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MICROBIAL CONTAMINATION OF FOOD REFRIGERATION EQUIPMENT.

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Summary

Refrigeration systems in chilled rooms in fifteen plants processing a variety of foods were studied. These included plants processing raw meat and salads, Chinese ready meals, dairy products, slicing and packing of cooked meats and catering establishments. An initial survey of total numbers of microbes at a total of 891 sites on evaporators, drip-trays and chilled room walls was followed up with a more detailed examination of 336 sites with high counts, selecting for *Listeria* spp, coliforms, enterococci, *Staphylococcus aureus* and *Bacillus cereus.* Temperatures (particularly air on and air off, maximum and near defrost heaters) relative humidity, airflow, layout and cleaning regimes were surveyed.

The work demonstrated that bacteria were present on evaporator cooling coils in all factory chill rooms visited. In general, no correlation could be found between any of the physical measurements and the numbers and types of bacteria detected. Further trials with an experimental evaporator indicated that bacteria could be transferred from the surface of the evaporator to the air within a cold room. These trials with the experimental evaporator also indicated that little microbial growth occurred on a clean evaporator.

Although evaporator cleaning procedures were carried out in some factories as part of routine maintenance these were not shown to be effective at maintaining low levels of bacteria on evaporators. To maintain evaporator hygiene it is suggested that more regular cleaning procedures, possibly by means of automated cleansing systems, should be considered.

Key words : evaporator, drip tray, food processing, temperature, bacteria.

Introduction

Although evaporators in food cold rooms are generally maintained at temperatures below which bacteria can grow there is unpublished anecdotal evidence suggesting that microbial contamination has been found to be a problem in some food plants. This may be due to defrosting where temperatures on and near the evaporator rise during periods when ice built up on the evaporator is melted and removed. In addition the majority of evaporators have drip trays beneath the evaporator designed to collect the melted water during defrost. These trays are rarely cleaned and may collect dirt and debris that provide nutrients for bacteria. Dirt and debris can also collect on the evaporator fins and if dislodged can be distributed around the cold room by the evaporator fans.

There are few published data on microbial contamination of refrigeration components and especially evaporator cooling coils in the food industry. Surface contamination of walls,

tables, floors and equipment used for food processing has been the subject of previous publications (Patterson, 1969; Nortjé et al, 1990). It is generally accepted that microbial loads on surfaces and equipment vary in different food plants depending on the microbial quality of the food and the cleaning programmes in operation (Nortjé et al,1989).

Contamination of air in a meat processing plant has been shown to influence the shelf life of the stored products (Al-Dagal et al, 1992). Although microbes do not multiply whilst airborne, it is an effective method of distributing bacteria to surfaces within a food plant. In chilled rooms evaporator fans draw large quantities of air over the evaporator cooling coils and distribute it around the room. Any contaminants in the air are likely to pass over the evaporator surfaces and some will be deposited. If conditions are suitable, attachment, growth and further distribution of airborne contaminants may occur. Microbes are likely to multiply if food particles and moisture are present and if the temperature for at least part of the time is above freezing. In addition to being a potential source of contamination for food, the development of a microbial biofilm on evaporator cooling coils may affect heat transfer rates of the equipment and may induce corrosion and necessitate subsequent replacement of equipment (Characklis, Nimmons and Picologlou. 1981; Characklis, 1983). Krafthefer and Bonne, 1986) estimated that significant deposition (doubling the air pressure drop across the coil) could occur in 4 to 7 years of typical operation. Braun (1986) found that if dirt was not removed from a cooling coil promptly, cleaning was ineffective and the coil required replacement. In addition he found that it was impossible to determine the cleanliness of the coil simply by looking at the surface. Often the external surfaces looked clean whereas central areas hidden from view were extremely dirty.

A limited amount of information has been published on microbial contamination of air handling systems. This has mainly concentrated on health problems such as humidifier fever, legionellosis and sick building syndrome which are thought to be associated with a build up of airborne pollutants. Work carried out by Hugenholtz and Fuerst (1992) over a period of a year details microbes found on and around a well maintained air handling system in Brisbane, Australia. These researchers found the highest numbers of bacteria in water samples from the supply side of the cooling coils. Fungi tended to dominate on dry surfaces where bacteria were never detected. The return sides of the cooling coil had highly variable microbial populations ranging from zero to 10^5 colony forming units per square centimetre (cfu.cm^{-2}). The supply side of the coil surface had consistently high bacterial numbers which were mainly between 10^5 and 10^6 cfu.cm^{-2}. Generally air samples contained low levels of microbes. The system was described as being visibly clean and was cleaned annually with a high pressure detergent spray. It was found that the composition of the biofilm changed little during the course of the year's investigation despite the cleaning of the coils which occurred during the trials.

