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LIFE CYCLE ANALYSIS OF THE ENVIRONMENTAL IMPACT OF DIFFERENT CABINET DESIGNS

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ABSTRACT
The design of refrigerated display cabinets greatly affects their subsequent environmental impact. To control this impact, a designer must primarily consider the operating efficiency of a cabinet. However, less account is taken of the materials used to make the cabinet, nor the construction techniques used. These both have a significant effect on the environmental impact of different cabinets outside the use phase of their life cycle. Initial construction impact, remanufacturability and recyclability are all affected. Given the ubiquity of the display cabinet in the retail sector, it is important to assess their lifetime impact in toto. This is particularly so with the increasing implementation of the WEEE directive in member states. Three typical refrigerated display cabinets are examined in this paper, all offering the same function, but manufactured with quite different constructions and materials. The mass of materials in each cabinet was determined experimentally and the methods of assembly examined. The stages in the life of each cabinet were then modelled and life cycle analyses performed. To compare the efficiency of the cabinets in terms of their environmental impact, the Eco Indicator Points/litre of refrigerated space/day were determined in each case. When combined with the energy performance (kWh/litre/day) this provides a good measure of the overall environmental impact of a cabinet and a way of choosing between different models that nominally provide the same refrigeration function. Different end of life scenarios, and improvements in the choice of materials, were also investigated depending on the type of construction.

INTRODUCTION
Refrigerated display cabinets are used worldwide to sell chilled food and beverages in supermarkets and smaller stores. The subject of this study is the open-fronted vertical display cabinet which offers the advantage of unimpeded selection and access to the products by a customer. This free access is also associated with the high energy use of this type of cabinet, compared with those cabinets fitted with doors or other thermal barriers. It is debatable whether these open-fronted cabinets would be introduced now in the current climate of high energy prices and concerns for global warming. However, given their continuing use, it is useful to look at ways of reducing their environmental impact. The particular type of cabinet examined in this paper is the integral cabinet, i.e. the refrigeration system and defrost water disposal are all provided within the cabinet itself, in contrast to the more usual remote systems of large supermarkets, serviced by central chilling plant. Integral cabinets have the advantage of simplifying changes in a store's layout, reducing the potential for a large loss of refrigerant inventory, and often providing a better balance between heating and cooling in a store. However, they usually operate with lower efficiency than their larger, remotely serviced counterparts.

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There is still a paucity of studies of the life cycle of integral, commercial refrigerated display cabinets. Most literature is confined to Life Cycle Assessments (LCAs) of selected components, e.g. the refrigerant (Pappasavva, 1998), or the blowing agents used in insulation (Katz, 2003), or parts of the life cycle only, e.g. materials and recycling (Kondo, 2001). Moreover, work has been directed at refrigerated cabinets operating with remote chillers which have much larger inventories of refrigerant (Frischkneecht, 2000).

The LCA reported in this paper considers three designs of cabinet that nominally perform the same function – to provide chilled display volume for merchandizing. However, the designs of these cabinets are different and use materials in different ways. They are also constructed with different approaches. In the following sections, the designs will be compared in terms of their material impact, as well as putting this in context with their total environmental impact in use.

METHODOLOGY

To assess the life cycle of a refrigerated cabinet, the approach chosen was based on the derivation of a single index of environmental impact, using the Eco-indicator 99 method (Goedkoop et al, 2000). This method implicitly weights the damage to resources, ecosystems and human health. Impacts are calculated with reference to the average annual environmental impact of a European inhabitant and expressed as Eco-Indicator points. It is relative differences in this that are used to compare different designs. For each cabinet, an inventory of materials used is compiled to establish the use of resources, land and emissions produced. These are then assessed for their environmental impact on resources, ecosystems and human health, and finally weighted and combined into a single index of environmental impact.

