Assessment of methods to reduce the energy consumption of food cold stores

Abbreviated title: energy use in cold stores

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Abstract

Energy is a major cost in the operation of food cold stores. Work has shown that considerable energy savings can be achieved in cold stores. Results from 38 cold store audits carried out across Europe are presented.

Substantial savings could be achieved if operation of cold storage facilities were optimised in terms of heat loads on the rooms and the operation of the refrigeration system. Many improvements identified were low in cost (improved door protection, defrost optimisation, control settings and

repairs). In large stores (> 100 m^3) most improvements identified were cost effective and had short pay back times, whereas in small stores there were fewer energy saving options that had realistic payback times. The potential for large energy savings of at minimum 8% and at maximum 72% were identified by optimising usage of stores, repairing current equipment and by retrofitting of energy efficient equipment. Often these improvements had short payback times of less than 1 year.

In each facility the options to reduce energy consumption varied. This indicated that to fully identify the maximum energy savings, recommendations need to be specific to a particular plant. General recommendations cannot fully exploit the energy savings available and therefore to maximise energy savings it is essential to monitor and analyse data from each facility.

Keywords: Refrigeration, Food, Cold store, Energy efficiency.

Nomenclature

$\dot{m}$ = Mass flow of refrigerant ($kg.s^{-1}$)

A = area of wall (m^2)

A_d = Area of cold store door (m^2)

$F_m = (2/(1+(\rho_r/\rho_i)^{0.333}))^{1.5}$

g = Acceleration due to gravity (9.81 $m.s^{-2}$)

H = Height of cold store door (m)

h_a = Enthalpy of ambient air ($kJ.kg^{-1}$)

h_i = Enthalpy at entry to evaporator ($kJ.\ kg^{-1}$)

h_o = Enthalpy at exit to evaporator ($kJ.\ kg^{-1}$)

h_r = Enthalpy of refrigerated air ($kJ.kg^{-1}$)

htc = Heat transfer coefficient ($W.m^{-2}.K^{-1}$)

htc_i = Heat transfer coefficient on inside of room ($W.m^{-2}.K^{-1}$)

htc_o = Heat transfer coefficient on outside of room ($W.m^{-2}.K^{-1}$)

k = Thermal conductivity of wall material ($W\cdot m^{-1}.K^{-1}$)

q = Heat load (W)

T = Temperature of room (°C)

U = Overall heat transfer coefficient ($W.m^{-2}.K$)

V = Air velocity ($m.s^{-1}$)

x = Thickness of wall (m)

ΔT = Air temperature difference either side of the wall (K)

ρ_i = Density of ambient air (kg.m^{-3})

ρ_r = Density of refrigerated air (kg.m^{-3}) calculated from $\rho = p / R T$ (where p = pressure in Pa (assumed to be 100,000), T = temperature in K and R = universal gas constant (287))

1 Introduction

The cold chain is believed to be responsible for approximately 2.5% of global greenhouse gas emissions through direct and indirect (energy consumption) effects [1]. Cold storage rooms consume considerable amounts of energy. Within cold storage facilities 60-70% of the electrical energy can be used for refrigeration. Therefore cold store users have considerable incentive to reduce energy consumption.

It is estimated that there are just under 1.5 million cold stores in Europe ranging from small stores with volumes of 10-20 m^3 to large distribution warehouses of hundreds of thousands of m^3. The majority of cold stores (67%) are small stores of less than 400 m^3 [2].

In 2002 the IIR estimated that cold stores used between 30 and 50 kWh/m^3/year [3]. Previous detailed energy audits carried out by Evans and Gigiel [4][5] on a small number of cold stores have shown that energy consumption can dramatically exceed this figure, often by at least double. These audits also demonstrated that energy savings of 30-40% were achievable by optimising usage of the stores, repairing current equipment and by retrofitting of energy efficient equipment. Although there are few published surveys comparing the performance of more than a few cold stores, the limited information available corroborates the wide range in efficiency generally found in cold stores in the audits. The most comprehensive recent survey was carried out in New Zealand by Werner et al (2006) which compared performance of 34 cold stores. This demonstrated that there was a large variation in energy consumed by cold stores and that savings of between 15 and 26% could be achieved by applying best practice technologies.

Although there are several surveys that benchmark the performance of cold stores there is little comprehensive information on the issues surrounding energy savings initiatives in cold stores. Several authors have examined methods to save energy in cold stores. However, these authors have tended to concentrate on a small number of technologies such as air flow, variable speed drives and heat conduction transfer [6], control parameters [7], condenser design [8], design of cold store docks [9] or free cooling systems [10].

The work carried out by Evans and Gigiel [4][5] on a limited number of cold stores demonstrated that the issues surrounding energy savings varied considerably between the cold stores examined. This meant that to effectively save energy that cold store operators needed tailored bespoke information specifically related to their cold store. As the information available to cold store operators is often generic in nature this may restrict the amount of energy that could be saved by operators.

The audits carried out by Evans and Gigiel only covered 6 cold store groups and so to determine whether specific energy saving information related to a cold store could help operators save energy a greater number of audits were required. As part of a European research project (ICE-E, Improving Cold store Equipment in Europe) the performance of 38 cold stores were examined to determine how much energy could be saved, areas of common problems and the initiatives that could be implemented that would save energy.

2 Materials and methods

Thirty-eight detailed energy audits were carried out. Audit sites were selected to provide a range of cold stores in terms of temperature setting, volume, products stored, refrigerants and location. A list of stores audited and their attributes is presented in Table 1. When analysed stores were divided into small stores (those of 100 m^3 and less) and larger stores (those with a volume greater than 100 m^3).

2.1 Audit procedure

2.1.1 Data collection

Data were obtained from a variety of sources depending on the cold store being audited. In some cases the cold store had their own on site data loggers that recorded sufficient information (temperatures in the cold rooms, energy consumed by each cold store and door openings) for the analysis. In other situations data loggers were attached by the auditors to the refrigeration system to measure refrigerant and air temperatures, pressures and energy consumption. In all cases temperatures were measured to an accuracy of ±0.5°C, pressures to ±2% of reading and power to ±2% of reading.