A report by Morey et al (1986) described an investigation of five buildings where hypersensitivity pneumonitis and other respiratory diseases had been reported. In all buildings microbes were found in stagnant water in the air handling systems. In three of the buildings microbial slime several millimetres thick was found on wetted surfaces of drain pans and cooling coils. A range of bacteria, fungi, protozoa and nematodes was found in slimes from the air handling units. A biofilm described by Harris and Lee (1991) on the aluminium cooling fins of heat pump equipment consisted primarily of pseudomonads, with large numbers of *Bacillus* spp, coryneforms, *Flavobacterium* spp, vibrios, azotobacters, *Alcaligenes* spp, *Spirillium* spp and staphylococci. Microscopic pits on the surface of the cooling coil fins were thought to provide favourable sites for microbial attachment. Industrial degreasers and surface films were also thought to contribute to microbial attachment and survival.

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The survey described in this paper was therefore carried out to determine the numbers and types of microbes present in chilled rooms, particularly on evaporator cooling coils, and to determine whether the ambient conditions surrounding the cooling coils influenced the numbers of microbes. In addition, laboratory-based work was carried out on an experimental evaporator to investigate bacterial survival under a variety of environmental conditions.

Materials and Methods

Assessment of evaporators in food factories.

Fifteen food processing plants were each visited twice within a 6 month period. The plants were chosen to represent a range of different sizes of operation, food products and stages in the chilled chain (Table 1). Up to 7 chilled rooms were examined in each facility, the number depending on the size of the plants and the ease of access to rooms.

Table 1. Types of food produced by each plant and stage in chilled chain that plant occupied.

Plant number	Types of food produced	Stage in chilled chain	Number of chilled rooms examined
1	Salads	Raw materials to packaged ready for retail sale	5
2	Ready prepared pasta meals	Raw materials to packaged ready for retail sale	6
3	Vegetarian meals	Raw materials to packaged ready for retail sale	4
4	Preparation of cooked meats	Cooking and preparation for further processing	6
5	Ready prepared meals	Raw materials to packaged ready for retail sale	6
6	Pies	Raw materials to packaged ready for retail sale	6
7	Cooked meats	Packaging for retail sale	6
8	Ready prepared Chinese meals	Raw materials to packaged ready for retail sale	6
9	Raw poultry	Primary poultry meat production	7
10	Mechanically recovered meat	Preparation for further processing or by-products	2
11	Dairy products	Raw materials to packaged ready for retail sale	5
12	Restaurant	Preparation for final consumption	3
13	Raw and cooked poultry	Preparation of meat for further processing	4
14	Restaurant	Preparation for final consumption	5
15	Raw meat	Primary red meat production	7

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Physical measurements.

During the initial visit two data loggers (Stickon, Ancon-Signatrol, Tewkesbury, Glos, accuracy ±0.2°C) were attached to each end of an evaporator coil in each chilled room to record air temperatures in and around the evaporator. The sensors from each data logger were placed to record temperatures in the following positions: 1. air returning to the evaporator from the room (air-on); 2. air leaving the evaporator (air-off); 3. air close to the defrost heaters; 4. the warmest position in the evaporator (close to the entry of the defrost heater if electric defrosts or suction line entry if saturated gas defrost); 5. drip tray.

Two additional sensors recorded the wet and dry bulb temperatures of the air returning to the evaporator to determine the relative humidity in the room. The wet bulb sensor was enclosed within a wick fed from a small pot of distilled water. All temperatures were recorded every 5 min for at least 6 days.

In addition spot measurements were taken of air velocities within each chilled room and the pattern of air flow in each room was determined. Measurements were taken using an Edra 6 vane anemometer (Air Flow Developments Ltd, High Wycombe, Bucks, accuracy ±2% of reading).

Notes also made in each chilled room of: 1. type of defrost (off cycle, electric, saturated/hot gas); 2. types of product stored in the room and whether they were wrapped or unwrapped; 3. the positions of evaporators, doors and products; 4. cleaning regimes employed in the plants and if possible the last time that the chilled room evaporators had been cleaned.

Microbiological sampling.

During the first visit to each plant microbiological swab samples were taken from five positions on each evaporator, plus three in the drip tray (Figure 1) and three on the walls of each chilled room. Samples from the evaporator and drip tray were all taken from the air-on side of the evaporator. Wall samples were selected at random around the chilled room as an indication of general cleanliness. Samples were taken by dipping a sterile cotton wool swab on a wooden applicator in sterile Maximum Recovery Diluent (MRD : Oxoid CM733) and swabbing a 10cm^2 area of the evaporator, drip tray or wall. In factories 3, 10 and 15 the swabs were immediately plated directly onto Plate Count Agar (PCA : Oxoid CM325). The plates were transported in a chilled cold box before being incubated at 25°C for 48 h. Counts per cm^2 were estimated by counting all the colonies on each plate. In all other factories the swab tips were placed into bottles containing 10ml of MRD, stored and transported to the laboratory in a cold box at 0°C and held overnight at 0°C before examination. Each sample was then mixed for 1 min using a vortex mixer and the supernatant examined for total viable microbes by surface plating decimal dilutions on PCA and incubating at 25°C for 48 h. All results were expressed as $\log_{10}$ cfu.cm^{-2}. The minimum detection level was 5 cfu.cm^{-2} and the maximum 10^5 cfu.cm^{-2}.