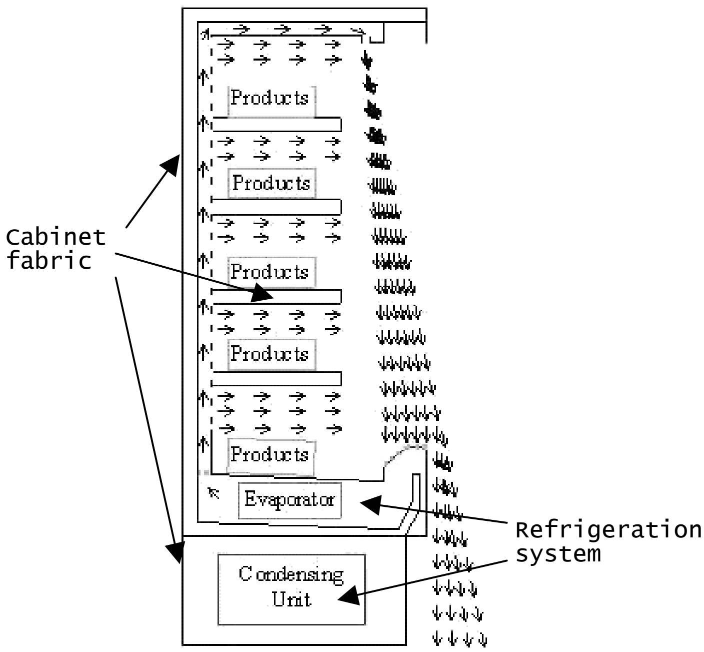

Figure 1. Cross section of typical refrigerated display cabinet

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FUNCTIONAL UNIT

Figure 1 shows a cross section of a typical refrigerated display cabinet. There are essentially two systems: the refrigeration system and the cabinet and shelves housing it. These were initially assessed separately.

Three cabinets (A, B & C) were assessed and form the three functional units of the analysis. The functional unit is defined here as:

An integral chilled display cabinet with shelves for use in food retail stores, operating for 24 hours a day for 8 years providing a chilled display volume of 500 litres and maintaining product temperatures between 1 and 8°C. The refrigeration is provided by an electrically powered compressor. The display volume is illuminated continuously and open at the front vertical face. Water from defrosting is evaporated within the cabinet’s volume & not drained externally.

The three cabinets are not exactly the same size. To be able to make more useful comparisons, the material data have been adjusted up or down by normalizing according to the useful product display volume provided by each cabinet. All mass data were thus normalized to the functional unit’s notional 500 litre product volume. The adjustment factors were: A (x 1.04), B (x 1.28) and C (x 0.78), corresponding to actual cabinet volumes of 480, 390 and 640 litres.

SYSTEM BOUNDARIES

The LCA takes into account the production of materials (e.g. steel from ore), the transportation of materials and the finished cabinets, the provision and use of energy, and disposal at end of life. It excludes the environmental impact of the capital goods used to make the cabinet, i.e. the factory, the lorries for transport, people, etc.

The emissions’ data are generally from average relevant conditions pertaining to Europe so that realistic, or generally applicable conclusions can be formed. An exception is the production of aluminium where its high embodied energy encourages a greater use of renewable energy, predominantly hydroelectricity. In this case the energy supply mix of the aluminium industry has been used.

INVENTORIES

The three cabinets were dismantled as far as possible without destroying them and their material content determined from detailed measurements. Additional material needed in manufacture, through wastage and cutting, has been ignored. Tables 1-3 gives the normalized masses for each functional unit (A, B & C): for the whole unit, for the cabinet, and for the refrigeration system respectively. Original (actual) masses may be obtained by dividing by the adjustment factors given above.

Some approximations have been made. The blowing agent for the foam insulation is not known but is most likely in Europe to be cyclopentane which has a very low global warming potential (GWP) and is not included in the inventory. Secondly, the refrigerant used in all three cabinets is R404A (52% R143a, 44% R125 and 4% R134a). Specific environmental impact data for this refrigerant blend were not available within the LCA software database. R134a alone was therefore used as a substitute by choosing an amount that had the same global warming potential as the blend over a 100 year time horizon. GWP is the most important environmental impact parameter for the refrigerant mixture.

The impact of refrigerant choice on energy use, and therefore environmental impact, is allowed for.

Table 1. Materials in the full functional units (normalized values)

Material, kg	A	B	C
Stainless Steel	73.3	175.0	44.5
Steel	49.7	63.6	74.7
Chipboard	76.4	0.0	0.0
Copper	13.8	20.5	10.8
Aluminium	6.4	7.6	6.1
Glass	18.8	0.3	25.0
Plastics	3.1	12.7	3.7
Foam	2.4	3.6	3.6
Total	**243.7**	**283.3**	**168.4**

Table 2. Materials in cabinet fabric only (normalized values)

