# Identification of changes needed in supermarket design for energy demand reduction

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**Abstract:**
Supermarkets use 3% of UK energy. To satisfy building regulations supermarket buildings are modeled in considerable detail. Lighting, occupancy, and small electrical energy impacts are included in this modeling. However, refrigeration energy is not, as it is classified as "process energy" rather than "building related". Refrigeration energy, which can be very significant, is therefore currently "unregulated" and as a result, heat transfers related to refrigeration cabinets are typically not incorporated in modeling of the building at design stage.

This paper explores the comparative energy demands of supermarket stores modeled, using a simple first-order dynamic model, executed on Excel, and "optimized" firstly with, and secondly without, the cooling effect of refrigeration cabinets included in the model. A recently built supermarket is modeled. Results suggest that the energy demand of a new store could be reduced by 15-25% by improvement of the building envelope design with process energy included in the modeling.

**Keywords:**
Building energy modeling, building regulations, refrigeration, supermarket energy

## 1. Introduction

In UK, supermarkets account for 3% of national electricity demand, and 1% of greenhouse gas emissions (Tassou et al, 2008). Any reduction in their consumption will therefore be significant in terms of overall energy use. A "supermarket" is a large multiproduct retail space with a primary focus on food. There are 91,500 supermarkets in UK, and 300 new stores are opened annually (BBC, 2010).

In common with all new commercial buildings in England and Wales, a new supermarket must be designed to comply with Approved Document L2A of the Building Regulations of England and Wales (HM Government UK, 2010). Similar rules apply in Scotland and Northern Ireland. Compliance requires that the building be modeled and improved in accordance with the National Calculation Methodology (NCM)(2010). This modeling must include heat inputs from lighting, occupancy and minor electrical equipment, as well as heating, cooling and air-conditioning from HVAC systems. "Process energy" specific to the building's function is not modeled.

The building is thus designed to balance heat gains from occupancy, lighting, appliances, and solar and radiant gains and losses via fabric and ventilation, and radiant losses by supplying heating and cooling, and achieve a temperature in the required range, eg 18-25$^0$C, as shown in Figure 1.

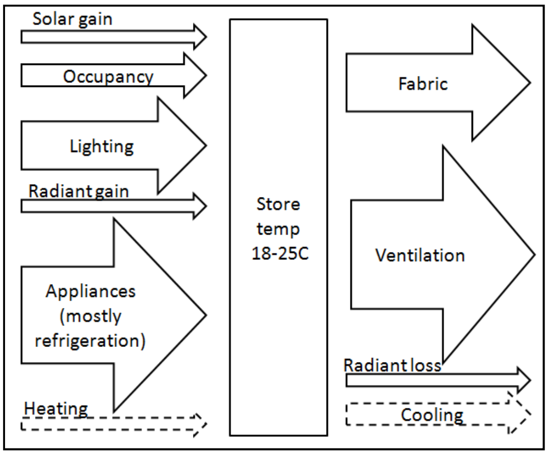


**Figure 1 Balance of heat gains and losses considered in conventional design of supermarkets**

In the case of supermarkets, in which refrigeration is regarded as "process energy", this means that heat transfers related to refrigerated display cabinets are not required to be included in the design calculations. Indeed, the software generally used for this purpose does not allow the inclusion of negative heat gains (losses), or for the modeling of in-store cabinets with infiltration related to door-opening.

Approved Document L2A further requires that the energy demands for heating and cooling must be reduced so that the design building (model) performs better than the notional, baseline, building (model) by a given percentage. This can be achieved by modification of these regulated components, and by use of renewables. Software tools used for building design provide methods for demonstrating compliance with Approved Document L2A as part of their overall capability, using the NCM for this purpose. Using these tools, with NCM inputs, designers therefore seek to improve the envelope of the building so as to decrease the energy demand.