At least 6 days after the initial visit, the plants were re-visited and the data loggers retrieved. A total of 336 sites (152 on evaporators, 129 in drip trays and 55 on walls) were re-examined in areas found to have high TVCs to determine whether specific bacteria were present. These constituted between 3 and 10 positions in each chilled room. Swabs were taken from 10cm^2 areas in positions that were close, but not identical, to the original sampling positions. Samples were transported and handled as above. Decimal dilutions were prepared and the following media were surface inoculated; PCA for total viable count incubated at 25°C for 48 h; MacConkey no.2 Agar (Oxoid CM109) for coliforms and enterococci incubated at 37°C for 24 h; Baird-Parker Agar (Oxoid CM275 + SR54) for

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Staphylococcus aureus incubated at 37°C for 48 h; Bacillus cereus Selective Agar (Oxoid CM617 + SR99) for *Bacillus cereus* incubated at 30°C for 24 and 48 h; PALCAM Agar (Oxoid CM877 + SR150E) for *Listeria* species incubated at 30°C for 48 h.

Confirmation of identity of organisms was based on colonial appearance, cellular morphology, motility, Gram stain, coagulase, oxidase and catalase reactions as appropriate. The minimum detection level for each group was 5 cfu.cm^{-2}. All results were expressed as $\log_{10}$ cfu.cm^{-2}.

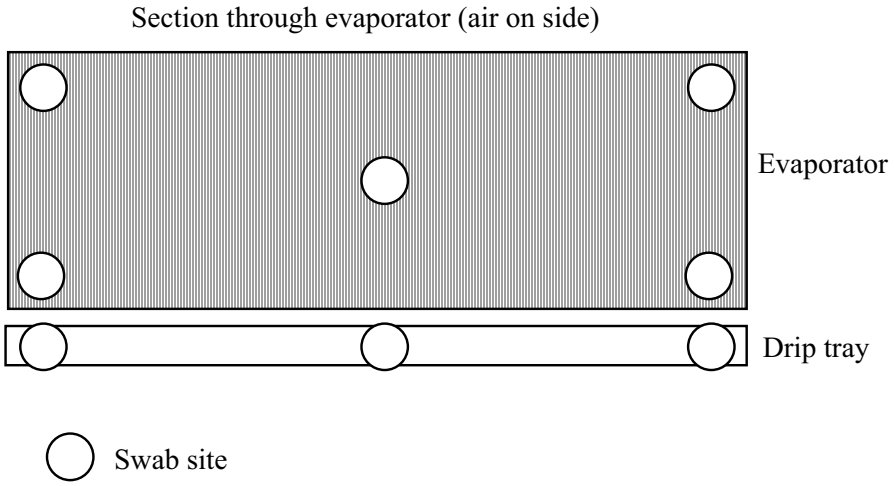

Figure 1. Evaporator positions for microbial samples.

Evaluation of bacteria on experimental evaporator.

An experimental test rig was constructed to simulate a commercial evaporator and installed in an environmental chamber (8m x 6m x 3m high). Cooling was provided from a tube through the centre of the fins through which propylene glycol circulated via a refrigerated reservoir tank. The assembly was designed to produce a range of temperatures across the cooling coil. Electric heating coils to defrost the cooling coil were placed in each section of the coil at a point between the corner of the fin and the refrigeration pipe. Air flow across the coil was controlled to 2± 0.1 m.s^{-1} using an external fan. Ambient conditions in the test chamber were controlled to a temperature of 10±0.5°C and relative humidity to 40, 60 or 90±5%. Trials were carried out with different combinations of ambient relative humidity (40, 60 or 90%), type of defrost (electric or off-cycle) and coil temperature (-6.7 to 9°C).

The evaporator was inoculated with 20 ml of an inoculum (consisting of a non-toxinogenic mesophilic strain of *Bacillus cereus* (F1078/89) obtained from Dr J Kramer, Food Hygiene Laboratory, Central Public Health Laboratory, Colindale [this culture had produced spores by the end of the incubation period], a non-pathogenic strain of *Escherichia coli* K12, *Listeria innocua* NCTC 11288 and *Enterococcus faecium* NCTC 8619) using a sterile 40 mm paint brush

The cooling fins and coils were allowed to drain free of excess inoculum into a tray for a 5 min period, before the initial bacteriological samples were taken. During the inoculation procedure and draining period all air circulation fans in the environmental room were switched off to minimise contamination.

Bacteriological sampling and counting.

The cooling fins were sampled in duplicate immediately after the 5 min draining period by swabbing two 10cm^2 areas of fin surface with separate sterile cotton wool swabs on wooden applicators that had been moistened with Maximum Recovery Diluent (Oxoid CM733). The swabs were placed in separate 10 ml quantities of the MRD and mixed for 1 min on a vortex mixer before dilution in MRD and surface plating on the selective media listed below. Further duplicate samples were taken from each coil (total of 4 positions) 3 h, 24 h and 6 days post inoculation.

The following media were used: MacConkey no.2 agar (Oxoid CM109) incubated at 37°C for 24 h for *Escherichia coli* and *Enterococcus faecium*.; Bacillus cereus selective agar (Oxoid CM617 + SR99 + SR47) incubated at 30°C for 30 h for *Bacillus cereus*; PALCAM agar (Oxoid CM877 + SR150) incubated at 37°C for 48 h for *Listeria innocua*.

Air contamination.

