible. Even without thermal imaging, the effect of warm moist air ingress is made obvious by clouds of condensation billowing upwards from the door head towards the cold store.

Remedies available include:

- Restriction of pedestrian movement through these doorways (use a separate pedestrian door)
- Installation of strip curtains
- Installation of rapid roll doors
- Installation of an air lock

(Evans, 2008) and

- Dehumidification of zone outside coldstore (Boast, 2003)

Operators of cold stores will be familiar with these solutions and their advantages/disadvantages. Cold stores may also feature installed air curtains.

2.3. Air Curtains: some background

"Air curtains reduce infiltration without taking up as much space as vestibules and without impeding traffic. Their origin dates back to a patent applied for by Van Kennel in 1904 and they have been popular for around 50 years." (Foster 2007).

However, from personal experience, many air curtains, where found installed, have been decommissioned and left unused for a considerable length of time. Whether it was an inappropriate installation or a design/selection fault, their performance had been a disappointment to the site. Therefore, a separate term is required to describe the system that is the subject of this case study. The whole concept of the air curtain in its various applications has been taken back to first principles. The air curtain derivative described by this paper is referred to as a "specialist air curtain" or an "air separation installation". They are also often called "air blades" or air knifes" due to the thin planar high-speed airstream emanating from the diffuser. This is just the starting point.

2.4. Defining "Air Separation Technology": its aims

In contrast to the commonly available air curtains, this technology sets specific aims and standards against which its performance can be measured. At a cold store doorway, the purpose of the air-separation technology is the reduction of thermal and substance (water vapour) transfer that occurs with air change/infiltration.

This objective should consist of three main parts:

- significant reduction of warm air ingress from the antechamber (zone outside the coldstore)
- significant reduction of cold air egress from the coldstore
- elimination of fog at the boundary zone between the inner and outer air-separation airstreams dependent on the water vapour pressure

2.5. Defining "Air Separation Technology": the equipment

An air separation installation should consist of several fans supplying linear vertical and possibly horizontal diffusers with differing airstream directions. The diffusers' airstreams should be designed to counteract in direction and strength, the normally prevailing airstreams (Figure. 1) at open doorways.

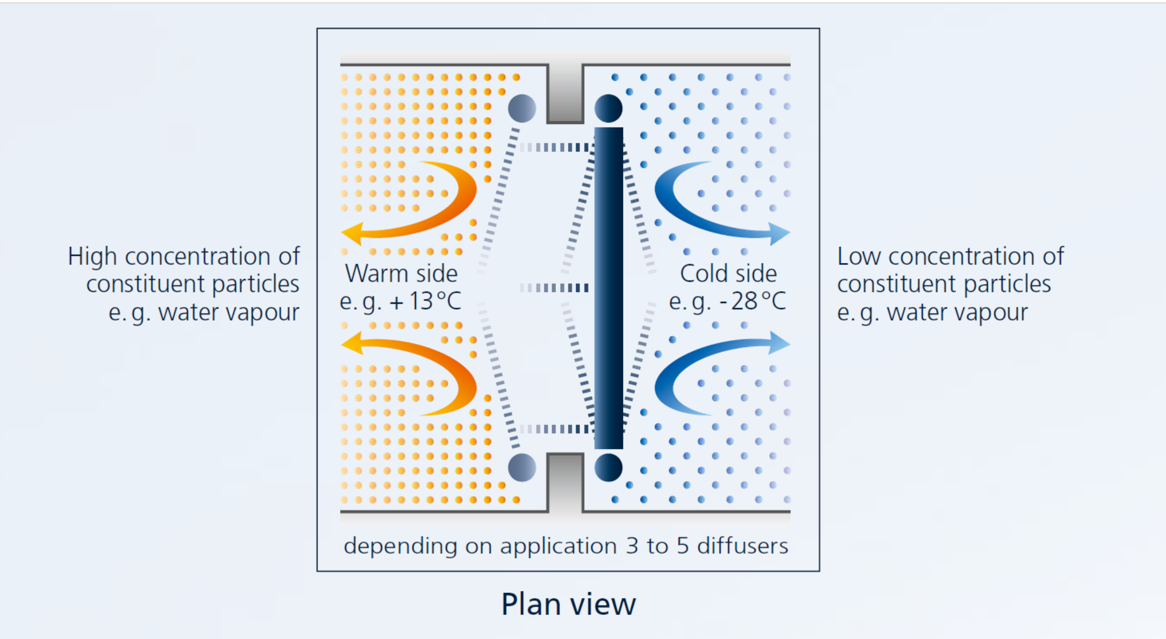


Figure. 2 Schematic layout of an air separation installation at a coldstore doorway