Although the compliance element of a software tool is not intended as a design tool, designers consulted do use the NCM figures for energy related to electrical equipment in their calculations in the "equipment schedule". In recognition of the high energy load for refrigeration, designers seek a figure to include for this. The figure given by NCM for retail refrigeration is +25W/m$^2$ (NCM, 2010). This leads to the inclusion of refrigeration as a heat gain on the retail floor. If the refrigeration were like a domestic refrigerator, or a standalone cabinet in a small store, with its condenser on the back of the cabinet then this would be appropriate. However, most supermarket refrigeration is supplied from a central chiller plant with the refrigeration cabinets absorbing heat from inside the store and the central chiller condenser units dumping the heat outside the store.

In reality, as shown in Figure 2, a considerable amount of heat is lost to refrigeration (typically above 40% of the store heat balance), increasing the heating demand, and reducing the requirement for HVAC cooling very significantly.

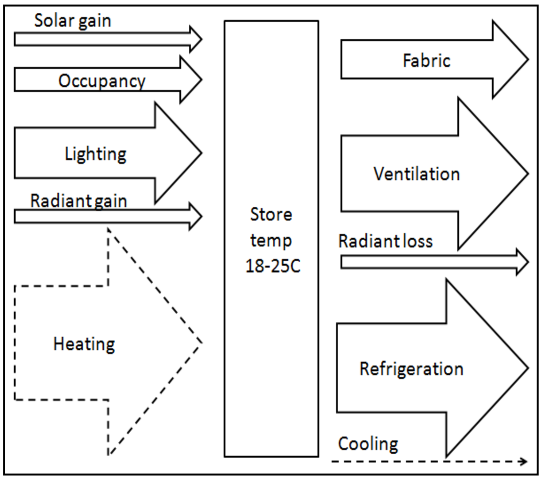


**Figure 2 Heat transfers in a supermarket including heat extracted via refrigeration cabinets**

This clearly leads to a very different picture for optimization.

This paper explores the impact of including thermal interactions between refrigeration cabinets and their surroundings in a model for energy demand optimization of the retail floor of a supermarket.

## 2. Simulation

2.1 Building envelope

The retail floor of a supermarket building, with refrigeration cabinets included, has been modeled both in Excel (Hill, 2011) and in EnergyPlus (Hill, 2012), and the results of simulations with refrigeration cabinets modeled as cold have been compared to the results of simulations with refrigeration energy entered as a heat gain. The models were based on the parameters of a newly built store in northern Manchester, optimized for compliance with Building Regulations, and simulations were run with hourly local weather data.

The retail floor was modeled as a lightweight box, with U values and ventilation rates variable as required, across the range shown in Table 1. The north facing wall was fully glazed, with an overhang for shading, and there was a clerestory window to the east. The south wall adjoined the storage, administration and technical section of the store, and was modeled as adiabatic. The retail floor was modeled with rooflights, to reflect the inclusion of rooflights on the Manchester store. The rooflight fraction was variable as required, across the range shown in Table 1. Surface emissivity and absorptivity characteristics appropriate for a polished aluminium roof, and polycarbonate sandwich rooflights were included. Thermal and light transmissivity values appropriate to the polycarbonate/nanogel sandwich were also applied (Hill, 2012).

Table 1 Design values and modeled values for ventilation rates, U values and rooflight fraction

| | | Design value for Manchester store | Range of values explored in modelling |
|---|---|---|---|
| Ventilation (infiltration) rate | | 0.36 ac/h | 0.10-0.5ac/h |
| U values | walls | 0.25 W/($m^2$K) | 0.05-0.5 W/($m^2$K) |
| | roof | 0.25 W/($m^2$K) | 0.05-0.5 W/($m^2$K) |
| | windows | 1.95 W/($m^2$K) | 1.95 W/($m^2$K) |
| | rooflights | 1.1 W/($m^2$K) | 1.1 W/($m^2$K) |
| Rooflight fraction | | 8% | 0% - 40% |

The store was designed for natural ventilation, entailing high level extraction of air. This was not included in the modeling, as its effect would be very dependent on the effect of stratification on the retention at the top of the store of radiant gains through the roof, and stratification is not automatically modeled in EnergyPlus, and could not readily be modeled in Excel. The models assumed a fully stirred body of air in the store, though they did not include fans to achieve this. The effect of stratification would be to increase the heating demand of the store, and therefore to increase the sensitivities explored below.