Air contamination was assessed by placing three 90 mm diameter exposure plates of each of the above media 3.5 metres from the inoculated coils 150 mm above floor level for the initial 3 hour period following inoculation and draining. Results were expressed as the bacterial precipitation rate on a horizontal surface and were calculated as the mean $\log_{10}$ cfu.m^{-2} per hour.

At the end of each trial the experimental cooling coils were sanitised.

Results

Assessment of evaporators in food factories.

1.1 Total viable counts (TVC).

Twelve out of the fifteen plants had at least one site where microbe counts were above the maximum measured value of 5 $\log_{10}$ cfu.cm^{-2}. At least one sampling position at each plant had numbers of microbes above 3.4 $\log_{10}$ cfu.cm^{-2}. In total 25% of the 891 sites investigated during the first part of the survey had values above the maximum measured value of 5 $\log_{10}$ cfu.cm^{-2}. The level of overall contamination (mean of all rooms and positions within one plant) varied significantly ($P<0.001$) between factories from 0.8 $\log_{10}$ cfu.cm^{-2} in plant 1 to 3.8 $\log_{10}$ cfu.cm^{-2} in plant 15 (Figure 2).

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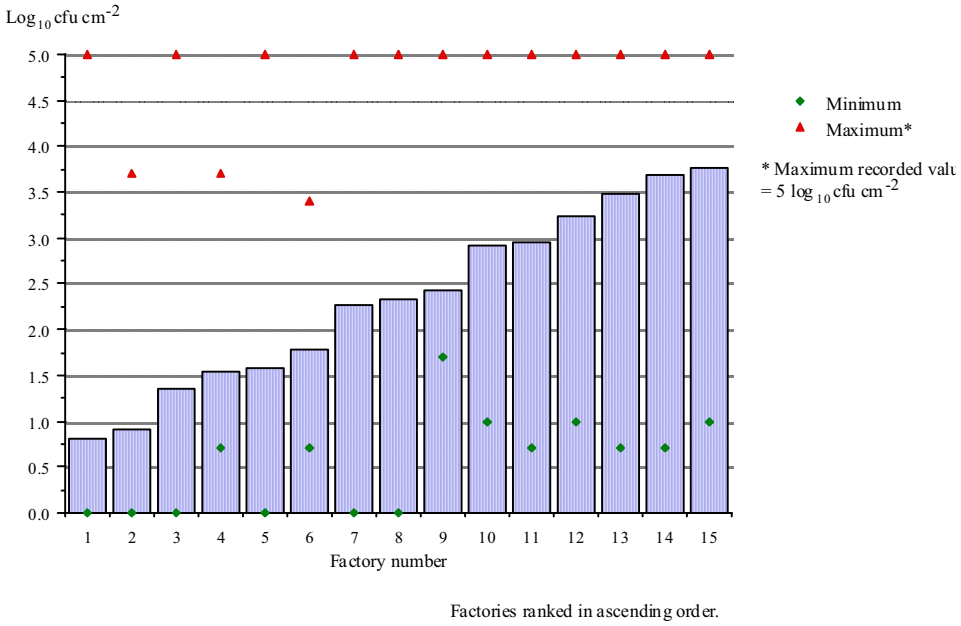

Figure 2. Mean, maximum and minimum levels of microbial contamination (log_{10} cfu.cm^{-2}) in each plant visited. Bars illustrate means.

Significant differences ($P<0.001$) were also found between chilled rooms within plants and this was found to be related to the types of product stored in the room. In rooms where products were wrapped the level of microbial contamination was significantly lower ($P<0.05$) than in rooms where product was unwrapped or consisted of a mixture of wrapped and unwrapped products (Figure 3). In addition the type of food stored in the chilled room significantly ($P<0.001$) influenced the level of microbial contamination.

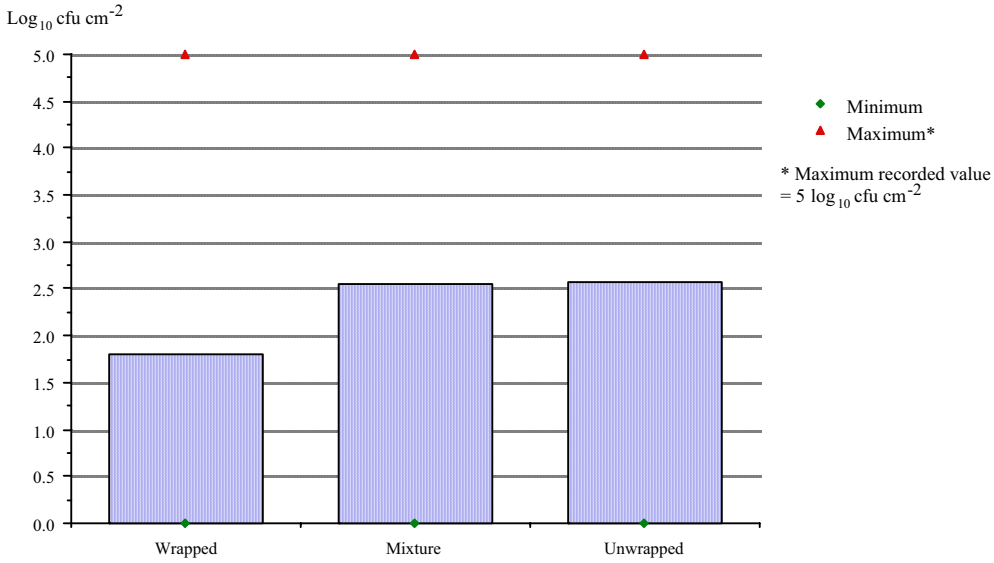

Figure 3. Levels of microbial contamination in chilled rooms related to type of wrapping of stored product. Bars illustrate means.