Material, kg	A	B	C
Stainless Steel	70.7	164.0	41.9
Steel	25.5	35.4	58.2
Chipboard	76.3	0.0	0.0
Copper	0.2	1.1	0.3
Aluminium	0.0	0.0	0.0
Glass	18.8	0.3	25.0
Plastics	2.4	11.8	2.8
Foam	2.4	3.6	3.6
Total	**196.3**	**216.3**	**131.8**

Table 3. Materials in refrigeration system only (normalized values)

Material, kg	A	B	C
S. Steel	2.6	11.2	2.5
Steel	24.3	28.2	16.3
Chipboard	0.0	0.0	0.0
Copper	13.5	19.5	10.8
Aluminium	6.3	7.6	6.1
Glass	0.0	0.0	0.0
Plastics	0.6	0.8	0.9
Foam	0.0	0.0	0.0
Total	**47.3**	**67.3**	**36.6**
R134a (equivalent)	1.9	3.1	1.7

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MODEL ASSUMPTIONS
In the life cycle of the cabinet, the materials are assumed to be first transported 1000km to the factory (by a 28 tonne lorry) and then onwards to a customer 1000km and finally 500km to landfill after 8 years. The energy used during the use-phase of each cabinet is taken here as a typical consumption for this type of cabinet. The thrust of this paper is the impact of material choices on the environmental impact rather than on differences in refrigeration efficiency. Energy use is therefore included only to put the material impact in context with the total impact; over 8 years 100,000 kWh is assumed to be used (34 kWh/day). To compute the environmental impact of this energy use an average European fuel mix has been used (34% nuclear, 26% coal, 17% gas, 16% renewables and 7% oil).

RESULTS
Figure 2 shows the environmental impacts associated with the different stages in the life of a cabinet. Cabinet-B is shown here to illustrate how the dominant cause of environmental impact is the consumption of electricity during the use-phase of the cabinet. Construction contributes 3% of the impact, and in general between 2-5% of the total lifetime environmental impact, depending on the daily energy use; the latter can vary by a factor of two between different cabinets of the same size. Transport and landfill are not, relative to the whole lifecycle, significant sources of impact.

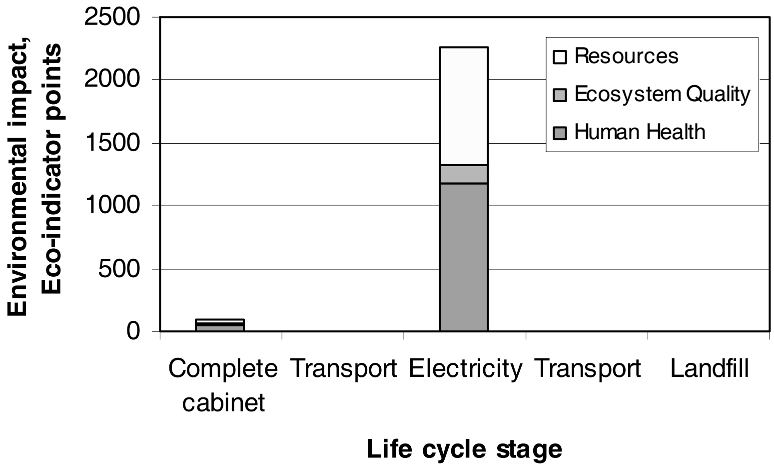

Figure 2. Environmental impact by life cycle component (Cabinet-B)

Figure 3 focuses on the environmental impacts of the materials alone. 90% of the impact of the cabinet materials results from three factors: the release of respiratory inorganics; the use of fossil fuel in winning, processing and manufacturing the raw materials. The total material impact is 80, 101 and 64 Eco-indicator points respectively for cabinets A, B & C. Cabinet B has almost a 60% higher impact than Cabinet-C.

Figure 4 shows the main contributions (83%) to the environmental impact of the materials in Cabinet-B, as a percentage of the total impact of the materials. Smaller contributions are not shown. It can be seen that 63% of the impact is caused by two materials: copper and nickel. It is difficult to substitute for copper because its combines such useful properties and is recyclable. Nickel appears mainly in the stainless steel and in this case it is possible to avoid the majority of nickel by using a different grade of stainless steel. Switching from the common austenitic 304 grade to the ferritic 430 (almost nickel free) would reduce the material environmental

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impact considerably. This grade of stainless steel is already used by some manufacturers of refrigerator panels and sinks. For Cabinet-B, if the environmental impact is recalculated substituting 430 grade for 304, the total material environmental impact reduces by 24% from 101 Eco-indicator points to 76.