In all situations data was recorded for a minimum of one week and in some cases for several months. In the case of stores where heat loads were variable (for example in produce stores where there was a high heat load post the initial loading after harvest and a lower heat load once field heat has been removed) the audits were carried out twice to cover the high and low heat loads. Data logged from the refrigeration system were recorded at intervals of between 30 seconds and 2 minutes.

Manual readings were taken to back up the above readings and pressure readings were taken from the gauges fitted to the plant. Where necessary, calibrated pressure gauges were substituted for each plant gauge to ensure accuracy. The electrical energy consumption of the plants was recorded using data loggers or taken from daily meter readings and spot measurements were made of the power consumption of the fixed loads (evaporator and condenser fans, electric defrosts, lights, pumps and any auxiliary power sources such as fan extraction for battery charging).

Meteorological data for the ambient conditions were obtained from the nearest weather recording station to the site or were recorded using data loggers.

2.1.2 Heat loads

Heat loads were calculated using either a steady state or dynamic heat load model previously developed by the authors and available from http://www.khlim-inet.be/drupalice/models [11]. The models did not predict latent heat load due to food freezing. In such cases (only cold store 1) a heat transfer model similar to that developed by Evans et al [12] was used.

2.1.2.1 Heat load across walls

The heat load on each room through the cold store fabric was calculated using the following equation:

$$= U.A.\Delta T \qquad \text{(Equation 1)}$$

U was calculated from:

$$\frac{1}{U} = \frac{1}{htc_i} + \frac{1}{htc_o} + \frac{x}{k} \quad \text{(Equation 2)}$$

The air temperature difference between either side of the wall was calculated from internal chamber temperature obtained from logged data and dry bulb temperature obtained from logged or meteorological data. The temperature of the air on the outside of the cold store walls and in the roof space was recorded using data loggers or the cold store logging system. The material in each wall/ceiling/floor was obtained from store design information and manual inspection. Thermal conductivities of the wall materials were taken from ASHRAE data tables [13]. Surface heat transfer coefficients were estimated from measured velocities using the following equation for vertical plane surfaces (where velocity is less than 5 m.s^{-1}) [13]:

$$htc = 5.62 + 3.9V \quad \text{(Equation 3)}$$

Most of the larger stores were regularly thermo graphically scanned and there was no indication from these scans that there was any major deterioration in the insulation of any of the stores. However, it should be noted that the calculations may have overestimated the effectiveness of the cold store panels if there had been any undetermined breakdown of the insulation.

2.1.2.2 Infiltration

Data on cold store door openings and usage obtained from the store data loggers, or from magnetic break sensors placed on the cold store doors were used to calculate the heat load on the room during door openings. If storage rooms were fitted with strip curtains the integrity of the protection was assessed be measuring the open area when the cold store door was opened and the strip curtains were stationary and when the strip curtains were parted to allow entry to people or forklifts. The heat load under each circumstance was calculated using the model developed by Gosney and Olama [15] and substituting the open area for the area of the door.

The model developed by Gosney and Olama [14] has been shown by Foster et al [15] to provide the most accurate prediction of infiltration through the cold room door in their study. The Gosney and Olama model (Equation 4) assumes that the air temperature within the cold room remains stable during door openings (this is a reasonable assumption in a large room that is not left open for extended periods).

$$q = 0.221 \cdot A_d \left(h_a - h_r\right) \rho_r \left(1 - \frac{\rho_i}{\rho_r}\right)^{0.5} \left(g \cdot H\right)^{0.5} F_m \qquad \text{(Equation 4)}$$

In all calculations the RH in the cold store was measured or assumed to be 90% (at low temperatures, the enthalpy of the water content of the cold store air does not vary much and therefore the RH value used was not critical).

2.1.2.3 Heat load from food

Although ideally food should not be frozen (change of phase) or chilled (reduced in temperature) in a cold store, occasionally food was cooled or frozen after entry into the chambers. Data provided by the cold store operator (quantity of food, size and packing of food pallets, entry temperature and food type) or from direct measurement of these parameters was used to calculate heat load on each store. Where relevant (in the case of store 1 where some product was frozen) latent load was included in the calculation. If product respired the respiration heat load was included in the heat loads calculated.

2.1.2.4 Fixed heat loads

The heat loads added to the room from pedestrian access and forklifts were derived from the door opening data and food entry data or from observation. Heat loads from forklifts were obtained from fork lift manufacturers' data. The heat load due to pedestrians was calculated from the following equation from ASHRAE [16]:

$$q = 273 - 6 \cdot \mathrm{T} \qquad \text{(Equation 5)}$$

The fixed heat loads on the rooms from lights, defrost heaters and evaporator fans were measured.

2.1.3 Heat extracted by evaporators

Refrigerant liquid temperature (measured prior to the evaporator expansion valve), saturated temperature (measured at the first evaporator pipe turn) and suction temperature (measured at the exit to the evaporator) were measured using data loggers by strapping a temperature sensor to the outside of the evaporator pipe and then insulating the sensor. In some cases saturated evaporating pressure was measured as an alternative to measurement of saturated evaporating temperature. Enthalpy into and out of the evaporator was then calculated using the thermophysical properties of the refrigerant obtained from data tables (NIST or CoolPack) [17] [18]. Temperatures measured as described before were also measured at the suction and discharge of the compressor(s) and together with measurement of pressure and power, the mass flow of the refrigerant was calculated from compressor manufacturers' data. To obtain accurate information on the performance of compressors detailed monitoring of compressor performance was required. This was achieved either by visual observation (in combination with monitoring or recording of plant controls) or by monitoring a component that was an indicator of changes in operation (e.g. temperature of unloading solenoids that reflected when cylinders in reciprocating compressors unloaded). Using equation 6 the heat extracted by the evaporator(s) was calculated.

$$q = \dot{m}(h_o - h_i) \quad \text{Equation 6}$$

The calculated heat extracted by the evaporators was compared to the cold store calculated heat load (transmission, infiltration, food, fixed) to check that the 2 calculations generated similar results. If anomalies were found the calculations were checked and reasons for any non-alignment identified.