Contamination was greatest in chilled rooms where raw meat, raw poultry and dry ingredients (e.g. flour, spices, coatings) were stored and least in chilled rooms where vegetables and cooked products were stored (Figure 4).

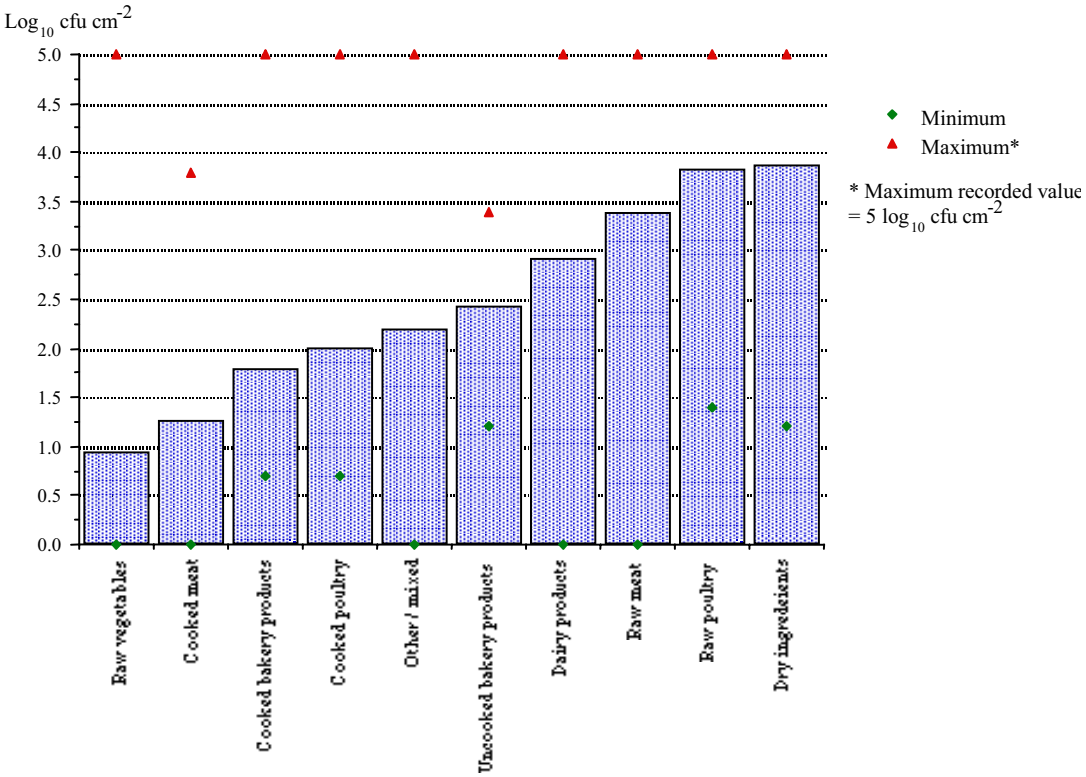

Figure 4. Level of contamination related to products stored in chilled room.

Significantly different ($P<0.01$) levels of microbial contamination were also found within chilled rooms, with drip trays being generally more contaminated than evaporators. Walls were the least contaminated areas examined (Figure 5).

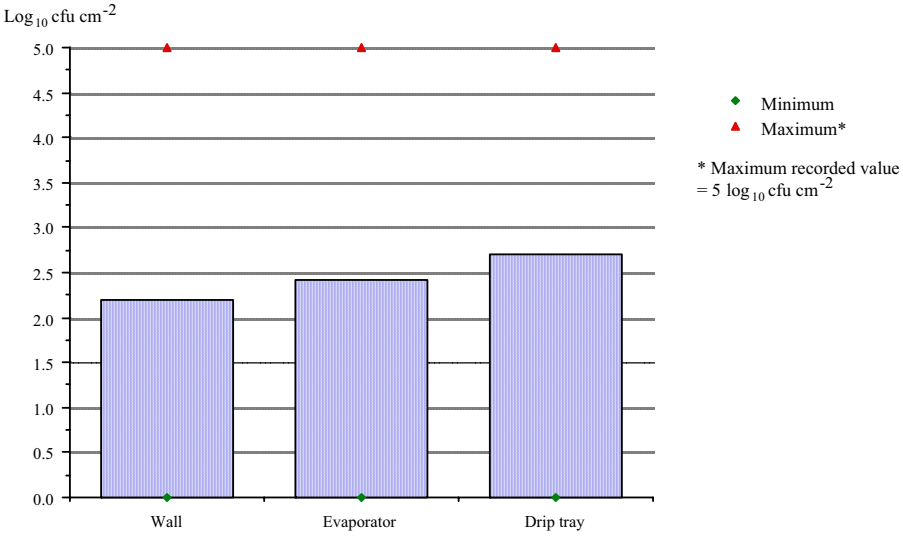

Figure 5. Level of contamination at different positions within chilled rooms.