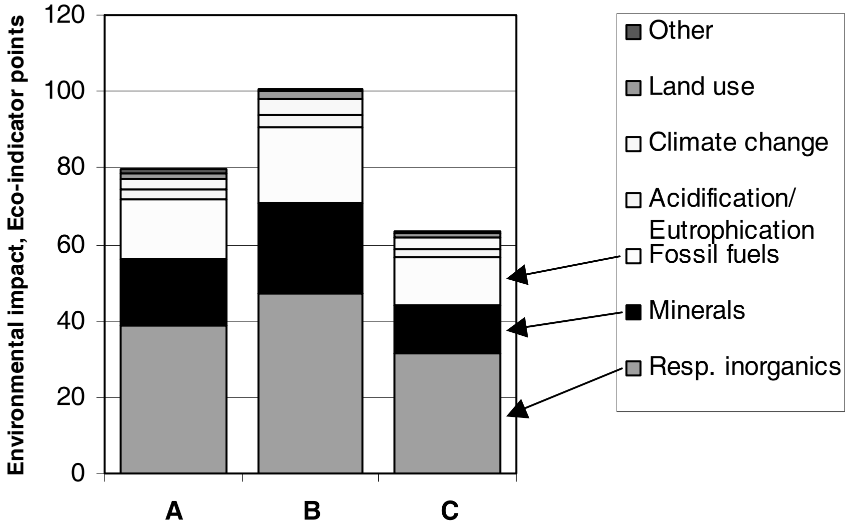

Figure 3. Environmental impact of cabinets' materials

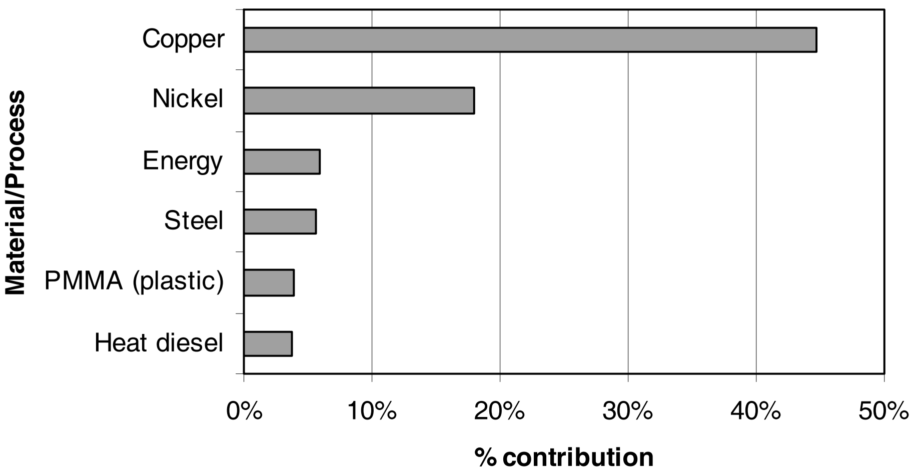

Figure 4. Main sources of the materials' environmental impact (Cabinet-B)

CABINET CONSTRUCTION

The three cabinets are constructed with quite different approaches and this has a bearing on whether recycling or remanufacturing is encouraged or discouraged. The following briefly describes and compares the construction of the three cabinets.

Cabinet-A uses chipboard to provide the main strength and weight needed to support and provide stability to the structure. For the side-walls this is sandwiched and tightly bonded to thin sheets of stainless steel. The rear wall is chipboard alone with expanded polystyrene on the inside facing the perforated stainless steel false wall. Cabinet-B uses heavier gauge (50%

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thicker) stainless steel sheets to form hollow walls enclosing sheets of Styrofoam. The rear wall is similar. These panels are joined with rivets. Cabinet-C uses double glazing for the side walls, held in place with stainless steel angle screwed to a steel frame, and a foam-filled galvanized steel sandwich for the rear wall.

Shelves, and panels inside the cabinets and facing the products are invariably stainless steel. The top construction is usually similar to the rear wall, but with possible downgrading of this unseen area, e.g. chromium plated steel for stainless steel.

The compressor chambers have stainless steel grilles at the front, but most of the items within, and the rear grille are mild steel, painted or enamelled. An exception is the defrost water tray which is always stainless steel, and the compressor heat exchanger: aluminium fins sweated on to copper pipes and housed within a riveted or spot-welded steel box, galvanized or painted. Fans blades may be plastic or aluminium bolted to a motor bolted to a steel bracket and a main base plate.