### 2.2 HVAC, lighting and occupancy

Heating and cooling setpoints were set at 18C and 25C. Dehumidification was applied to maintain the humidity ratio at or below 7.5g/kg (equivalent to 55% relative humidity at 19C), as is considered necessary to maintain the efficiency of refrigeration cabinets. The Manchester store opens “24 hours”, and the design documents showed a lighting requirement of 900lux by day, and 400lux by night, so this was applied to the models, in which no distinction was made between days of the week. A daily occupancy profile was based on figures included in the Manchester store’s design document, and the anthropogenic heat gains were included (both sensible and latent). This profile of occupancy was subsequently applied to the refrigeration module, as customer numbers would determine the frequency of opening of cabinet doors, and therefore the heat exchange by infiltration.

### 2.3 Refrigeration

Refrigeration was modeled both according to the NCM, as used by compliance to Building Regulations, and with cold heat exchange at the cabinets.

#### 2.3.1 Refrigeration set according to National Calculation Methodology

The NCM activity database specifies the input for “internal gains” from refrigeration in a food retail store as a heat gain of 25 W/$m^2$ for the refrigerated zone, as is appropriate for domestic fridges, where the extracted heat is dumped into the room. This was added to one variant of both models, to replicate the conventional modeling of a store.

2.3.2 Refrigeration cabinets with heat exchange

In order to explore the impact of thermal interactions between the refrigeration cabinets and the store on the heat demand of the store, a second variant was modeled with cold cabinets, with heat exchange through the fabric and by infiltration.

A mix of cabinets with and without doors, on both freezers and chillers was based on the Manchester store. Based on observation, the doors were modeled as being open for 3 seconds every minute when the store was at peak occupancy, and for reduced fractions of the time in proportion to the occupancy profile. U values were taken from design specifications or the EnergyPlus defaults, and internal temperatures were set at -20C for freezers, and 4C for chillers.

2.4 Comparison of simulation outputs to store data, and to design experience

The models only simulated the energy interactions on the retail floor of the store. The energy demands they calculated for the store were 43-55% of both the electrical and heat demand data available from the Manchester store for the whole building, including the “back area” with offices and storage areas (including chilled and frozen storage). This suggests that the modeling is broadly accurate, and useable for simulations.

Simulations run on the models with refrigeration modeled as a heat gain, on NCM figures, also give the result reported by design engineers, with an optimization saddle for ventilation and insulation at approximately 0.36ac/h and 0.25W/(m$^2$K), as seen on the Excel model in Figures 3 and 4. At ventilation rates below this saddle point, or higher levels of insulation (U values immediately below the saddle point), the simulation results indicate that the additional cooling need outweighs the reduction in heating load. These saddles occur at the same values as selected for optimization of the Manchester store (XXX?). This suggests that the models behave similarly to models used commercially. However, Figure 4 additionally suggests that further demand reduction appears possible at U values below 0.1W/(m$^2$K).

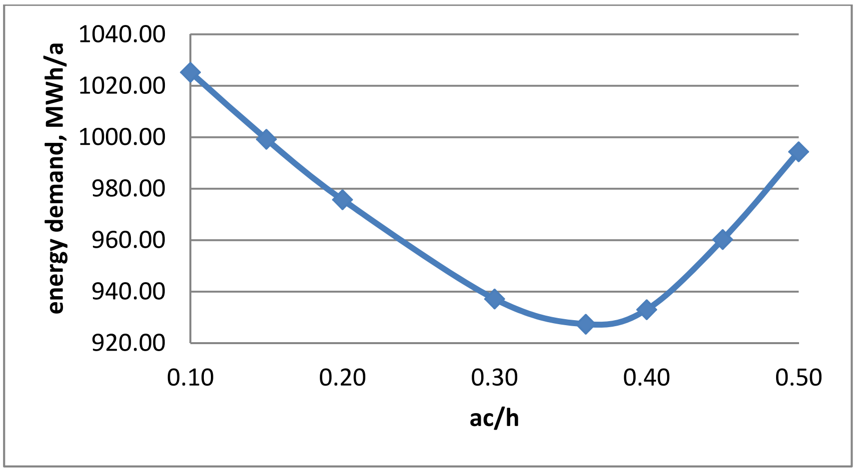


Figure 3 Variation of energy demand with ventilation rates, according to NCM model, in which refrigeration is included as a heat gain