Pressurised air should issue from the linear diffusers creates planar airstreams across the whole height of the doorway so that in the middle of the doorway a standing vertical air barrier is formed. One could compare it with closed lock gates at a canal, damming against prevailing pressure of water. In this case study, these airstreams should face inwards at low level and outwards at high level. It is these planar, directional airstreams, in conjunction with the air barrier formed, that should result in the prevention of through drafts. Under certain circumstances, a horizontal linear diffuser should be mounted above the doorway to counteract the warm moist air entering just below the head of the door. In addition, depending on the conditions prevailing outside the cold store, a separate installation (vertical diffusers only, no demisting equipment) will be required on the warm side of the doorway (Figure. 2).

Figure. 3 View of air separation on the inside of a cold store doorway

Figure. 3 shows two vertical diffusers and the horizontal diffuser as seen in Figure. 2 Plan View. Demisting is integrated within the fan module and is in this case electrically powered. At the base of the vertical diffusers is the heavy duty yellow-painted collision protection featuring a slot for the inward-facing low-level airstreams.

2.6. Cold side air handling: "demisting"

On the cold side of the doorway, the air emanating from the diffusers should be specifically conditioned to eliminate fog at the boundary zone between the two air masses. It also serves to prevent ice formation and the other consequences of water vapour ingress to the cold store. For this paper, the conditioning will be simply termed "demisting". This should be achieved by raising the temperature of the resulting mixing airstreams in a buffer zone outside the doorway to above the dewpoint.

Demisting functions at the interface between the cold (sub-zero) and the warm humid air masses. Demisting in air separation equipment is achieved by reducing the water vapour pressure at this interface. This demisting feature is not required if the conditions on the outside of the sub-zero protected zone are also sub-zero or close to zero together with low enough relative humidity. At higher protected zone temperatures (e.g. a doorway to a chilled store operating at +3 °C from an ambient marshalling zone) the demisting should not be required. In this case air separation should rely upon untreated directional planar airstreams.

In practice, even where dehumidification has been installed in the zone outside the cold store, demisting or even the extra air separation module for the warm side will be required where humidity and temperatures are above design conditions. This underperformance of the dehumidification may be due to excessive infiltration from outdoors combined with high outdoor ambient temperatures. Badly fitting docking door seals, external level deck doors remaining open for unnecessarily long periods or even empty refrigerated vehicles where the internal temperatures have not already reached sub-zero conditions.

2.7. No "one size fits all"

Given the defined design objectives listed above, the performance of an air separation unit should be *project-specifically* determined according to the size of the doorway and the environmental conditions both sides of the doorway (cold store and antechamber). It should be designed for normal airstream conditions (balanced mechanical supply and extract ventilation within the building and no drafts from changing directions). If an air imbalance prevails (mechanical supply or extract units) or drafts occur from changing directions, the optimum function of the equipment could not be guaranteed. These units should therefore be intended for normal internal cold store conditions.

2.8. Setting boundaries to performance

To ensure an economical design, the intended performance of the air separation installation should be suited to the prevailing design/practically experienced conditions. Environmental limits should be set i.e. certain rarely-occurring extremes ruled out. With antechamber temperatures ranging between -2 °C and +13 °C, fog may occur at open doorways when water vapour pressure exceeds 11 mbar or the relative humidity exceeds 70%. A horizontal diffuser on the cold side might then be necessary to counteract fog formation. Even without the horizontal diffuser, the unit would continue to achieve its core aims of reduction of air change/infiltration.

2.9. Prolonged door open periods

Whilst the air separation installations can be synchronised with the rapid rise or sliding door controls, they should be robustly conceived for uninterrupted extended periods of open doorway. For the purposes of calculating the design refrigeration load, engineers should allow for the normal air change/infiltration loads, without an air separation unit in operation. In practice, the longer a door is required open under normal operational circumstances, the greater the savings generated by operating the air separation equipment.

Should a cold store door break down in the open position, the cold store environment will be maintained. This situation could continue for months on end whilst the air separation unit is in operation. If the door is unnecessarily open, this is obviously not desirable due to the energy used to run the equipment. However, it should be a design feature of the robustly conceived air separation equipment.

Some cold store operators may want to use the equipment as an opportunity of reducing wear and tear on their rapid-rise doors. Timers on this equipment could be extended from a door open/door closed cycle of say 20 seconds to 2 minutes, allowing for two or more movements of forklift trucks per open/shut cycle.