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1.2 Specific bacteria.

The specific types of bacteria tested for were either not detected or found in very small numbers (< 2.7 $\log_{10}$ cfu.cm^{-2}) in all the chilled rooms investigated. *Listeria* spp were not found in any chilled rooms, coliforms were only found in one plant (number 3) and enterococci were found in two plants (numbers 12 and 15). Low numbers of *S. aureus* or *B. cereus* were found in nine of the fifteen plants visited (Table 2). Enterococci, *S. aureus* and *B. cereus* were found in more than one position in chilled rooms within several plants. Multiple samples of enterococci were found in 3 chilled rooms, *S. aureus* in 6 chilled rooms and *B. cereus* in 12 chilled rooms. Plants where high TVCs were found did not necessarily have high levels of specific bacteria.

Table 2. Mean numbers (all sampling sites) of bacteria found at each plant. Minimum and maximum values are shown in brackets.

Plant	Coliforms	Enterococci	*S. aureus*	*B. cereus*	*Listeria* spp
			Mean $\log_{10}$ cfu.cm^{-2}		
1	-	-	0.1 (0-1.1)	0.1 (0-1.0)	-
2	-	-	-	-	-
3	0.1 (0-1.1)	-	0.1 (0-1.1)	0.1 (0-1.0)	-
4	-	-	0.1 (0-1.3)	0.4 (0-1.6)	-
5	-	-	-	0.2 (0-2.7)	-
6	-	-	-	-	-
7	-	-	0.1 (0-1.3)	0.3 (0-1.6)	-
8	-	-	-	-	-
9	-	-	-	-	-
10	-	-	-	-	-
11	-	-	0.1 (0-0.7)	-	-
12	-	0.1 (0-1.0)	0.2 (0-1.7)	0.5 (0-1.4)	-
13	-	-	0.1 (0-0.7)	-	-
14	-	-	-	0.2 (0-1.5)	-
15	-	0.5 (0-2.4)	0.3 (0-1.7)	0.1 (0-0.7)	-

- = less than 0.69 $\log_{10}$ cfu.cm^{-2}

Overall mean levels of enterococci, *S. aureus* and *B. cereus* were found to be similar on the evaporator, drip tray and wall, indicating that contamination did not occur in any one area alone (Table 3). Contamination was not directly related to whether products were wrapped or unwrapped, with similar levels being found in all cases except in the case of wrapped products where enterococci were never found (Table 4). Specific bacteria were never found in chilled rooms storing dairy products, cooked poultry, uncooked bakery and cooked bakery products. Enterococci were only found in chilled rooms storing raw meat and miscellaneous/mixed products and *B. cereus* was only found in chilled rooms where raw and cooked meat, vegetables or miscellaneous/mixed products were stored. *S. aureus* was found

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in the widest range of chilled rooms where raw red meat (most often), cooked meat, vegetables, raw poultry, dry ingredients or miscellaneous/mixed products were stored (Table 5).

Table 3. Mean numbers (all sampling sites) of bacteria found at each monitoring position. Minimum and maximum values are shown in brackets.

Position	Enterococci	*S. aureus*	*B. cereus*
	Mean $\log_{10}$ cfu.cm^{-2}		
Evaporator	0.1 (0-2.4)	0.1 (0-1.7)	0.1 (0-2.7)
Drip tray	0.1 (0-1.3)	0.1 (0-1.3)	0.1 (0-1.4)
Wall	0.1 (0-2.0)	0.1 (0-1.7)	0.1 (0-1.0)

Table 4. Mean numbers (all sampling sites) of bacteria associated with product wrapping. Minimum and maximum values are shown in brackets.

Wrapping	Enterococci	*S. aureus*	*B. cereus*
	Mean $\log_{10}$ cfu.cm^{-2}		
Wrapped	-	0.1 (0-1.7)	0.2 (0-1.6)
Unwrapped	0.1 (0-1.7)	0.1 (0-1.3)	0.1 (0-1.0)
Mixed	0.1 (0-2.4)	0.1 (0-1.7)	0.2 (0-2.7)

Table 5. Mean numbers (all sampling sites) of bacteria associated with different products. Minimum and maximum values are shown in brackets.

Food type	Enterococci	*S. aureus*	*B. cereus*
	Mean $\log_{10}$ cfu.cm^{-2}		
Raw meat	0.2 (0-2.4)	0.2 (0-1.7)	0.1 (0-1.0)
Cooked meat	-	0.1 (0-1.3)	0.2 (0-1.6)
Dairy	-	-	-
Vegetables	-	0.1 (0-1.1)	0.9
Raw poultry	-	0.1 (0-0.7)	-
Cooked poultry	-	-	-
Dry ingredients	-	0.7	-
Uncooked bakery	-	-	-
Cooked bakery	-	-	-
Other/misc.	0.1 (0-1.0)	0.1 (0-1.1)	0.2 (0-2.7)

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1.3 Effect of temperature, relative humidity and air velocity.