2.1.4 Efficiency of refrigeration plant

The COSP (Coefficient Of System Performance) of the refrigeration system was calculated from the total calculated heat load (from transmission, infiltration, food, fixed) divided by the total energy used by the refrigeration system (including compressors, condenser and evaporator fans, defrosts and any refrigeration ancillaries). The efficiency of each cold store was compared and options to improve efficiency identified and the savings in energy calculated.

The methodology for identifying and calculating energy savings varied according to the cold store. However, in all cases evaporating and condensing temperature levels were investigated to determine whether condensing pressure could be reduced and evaporating pressure increased. Levels of evaporator superheat and condenser sub cooling were also assessed to determine whether they impacted on operational efficiency. The major heat loads were investigated to determine whether they could be reduced. Inefficiencies in the operation of equipment and design of the refrigeration plant and cold store were also investigated if relevant.

3 Results

3.1 Areas where energy savings were identified

Issues identified in the audits were classified under 21 general headings. An overview of the issues and examples of typical issues within each category are presented in Table 2.

In large stores (> 100 m^3) between 2 and 12 issues were identified in each store with an overall mean of 5 issues identified per store. In the smaller stores (< 100 m^3) between 1 and 4 issues were identified (mean of 3). A list of the issues and the regularity (as a percentage of the total number of issues) that they were found are shown in Figure 1. No one issue dominated, but issues associated with control of the refrigeration plant (compressor control, condensing pressure, defrosts and evaporator fans) accounted for 33% of the issues identified.

3.2 Energy savings identified

The potential energy savings were calculated for each issue identified. The savings are presented in Figure 2 and were calculated based on the potential energy savings as a percentage total energy consumed by the cold store (total energy for refrigeration plant, condenser and evaporator fans, defrost heaters, lights and any ancillaries directly related to the cold store itself). The savings were based on either measured data or data obtained on the operation of the installed components from manufacturers' data. The opportunity to rectify any differences from the original installed performance was investigated. This was particularly relevant to compressors where efficiency had sometimes become compromised by changes to the plant or lack of maintenance. Savings obtainable by fitting components such as new fans, lights and defrost systems was obtained by comparing the performance of the existing components with more efficient components. Data on the performance of the new components was obtained from manufacturers of the components and from published information on installed performance of the components. Savings obtained from reducing infiltration, product load or transmission were obtained by comparing the measured current situation with a calculated improved situation.

Potential energy savings were found in all stores audited but the level of total savings varied between 8-72% of the annual energy consumption for large stores (> 100 m^3) and between 8 and 28% for small stores (< 100 m^3). Overall service, maintenance and monitoring had the greatest potential to save energy. However, there was a large range in the energy savings potential of between 6 and 34%. Although the greatest potential savings were from maintenance and monitoring there were a limited number of maintenance and monitoring issues identified with maintenance and monitoring being only 3% of the issues identified (Figure 1).

Further analysis of the data collected showed that there was very little difference in the savings available in chilled stores and frozen stores (Figure 3). Percentage energy savings from small stores (<100 m^3) were quite similar to those achievable in large stores, however, there were more opportunities for large savings in the larger stores (> 100 m^3) (Figure 4). Greater savings were found in dairy, mixed and vegetable stores (Figure 5) but the variability in the potential savings was too high to clearly show that certain store types had greater potential to save energy.

3.3 Cost effectiveness of initiatives to save energy.

The payback time for each of the energy saving initiatives were calculated. The calculation involved a straight comparison of direct cost and time to repay the cost of applying each initiative through energy savings. The energy costs used was 0.11 €/kWh. No account was taken of any future increase in energy costs or of the impact that any of the initiatives would have on improved product quality, reduced maintenance costs or improved logistics.

The average payback time for each initiative is shown in Figure 6 together with the range in payback times calculated. When examining average paybacks it is clear that in small stores (< 100 m^3) all initiatives apart from adjusting control of evaporator fans (which had paybacks of approximately 1 year) had average paybacks of greater than 20 years with minimum paybacks of at least 9 years. Therefore many of these interventions would be very unlikely to be economic. The interventions applied to larger stores (> 100 m^3) were more likely to be economic with only improvements associated with the building, system design and investment in new equipment having average paybacks of greater than 4 years. In all except 3 of the cold stores audited there was at least one intervention that had a payback of 2 years of less.

Overall 54% of issues identified had paybacks of less than 1 year, 64% had paybacks of less than 2 years, 71% had paybacks of less than 3 years and 83% had paybacks of less than 5 years. Depending on the company structure, paybacks of up to 10 years were acceptable to the companies that were audited. If 10 years was an acceptable payback time only 11% of the initiatives would be unacceptable financially.

3.4 Energy saving potential for cold stores.

Using the information generated from the audits the issues identified were ranked in terms of expertise required to identify and solve each issue. It was found that 24% of issues could be identified and quantified by a reasonably astute cold store manager who could use engineering knowledge and freely available modelling tools to identify the level of savings that could be achieved. A further level of savings could only be achieved with the input of a refrigeration engineer as these involved handling refrigerant or modifications to the refrigeration system. Above this there was a level where expert/specialist help was required (Figure 7).

4 Discussion

The audits were carried out in 6 different European countries. There was not sufficient number of replicates from each country to fully analyse whether there were fundamental differences between countries. Previous audits which had been carried out in the UK [4][5] had shown that savings of 30-40% were achievable and this result was borne out by the results from this work where savings of between 8 and 72% were found. Over all 38 stores the average energy saving was 28% which confirms that considerable energy savings are possible. In small stores of less than 100 m^3 energy savings of up to 28% were found (average 21%) but most of these savings had long payback periods that were longer than would be acceptable to most companies. Therefore the audit results indicated that it is essential to ensure that a new small store is energy efficient when purchased. With a large store (> 100 m^3) there were a greater number of interventions that could be applied economically throughout the life of the store and therefore there were benefits in regular inspection and auditing to identify energy savings.