2.10. Infiltration reduction design certainty

Air transfer at open cold store doorways is generated by:

1. negative pressure effect of low-density warm air passing over evaporator coils to become high density cold air (Boast 2003).
2. difference in air density between air masses internal and external to the cold store.

"The infiltration air velocity through an open cold store door will be between 0.5 m/s and up to 2 m/s depending on door size and cold store height." (Boast 2003).

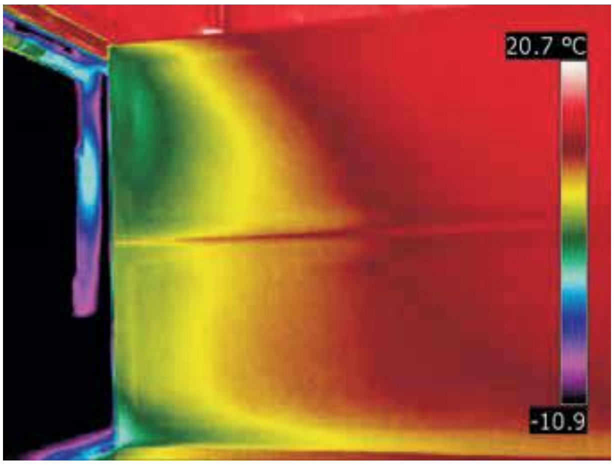


Figure. 3 Air separation in operation at open cold store doorway

Note the cushion of treated air emanating from the upper horizontal diffuser, preventing the warm moist air to get near the cold store doorway. The air velocities predicted have been successfully counteracted by the air separation system.

Increasingly, the cold store's volume is being more efficiently utilised with many racking systems allowing for more intensive product storage. High bay, clad-rack designs may involve store heights of up to 45 m. Air separation equipment should have a design to counteract the considered building's infiltration air streams and their predictable velocities at doorways.

Given the certainty and reliability of reducing infiltration/air change by use of predictably performing air separation equipment, there are many ways of applying it to temperature-controlled storage or food manufacturing facilities. One could start at the outside of the building envelope and work inwards with the application of this technology. Here are some possibilities:

- Docking doors to ambient, chilled or humidity-controlled marshalling areas.
- Level deck access doors (without vehicle docking).
- Inner docking pod doors to frozen, sub-zero marshalling areas.
- Internal doors for conveyors/automated logistics at any specified size/any environmental conditions.
- Frequently used personnel doors.
- Internal doors between ambient and chilled zones.
- Internal doors between ambient outer zone and cold store.
- Internal doors between chilled outer zone and cold store.
- Internal doors between sub-zero outer zone and inert atmosphere cold store.
- Blast freezer conveyor apertures from production areas.

Figure. 4 Air separation at a blast freezer

In summary, this technology allows a rethink of many of the design options and procedures available to cold store designers and operators. Note for example, the emphasis on placed on dehumidification of an outer zone to a cold store: "Refrigerated enclosed loading bays may need to be provided with a means of dehumidification to keep the floor dry." (IoR 2016). This advice could now be switched to aiming firstly for the reduction of ambient warm moist air ingress. External water vapour hindered from entering the building at its source will reduce the overall process energy needed to control humidity. Also, more frequent occurrence of extreme weather conditions leads the National Adaptation Programme to urging resilience to climate change from industry (DEFRA 2018). The reduction of heat loads caused by infiltration during extremely hot outdoor conditions will benefit refrigeration equipment that may be operating at its design limits. Sustainable temperature control, especially under these conditions, is critical to the preservation of food stored.

2.11. Balancing Heating and Cooling Demand

Returning to the topic of demisting, we have another opportunity for efficient refrigeration usage. The air separation demisting equipment is basically a heater battery integrated within the fan module on the cold store side of the doorway. It can be formed of an array of electrical heating elements. Preferably, however, demisting should be constructed using a heater battery (water to air heat exchanger) connected to a low-grade heat source (pumped warm brine: 30/15 °C or 25/10 °C). Associated with most logistics centres are items requiring heating, e.g. underfloor heating to the coldstore, heating to associated office accommodation or social facilities. This low-grade heating can be obtained from the heat discharge side of the condensers and, via a heat exchanger, used for the features requiring heating, air separation demisting being one of them. One could call it "free heating" but there is obviously a cost to running the pumps to the circuits. Such a connection could be beneficial to the refrigeration system with a reliable demand on it occurring simultaneously with active cold store operation and doorway usage.