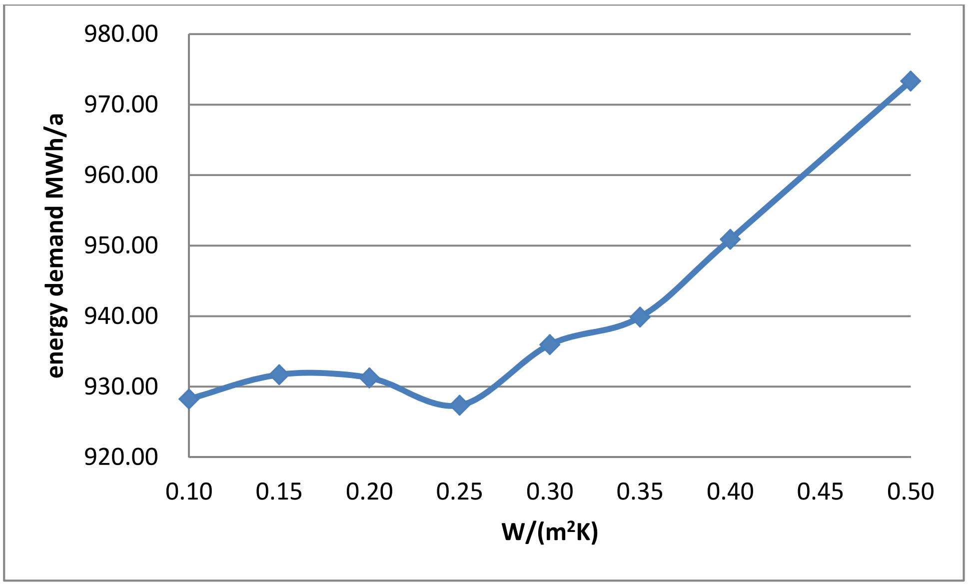


Figure 4 Variation of energy demand with insulation level, according to NCM model, in which refrigeration is included as a heat gain

## 3. Sensitivity analysis of energy demand of store with commercial, cold, refrigeration cabinets to envelope design

Simulations were then performed on the models with cold heat transfers at the refrigeration cabinets, to test the sensitivity of the energy demand of the retail floor to variations in the ventilation rate, insulation level, and rooflight fraction. Initially each parameter was investigated separately while keeping the others at the design values identified in Table 1.

### 3.1 Sensitivity to variation in ventilation rate

With cold refrigeration cabinets, the energy demand is shown by both models to have an approximately linear relationship with ventilation rate (Figure 5). Halving the ventilation rate from the conventional design value of 0.36 to 0.18 ac/h is seen on the Excel model to reduce the energy demand by 13% (230MWh/a), and by rather more on the EnergyPlus model.