Overall there were low correlations between any of the measured mean temperatures, air velocities or relative humidities around the evaporator and total viable counts.

1.4 Cleaning procedures.

Few plants had scheduled cleaning routines for evaporators although all cleaned chilled room walls and surfaces regularly (at least once a week). Where evaporators were occasionally cleaned the routines tended to be irregular and usually occurred when evaporators required attention for maintenance work.

Evaluation of bacteria on experimental evaporator.

Data from 9 trials were evaluated using analysis of variance (ANOVA) to determine whether coil temperature, relative humidity, type of defrost and time influenced the bacterial population. For all bacteria examined (*E. coli*, *E. faecium, B. cereus* and *L. innocua*) the temperature of the coil and type of defrost was never significant (P>0.05). Relative humidity and time significantly affected the reduction in numbers of *E. coli*, *E. faecium* and *L. innocua* (P=0.0001). Reductions in *B. cereus* were solely influenced by time (P=0.001).

ANOVA demonstrated that the contamination of the exposure plates was not influenced by relative humidity or coil temperature. In all trials *E. coli* was never found on the exposure plates, whereas small numbers of the other three bacteria were common (Figure 6).

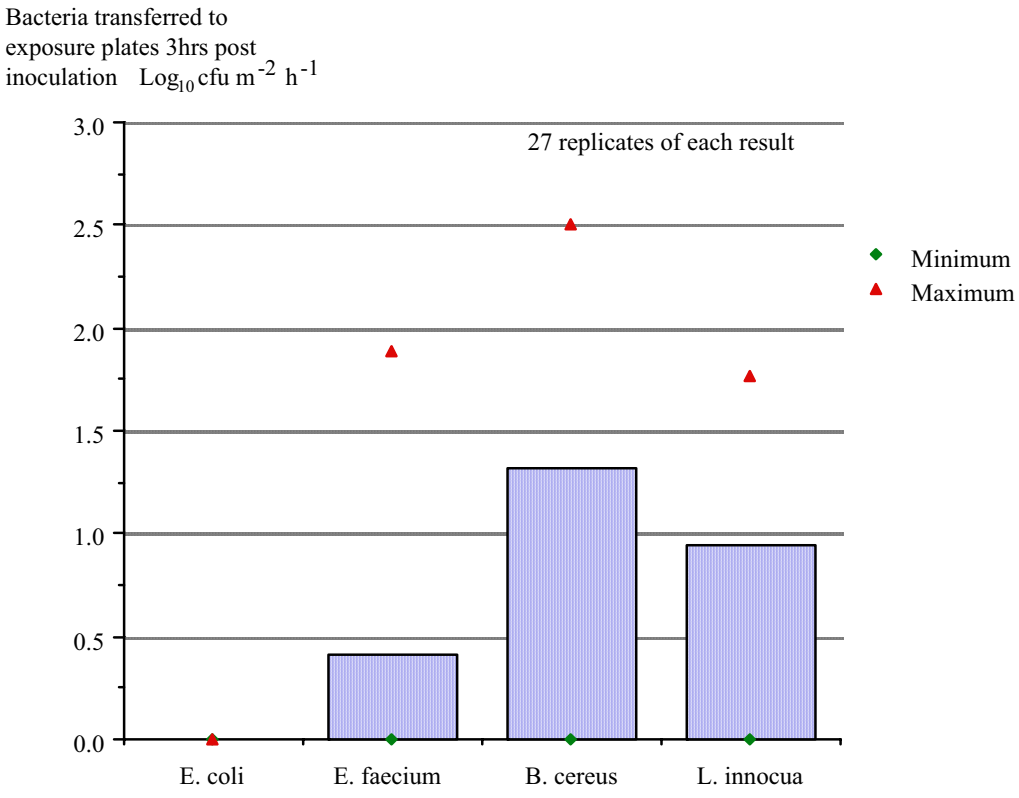

Figure 6. Mean, minimum and maximum numbers of bacteria transferred to air during the initial 3 h of trial.

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Discussion

The initial investigation within fifteen food plants found microbial contamination on the cooling coils in all the plants visited. Levels of contamination (total viable counts) were found to vary between chilled rooms within each plant and also between sampling positions on the cooling coils. In total 25% of the 891 sites investigated had contamination above the maximum measured value of 5 $\log_{10}$ cfu.cm^{-2} and 8% of all sites contained less than 5 cfu.cm^{-2}. This difference in the level of contamination was related to how the food was packed and its type. Temperature, air velocity and relative humidity did not influence levels of bacteria. Further investigations at each plant to determine levels of specific bacteria (coliforms, enterococci, *S. aureus*, *B. cereus* and *Listeria* spp) found that high levels of total viable microbes on the cooling coils did not necessarily yield high levels of specific bacteria. Few of the plants visited had a scheduled cleaning procedure for cooling coils and a great deal of dirt had been allowed to build up on many of the evaporators.