2.12. Air separation installations applied to controlled atmosphere storage.

Whilst internal doors between sub-zero outer zone and inert atmosphere cold store (e.g. high bay) may gain little benefit from air separation based merely on the difference in enthalpy, the conservation of the inert atmosphere, i.e. its containment within the high bay storage, will prove of value.

Figure. 5 Air separation at conveyor doors to inert cold storage

The facilities with inert atmosphere (reduced oxygen content) have what is categorised as a controlled atmosphere environment. This might be used as an alternative means of fire prevention/protection to sprinkler systems. Other controlled atmospheres are those for certain fruit storage. Outside the cold storage sector, inert atmospheres can be used for the protection of automated archives, for example at the British Library.

The air separation equipment for inert cold storage will negate the need for an air lock, speed up automated logistics and reduce the running costs of the nitrogen-generating equipment. They contain a sufficient proportion of nitrogen to reduce the proportion of oxygen to below the threshold needed for combustion. Because enthalpy or temperature is relatively close on both side of the doorway, the air separation equipment will not require the demisting function and will consist of fan units and diffusers on both sides of the doorway simply using untreated recirculated air for the directional planar airstreams.

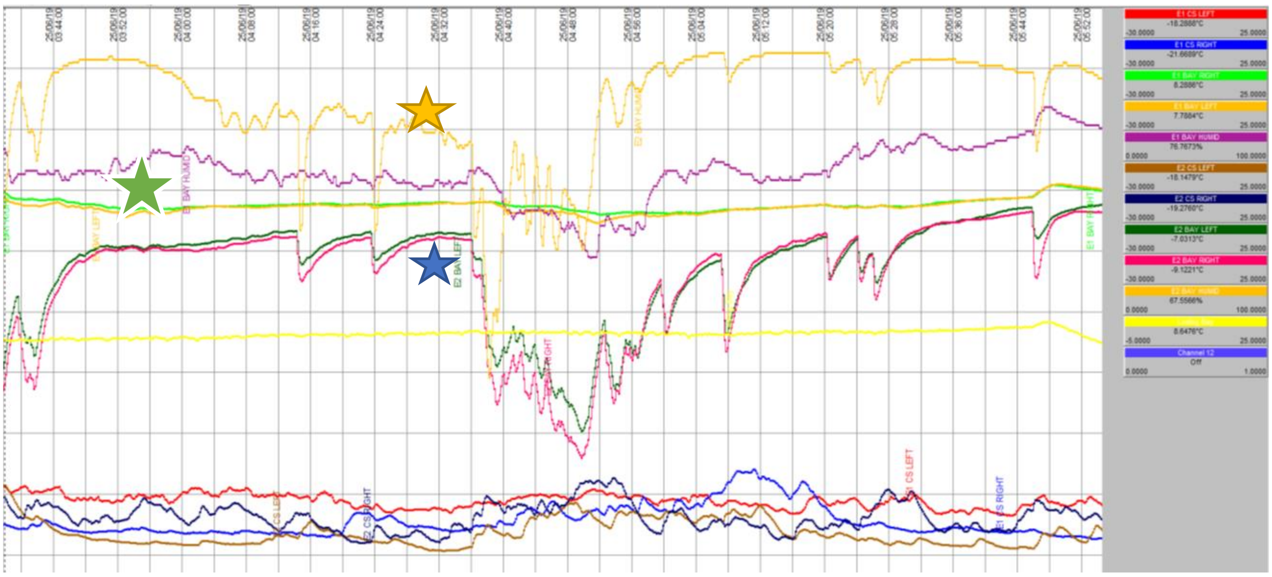
2.13. Return on Investment/Payback Calculations

RoI calculations should be provided on request by the specialist equipment manufacturer. The infiltration is predictable and calculable and, using the enthalpy difference, will determine the energy lost at an unprotected open doorway. The predicted reduction of open door losses using air separation protection will require the sacrificial equipment loads subtracted taken into account. Generally, a net reduction of over 65% energy losses is achievable. Input required from the user: A) cost per unit of power, B) estimated aggregate annual door open period and C) availability or not of waste heat of refrigeration (pumped warm brine) as a heat source for demisting. This input data is used to determine running costs. If using brine demisting, running costs are reduced to those of fans' and brine pump's power supplies. Operational benefits must be assessed separately by the user. If "B" above is over 1000 hours per year, payback periods of 2 years are achievable.