The evaporator chambers have heat exchangers similar to those in the compressor chambers, but without a surrounding steel box. They have aluminium or galvanized steel end-plates that are screwed to location plates fixed to the side walls, or the rear false wall. The tray of Cabinet-A has a deep plastic coated steel tray screwed to a lower layer of steel. Cabinet-B has an all stainless steel upper tray resting on a galvanized lower wall. Cabinet-C has a two part construction with a plastic tray lapping and riveted to a galvanized upper part which wraps round to form the lower wall. The space between the top tray and lower wall is filled with insulation. The fans have aluminium blades bolted to a motor riveted or bolted to fan plates.

At the end of the life of a cabinet, it may be discarded completely (landfilled), or sent for recycling, or remanufactured. Legislation may not preclude direct dumping in some regions of the world and designs that encourage repair, recycling and remanufacturing are to be encouraged. In a scenario where a cabinet is remanufactured at the end of its first life (approximately 8 years), the preferred construction is such as will allow the easy separation of its components. Welding is the least preferred method of fixing, followed by riveting, screwing and keyhole drop-in fixing. For recycling, designs that reduce the number of materials used, avoid plastic because of the difficulty of separating different types, and keep electrical components together and accessible (for WEEE recovery), are preferable.

ENERGY AND ENVIRONMENTAL IMPACT

Finally, the environmental impact of the materials used to make a cabinet may be compared with the energy it uses. There is a materials' environmental impact associated with providing the useful storage volume for products in the cabinet. This index is given as Eco-indicator points/litre/day. There is similarly an energy needed to refrigerate this volume and this is given as kWh/litre/day. The two are compared for the three cabinets in Figure 5. Here the actual volumes of each cabinet are used. In practice there is a difference in the energy use for each cabinet, but for this study the energy has been fixed at 100,000kWh in eight years. The graph essentially illustrates the comparison of the significant use- and non-use phases of the lifecycle of a refrigerated cabinet. It can be seen that Cabinet-B has the highest per litre consumption of energy and highest materials' impact per litre. This reflects the design of the cabinet: it is heavily constructed of stainless steel, and has a shallow depth and therefore a small useful product volume. In the overall index it is therefore "penalized" for using greater resources with environmental impact (stainless steel) but also for providing only a slim volume for actual storage of refrigerated products.

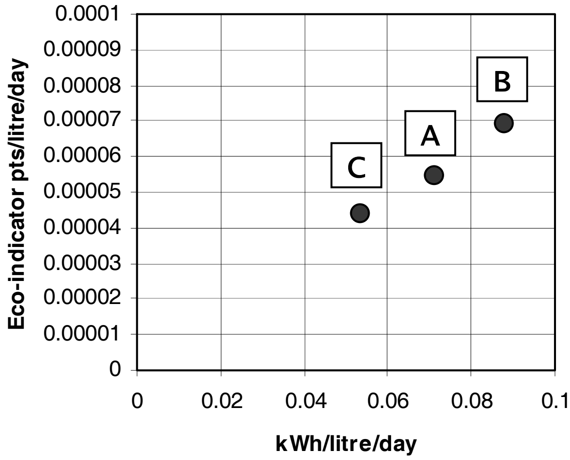

Figure 5. Environmental impact and energy use compared for three cabinets

CONCLUSIONS

Three refrigerated cabinets have been assessed for the environmental impact they make during their lifetime. Between 2-5% of impact can be attributed to the material content and the majority of the rest to the electricity used during the use-phase. Reducing the energy used in refrigeration is therefore a priority for making cabinets more environmentally benign. However, the impact of the material use is globally significant, and coupled with the increasing need, and, in many countries, legislative pressure to recover and recycle materials, worthy of considering changes to cabinet design. Cabinets of around 500l volume weigh approximately 0.25 tonne in order to make them stable when fully laden. Very slim cabinets need to be even heavier to retain stability. In the case of Cabinet-B (a slim design) the amount of stainless steel used is four times the amount used in Cabinet-C even though the latter provides 65% more volume for products. The use of mild steel for areas not in contact with food, or facing the customer, is to be recommended (Cabinets-A and C), together with the option of changing from a nickel containing stainless steel (304) to a nickel-free one (430) – reducing environmental impact by 25%. It is possible to compare the environmental impact from materials with the energy used on the basis of the litres refrigerated space provided. This may be useful for comparing different cabinets.

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