Although high numbers of microbes were found it was not clear how the cooling coils became contaminated and whether contamination from the coil could be passed to foods stored in the chilled rooms. An investigation sponsored by the UK Ministry of Agriculture Fisheries and Food (Anon, 1995) evaluated contamination of cooked meat products at three stages in the production process. The investigation found low levels of contamination with *L. monocytogenes* and *S. aureus* but no *Salmonella* or *Campylobacter* spp on the food samples tested. This correlates well with the low levels of *L. monocytogenes* and *S. aureus* found on the evaporator cooling coils in our investigation. However, very few of the microbes detected on the coils were identified and further work would be needed to determine the predominant types present on the coils. It is possible that these were spoilage bacteria but potential pathogens such as *Aeromonas* or *Yersinia* spp. could colonise this environment as they commonly grow at low temperatures.

The trials carried out with an artificially inoculated cooling coil demonstrated that the temperature of the coil fins (within the range evaluated; -6.7 to 9°C) had little effect on bacterial survival. Defrosting the coil, either by means of electric coils or off-cycle was also found to have little influence on bacteria. The major influence on bacterial survival was found to be time and to a lesser extent relative humidity.

Results from the experimental trials indicated that contamination via the air was a potential means of spread of bacteria. Levels of bacteria found on exposure plates 3 h after inoculation indicated that *E. faecium, B. cereus* and *L. innocua* were all spread by the air from the inoculated cooling coil. On the cooling coil itself *B. cereus* was found to have the highest survival rate (probably because of spores present in the inoculum) followed by *E. faecium* and *L. innocua*. *E. coli* was the least hardy with reductions in excess of 4 $\log_{10}$ cfu.cm^{-2} occurring within 24 hours.

The investigation demonstrated that all the evaporator cooling coils examined in food storage chill rooms were contaminated with bacteria. In the majority of cases these bacteria were likely to be spoilage bacteria but in 10 out of the 15 factories visited, low levels of specific bacteria (coliforms, enterococci, *S. aureus*, or *B. cereus*) were found. The levels of bacteria found within the chill rooms examined indicated that bacteria could collect on evaporators and survive and possibly grow when conditions were favourable.

The major difference between the cooling coil in the experimental study and those examined in food factories was cleanliness; the coil used for the laboratory tests was scrupulously cleaned before each trial, whereas cooling coils examined in food factories were often visibly dirty. Very few factories were found to have regular cleaning and maintenance programme for cooling coils and therefore a great deal of dirt and grime was allowed to

build up. The available literature (Braun, 1986) indicates that evaporators should be cleaned regularly to prevent build up of contamination. It is clear from the laboratory study that clean coils will not support bacterial growth and that only survival of the most resistant bacteria is possible. It would appear that the major factor influencing contamination of cooling coils within the food industry is a lack of regular and thorough cleaning.

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References

Anon. (1995). Study of food processors. Ready to eat meat and meat products. MAFF Food Safely Information Bulletin, 15, 14-15.

Al-Dagal, M., Mo, O., Fung, D. Y. C. and Kastner, C. (1992). A case study of the influence of microbial quality of air on product shelf life in a meat processing plant. Dairy, Food Environ Sanit., 12, 69-70.

Braun, R. H. (1986). Problem and solution to plugging of a finned-tube cooling coil in an air handler. ASHRAE Transactions part 1B, vol. 92, 385-387.

Characklis, W. G. (1983). A rational approach to problems of fouling deposition. p1-31 in R. W. Bryers (ed.), Fouling of Heat Exchange Surfaces, United Engineering Trustees, New York.

Characklis, W. G., Nimmons, M. J. and Picologlou, B. F. (1981). Influence of fouling biofilms on heat transfer. Heat Transfer Eng. 3, 23-37.

Harris, E. F. and Lee, C. A. (1991). Biofilm formation on heat pump equipment, abst. Q-199, p309. Abstr, 91st Annual Meet. Am. Soc. Microbiol. American Society for Microbiology, Washington DC.

Hugenholtz, P. and Feurst, J. A. (1992). Heterotrophic bacteria in an air-handling system. Appl. Environ. Microbiol, 58, 3914-3920.

Krafthefer, B. C. and Bonne, U. (1986). Energy use implications of methods to maintain heat exchanger coil cleanliness. ASHRAE Transactions part 1B, vol. 92, 420-431.

Morey, P. R., Hodgson, M. J., Sorensen, W. G., Kullman, G. J., Rhodes, W. W. and Visvervara, G. S. (1986). Environmental studies in mouldy office buildings. ASHRAE Transactions part 1B, vol. 92, 399-419.

Nortjé, G. L., Nel, E., Jordan, E., Naudé, R. T., Holzafel, W. H. and Grimbeek, R. J. (1989). A microbiological survey of fresh meat in the supermarket Trade. Part 1: Carcasses and contact surfaces. Meat Science 25 81-97.

Nortjé, G. L., Nel, L., Jordan, E., Badenhorst, K., Goedhart, G., Holzapfel, W. H. and Grimbeek, R. J. (1990). A quantitative survey of a meat production chain to determine the microbial profile of the final product. J. Food Protect. 53, 411-417.

Patterson, J. T. (1969). Meat Hygiene : II. Hygiene during slaughter and subsequent treatment of the carcass. Vet. Rec. 85, 536-541.