As was found by Evans and Gigiel [4][5] each cold store exhibited particular energy issues and paybacks could be very variable. As would be expected, paybacks on large capital items such as new equipment, replacing insulation and major system design changes were often uneconomic. However, the payback levels was very cold store specific and in some instances purchase of major equipment such as new LED lighting or major changes to the refrigeration plant were extremely economic. Overall it was clear that few cold stores regularly checked the operation of their plant and that there were considerable energy savings from relatively simple checks to ensure that the refrigeration pant was operating efficiently. Also in several cases the cold store was being operated at too low a temperature and there was potential to very cheaply and simply raise the operating temperature. In addition many issues were due to long term gradual decline in the operation of systems or due to damage to equipment that was not repaired. Often these issues could be easily identified (e.g. damaged door strip curtains, damaged doors, ice build up on evaporators, damage to evaporator fans) and had extremely economic paybacks. Such items could simply be identified by cold store operators and could be part of a weekly or monthly check on the operation of the cold store.

Within the stores examined there would appear to be considerable potential to make larger energy saving interventions. Twenty-one percent of stores were still operating on R22 as the refrigerant. In a recent survey of 137 food companies in Europe it was found that 31% of respondents still had R22 on site [19]. This was similar to that reported in a Carbon Trust survey in 2006 [20]. R22 is currently being phased out and recycled refrigerant will no longer be able to be used after 2015. Therefore many of the stores are likely to be either replaced or upgraded in the next few years. This is an opportunity to install more efficient equipment and to optimise the performance of the refrigeration plant. Three of the stores had already been retrofitted with an R22 replacement (R422D) but considerable issues were found with the optimisation of the refrigeration plant. These issues included setting of superheats, condenser sub cooling and general efficiency of the refrigeration system. Therefore some of the opportunities available during retrofitting of a new refrigerant are possibly being lost.

Although the issues identified in each cold store were considered under generic headings there was often a relationship between different issues. For example poor door control which resulted in high infiltration loads would also have an impact on defrosting of evaporator and would add an additional load to the refrigeration plant. In the analysis of each store the integration of these factors were assessed together to determine the overall energy savings. Therefore it is not always possible to totally apply one energy saving option without also applying another. The interrelationship between issues is therefore important and when making changes to improve one issue the impact that this has on other factors also needs to be taken into account.

5 Conclusions

The audits carried out demonstrated that savings were achievable in all the stores examined. The level of savings varied considerably with no one issue dominating. The potential energy savings varied widely with issues related to the way in which the refrigeration system was controlled and operated having the lowest paybacks. Payback periods tended to be higher in small stores and this emphasised the need to ensure the efficiency of small stores when purchased as limited improvements were economic during the life of the cold store. Twenty-four percent of the savings could be identified by a reasonably able cold store manager and a further 43% by their refrigeration engineer. This highlighted the need for regular checks of the operation of the refrigeration system to check set points, superheat, sub cooling and controls. Some of this could be automated and many of the issues identified in the audits could be simply highlighted to cold store managers through automated monitoring systems.

By far the majority of the savings identified had paybacks of less than 3 years. However, the payback period for each issue identified varied considerably and could range from being a very economic option to not being economically feasible. Therefore it was not possible to unequivocally state that certain technologies were economically attractive as a greater level of understanding of each refrigeration systems operation and use was required to fully quantify the energy savings that could be achieved.

The overall result of this study demonstrates that generic advice is of limited use to cold store operators. Each cold store must be assessed individually to fully optimise performance and to maximise energy savings.

6 Acknowledgements

The authors would like to thank EACI (Executive Agency for Competitiveness and Innovation) for funding this work and in particular the project officer, Christophe Coudun for his help in managing the project.

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Tables and figures

Tables:

Table 1. Cold stores audited.

Table 2. Energy savings categories and issues.

Figures:

Figure 1. Issues identified in the audits.

Figure 2. Energy saving potential for each issue identified in the audits (bars: minimum and maximum % savings).

Figure 3. Potential savings related to store temperature.

Figure 4. Potential savings related to store volume.

Figure 5. Potential savings related to product type stored.

Figure 6. Payback time for each issue identified in the audits.

Figure 7. Level of expertise required to identify and quantify issues identified in the audits.

Table(s)

Store no.	Country	Volume (m^3)	Product	Refrigerant	Calculated heat load (kW)	Set point temperature (°C)
1	Belgium	180,000	Chips	R717	950	-22
2	Bulgaria	9,512	Ice cream	R717	150	-21
3	Bulgaria	2,983	Mixed	R404A	35	-20
4	Bulgaria	1,741	Mixed	R404A	15	2
5	Bulgaria	1,200	Mixed	R404A	30	8
6	Denmark	125,000	Mixed	R717	250	-20
7	Denmark	500	Vegetable	R717/secondary	43	4
8	Denmark	800	Smoked meat	R22/R134a	10.9	4
9	Denmark	98,500	Meat	R717	140	-21
10	Denmark	2,400	Meat	R717	55	-21
11	Italy	94	Salami	R404A	3	3
12	Italy	92	Salami	R404A	3	3
13	Italy	34	Salami	R404A	1.5	3
14	Italy	14	Salami	R404A	0.5	3
15	Italy	19	Salami	R404A	1	3
16	Italy	46	Salami	R404A	1.5	3
17	Italy	1,000	Mixed	R717	10	3
18	Italy	14,000	Mixed	R717	130	-22
19	Italy	57	Pasta	R404A	3	1.5
20	Italy	34,940	Dairy	R22	281	2
21	Italy	14,000	Vegetable	R717	85	3
22	Switzerland	227	Mixed	R744	18	-23
23	UK	6,442	Potato	R22	55/25	3
24	UK	7,068	Potato/celeriac	R507	30	3
25	UK	3,588	Potato	R22	115/45	3
26	UK	7,176	Potato	R422D	105/40	3
27	UK	5,544	Potato	R422D	45/20	3
28	UK	20,160	Potato	R422D	215/80	3
29	UK	36,036	Dairy (mixed)	R404A	179	2
30	UK	12,512	Dairy (mixed)	R404A	105	2
31	UK	43,758	Dairy (mixed)	R404A	270	2
32	UK	12,399	Mixed	R22	101	-23

33	UK	7,347	Mixed	R22	64	-23
34	UK	19,659	Mixed	R22	118	-23
35	UK	12,399	Mixed	R717	115	-22 (2 stores) / 3 (3 stores)
36	UK	7,347	Mixed	R717	171	-22
37	UK	13,925	Mixed	R717	85	-19
38	UK	21,783	Mixed	R717	268	-18

n.b. Stores where 2 heat loads are reported refer to a pull down heat load associated with initial temperature reduction after harvest and a stable heat load once ‘field heat’ had been removed.