2.14. Case study: cold store doorway at Norish PLC, Wrexham

This facility has three large cold stores linked by a common marshalling area, "bay". This outer zone is humidity controlled using supplies of refrigerated air fed by evaporators in air handling units above. The aim is to keep humidity below the threshold whereby condensation occurs on the products, floor and other built surfaces. Under normal circumstances, the humidity setpoint is 65% relative humidity, resulting in temperatures normally between 5°C and 12°C. The single entrances to each cold store have the same dimensions and are fitted with Union Industries cold store Eiger doors. These feature a small dehumidification unit which retains a dry atmosphere around all the door's moving parts.

In May 2019, Cold Store 1 was fitted with air separation units inside and outside the door (Figure. 7). To demonstrate internally if the equipment was performing adequately, long term monitoring of temperature and humidity at strategic points was installed at Door 1 and Door 2 (as a control). A Eurotherm 12-channel data logger was used to record. Below is a sample of the recording.



Temp & humidity outside Door 1 (purple = humidity, green & ochre = temperatures)

Humidity outside Door 2 (ochre trace) Temp. outside Door 2 (green & red traces)

Figure. 6 Temperature and humidity tracked at cold store doorways

The sharp drops in temperature and relative humidity occur outside Door 2 at every instance the door opens. No such tendency can be observed at Door 1 which has air separation fitted. The warm-side temperature/humidity sensors were located close to floor level approximately 3 metres from the doors within the humidity-controlled marshalling zone (bay). Cold side temperature sensors were placed at high level to the left and right of the doorway.

The Norish internal survey results were sufficient to verify the air separation function to those within the company responsible for the project's Capital Expenditure.

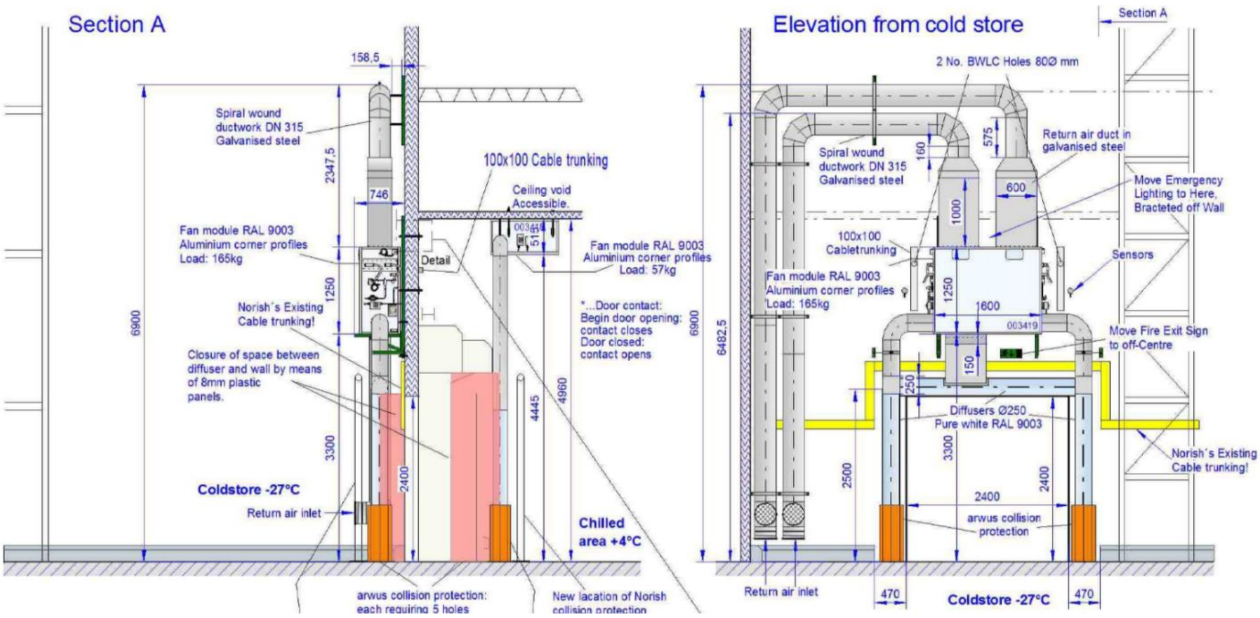


Figure. 7 As-built drawing of the air separation inside and outside Door 1

3. CONCLUSIONS

The results from the Norish PLC survey are repeatable wherever air separation has been correctly designed and installed. Experience gained over the past 25 years in developing and improving this technology serves to ensure that it can be effectively and reliably used at an array of applications in cold storage and frozen food production. It has widespread use on mainland Europe. It remains for most companies in the UK and Ireland as an untried opportunity for energy reduction at cold stores.

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