Table(s)

Issue	**No. of times seen**	**Typical problem**	**Reason**	**Options to improve**
Battery charging	2	Charging of forklift batteries in the cold store. When charging batteries the charging area should be ventilated and this draws warm air into the store.	Damage to charging areas doors.	Repair doors.
Control of compressors	15	Inefficient use of compressors	Using screw compressors at part load, poor sequencing of compressors, lack of system optimisation requiring more compressor to operate than necessary.	In case of a mix of screws and reciprocating compressors recommended to do the part load operation on the reciprocating compressors. Optimisation of system
Control of condenser fans	2	Condenser fans operated at fixed or too high pressure.	Need for gas defrosting. Lack of system optimisation. Poor condenser design.	Float high pressure in periods when defrosts not required.

Control of evaporator fans	13	Fan used when not necessary.	Poor system optimisation. Poor air flow around cold room.	Pulse fans. Switch of unnecessary fans. Control fan according to room temperature Ensure air flow in cold room is efficient.
Defrost control	14	Over defrosting evaporators to ensure no build up of ice.	Poor system optimisation.	Reduce defrost duration, regular checking of evaporator performance. Defrost on demand. Do not defrost evaporators unless necessary. Reduce infiltration into cold room. Passive (off-cycle) defrost in chilled stores.
EC fans	3	Use of shaded pole motor fans	EC motors are more efficient than shaded pole motors and can be driven at variable	Consider when changing fan motors.

			speeds	
Expansion device	4	Poor refrigerant control and super-heats	The size and function of the expansion valve in DX systems has an enormous impact on the performance of the evaporator and the evaporating temperature.	Optimisation of system Regular checking of refrigeration system operation.
Infiltration/ door protection	13	High infiltration load	Infiltration of warm and moist air through doors	Repair door seals. Ensure door protection is in good condition and effective. Consider automated door controls and if necessary dehumidified air locks.
Insulation	13	Poor insulation integrity or insulation too thin.	Using chilled store as freezer. Damage to insulation. Insulation breakdown.	Repair insulation.
Lighting	10	High heat load from lights.	Excessive lighting, poor choice of lights.	Replace with LED lights (possibly sensor controlled).
New equipment	9	Equipment (apart from items separately listed)	Damage to equipment Inefficient equipment initially installed to save cost.	Replace pumps, heat exchangers etc.

		old or poorly performing. Equipment old or poorly performing.		Investigate more efficient systems /refrigerants.
Other controls	8	Other control issues and problems not separately listed.	Poor understanding of system operation.	Optimisation of system.
Other refrigeration system issues	8	Other refrigeration system issues and problems not separately listed.	Poor understanding of system operation.	Optimisation of system.
Product temperature	4	Product brought into store at above store temperature.	Poor cold chain, product left on loading bay.	Reduce time on loading bay. Ensure product delivered at correct temperature.
Reduce condensing pressure	14	Excessive condensing pressure.	Poor monitoring and control (a rule of thumb 1°C too high condensing temperature equals 2-3% extra power consumption).	Optimisation of system. Use of evaporative condenser.
Restoring of control settings	6	Control settings adjusted inefficiently.	Set points are allowed to “slip” and are changed due to some event but never changed back.	Regularly check settings.
Room temp settings	8	Cold store temperature too	Poor monitoring and control (as a rule of thumb 1°C too low	Rest room controls.

		cold or too warm.	cold store air temperature equals 2-3% extra power).	
Service/maintenance/monitoring	5	General operation of refrigeration plant, insulation of pipes, service of components	Lack of investment, knowledge of operator, poor servicing and maintenance.	Daily monitoring of the running condition of the refrigeration system.
Sub cooling	3	Lack of sub cooling at entry to evaporator in DX systems.	This is especially a problem for DX systems: loosing the sub cooling of the liquid refrigerant supplied to the expansion valves can cause too little liquid supply.	System optimisation.
Superheat control	4	Excessive evaporator superheat.	Too high superheat out of the evaporator on DX systems indicates poor expansion valve control, loss of refrigerant or lack of sub cooling (as a rule of thumb 1°C too low evaporation temperature equals 2-3% extra power consumption).	System maintenance/ optimisation
System design	12	Badly designed system	Cost savings, poor specification or design.	Retrofitting of improved components, change to system configuration.

Figure(s)

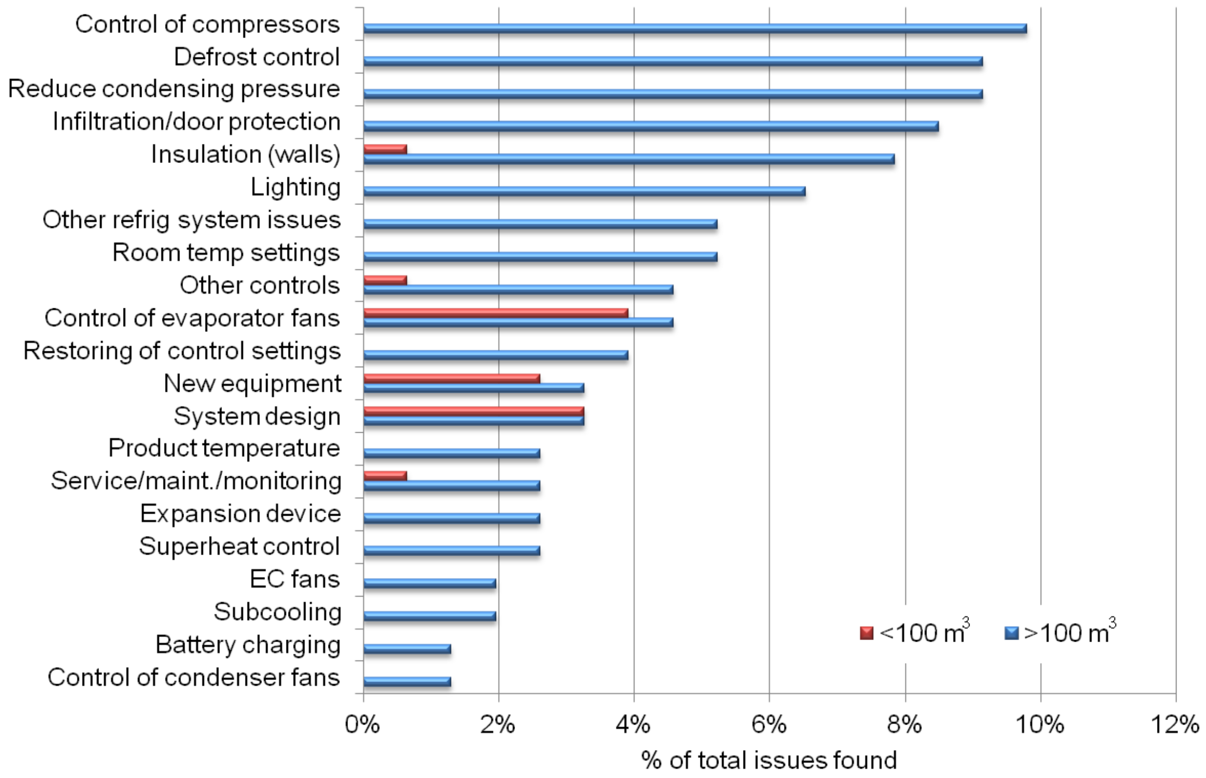

Figure 1. Issues identified in the audits.

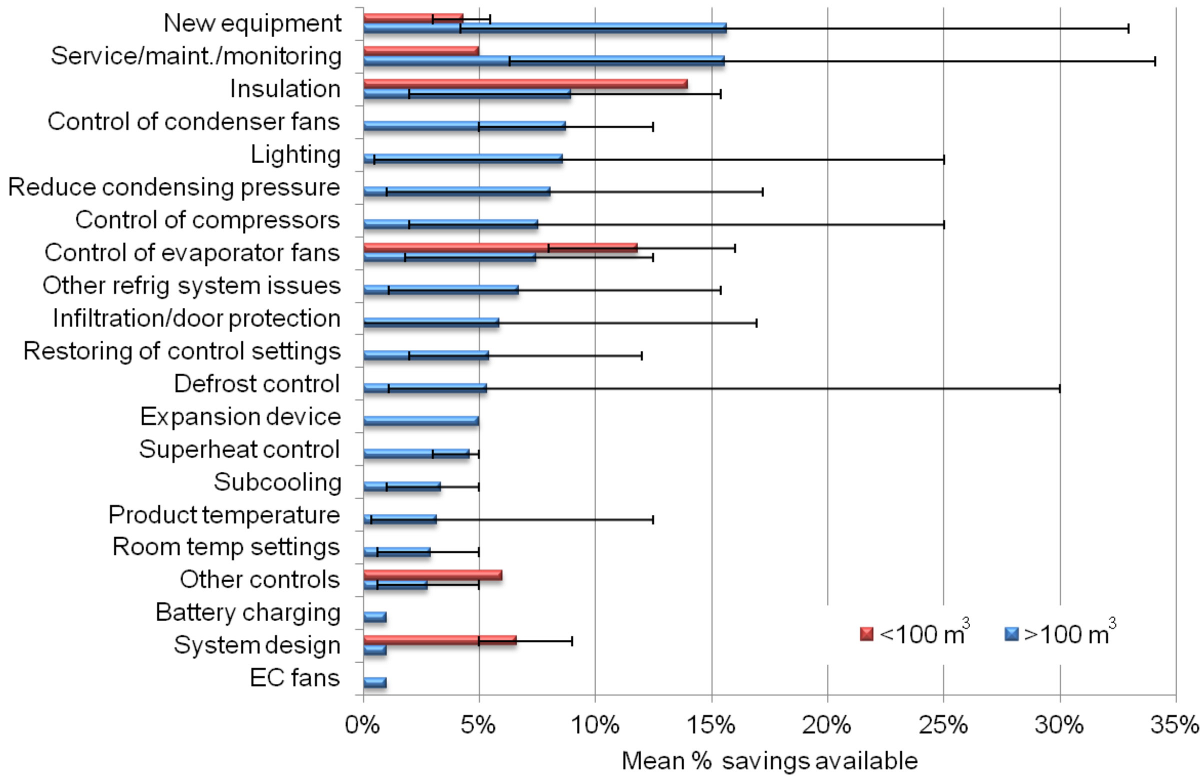

Figure 2. Energy saving potential for each issue identified in the audits (bars: minimum and maximum % savings).

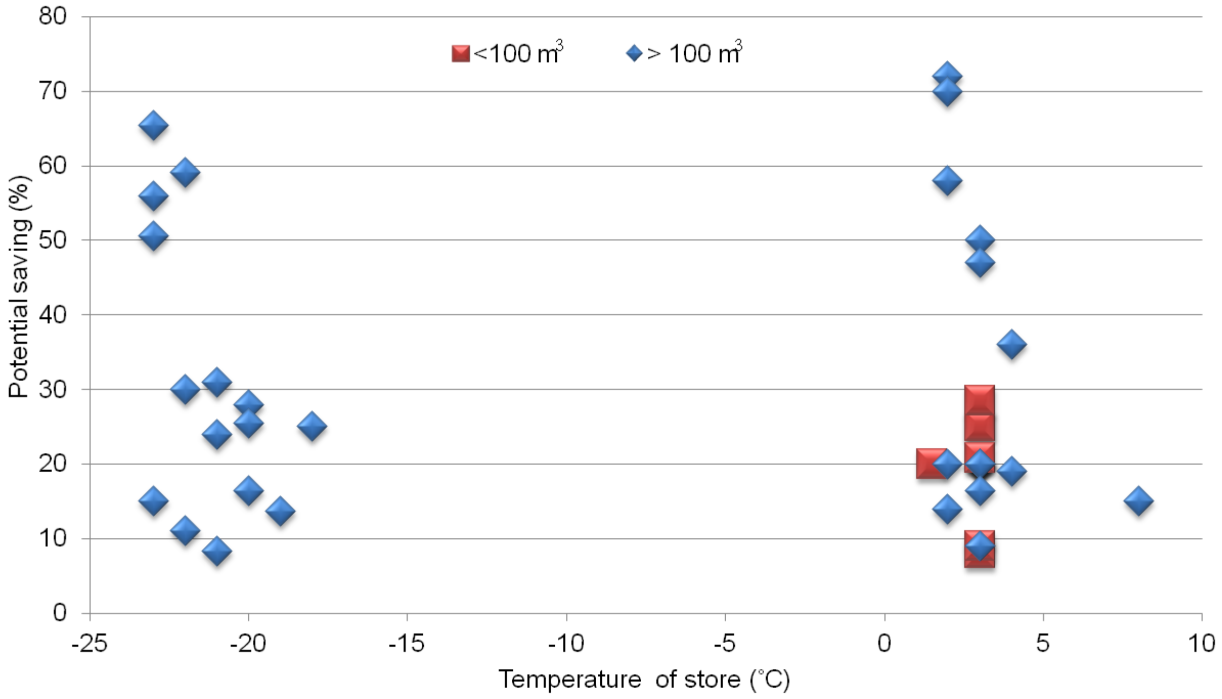

Figure 3. Potential savings related to store temperature.

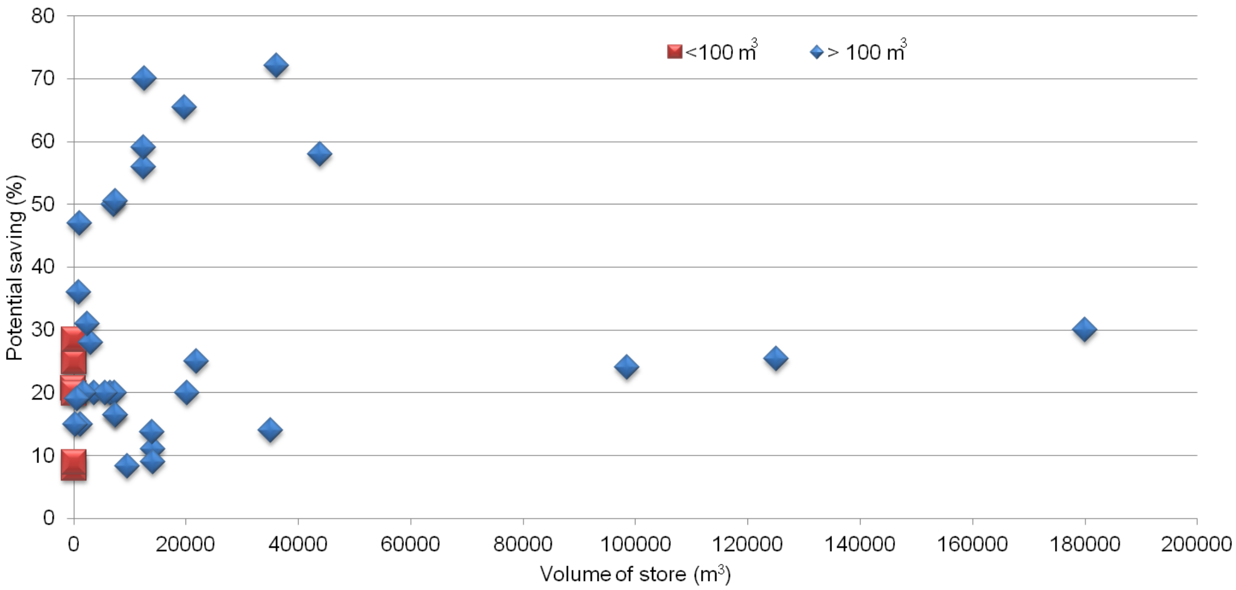

Figure 4. Potential savings related to store volume.

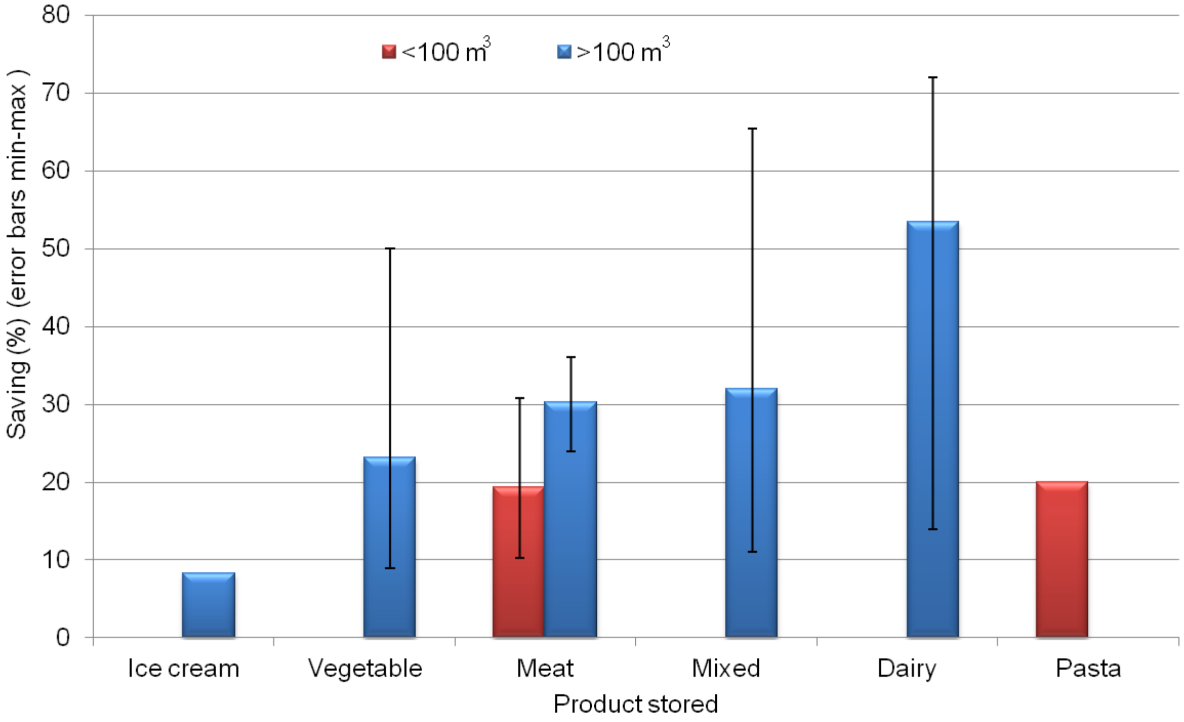

Figure 5. Potential savings related to product type stored.

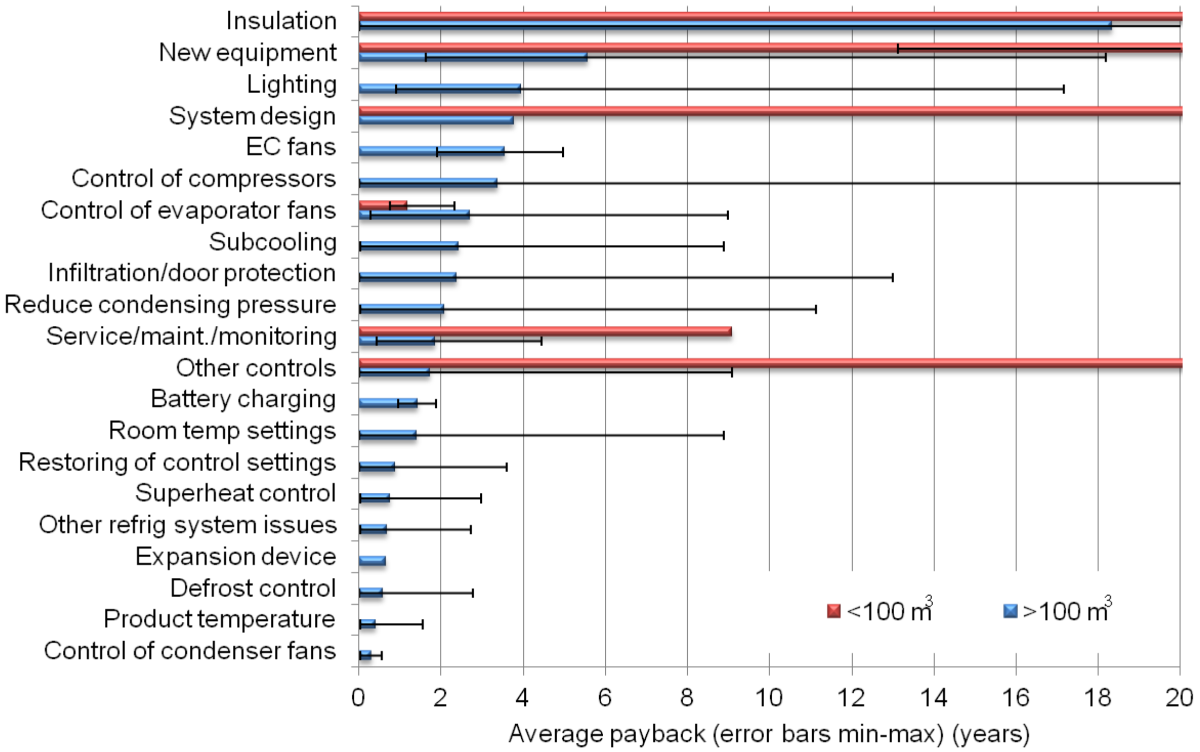

Figure 6. Payback time for each issue identified in the audits.

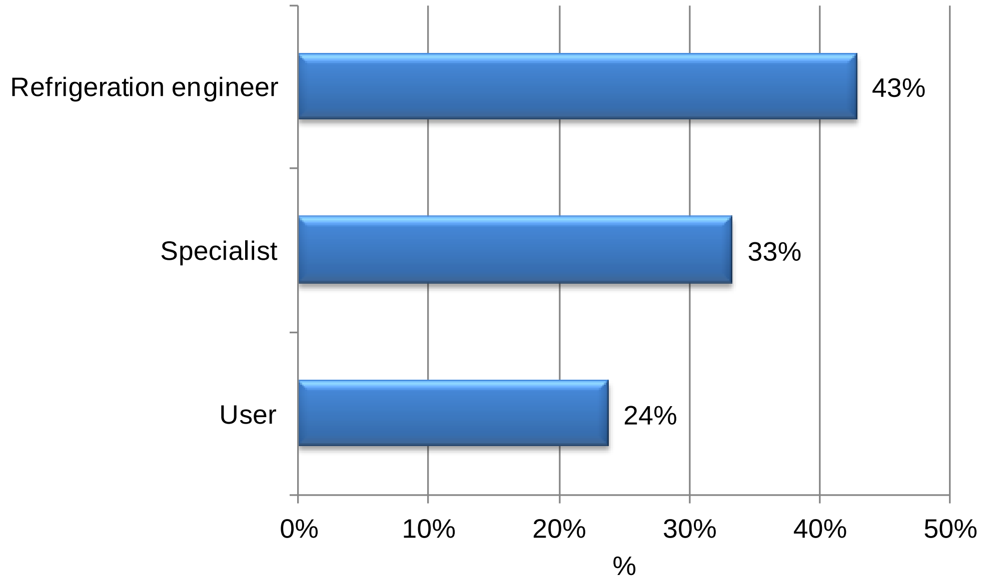

Figure 7. Level of expertise required to identify and quantify issues identified in the audits.