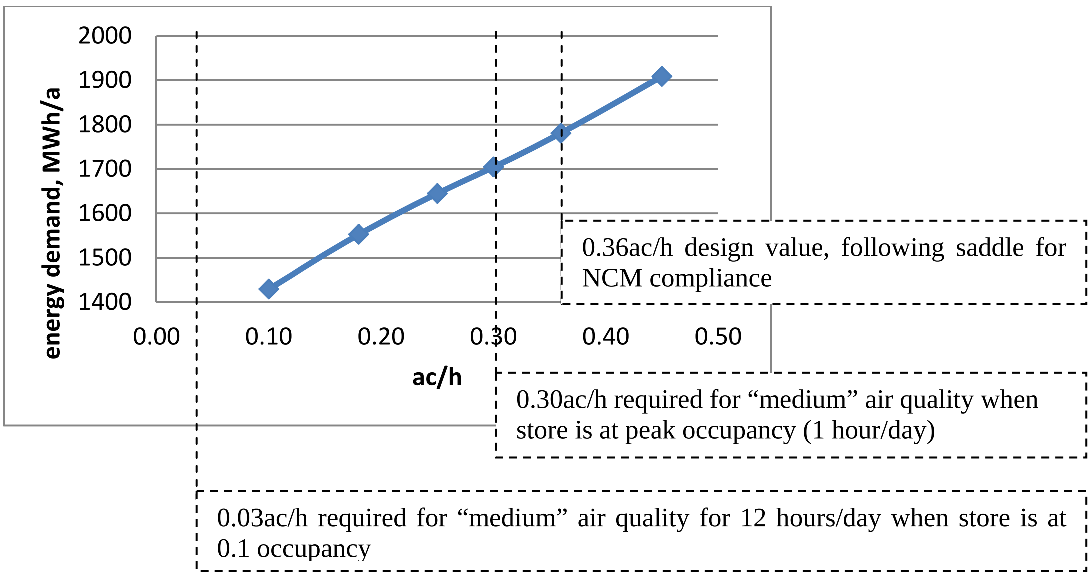

Figure 5 Sensitivity of energy demand to variation in ventilation rate, according to Excel model with cold refrigeration cabinets

This linear relationship contrasts starkly with the optimization saddle indicated by the model with NCM inputs (Figure 3). This is due to the almost entire absence of a need for cooling in the presence of refrigeration cabinets in the store. The energy demand is therefore dominated by the heating demand, and a more airtight store has a lower heating demand. It can be seen that the design value for ventilation is generous for achievement of a medium air quality for the expected maximum occupancy of the store, and exceeds by a factor of 12 the ventilation rate required for the 50% of the time when the store is at minimum occupancy.

3.2 Sensitivity to variation in level of insulation

Similarly, in the presence of cold refrigeration cabinets, the energy demand is shown by both models to have an approximately linear relationship to the level of insulation in the store envelope (figure 6). If the insulation level is doubled, from U=0.25 to U=0.125 W/($m^2$K), the energy demand is seen on the Excel model to be reduced by 1.5% (25 MWh/a), and by a little more on the EnergyPlus model.

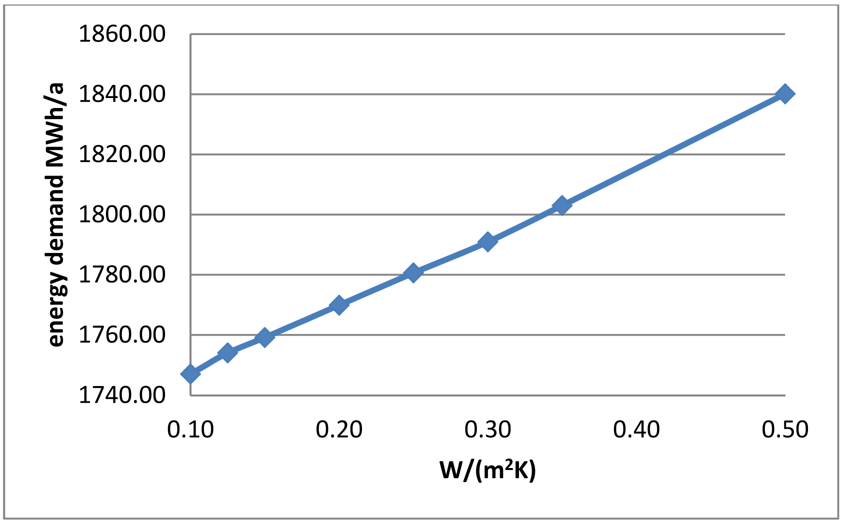


Figure 6 Sensitivity of energy demand to variation in level of insulation, according to Excel model with cold refrigeration cabinets

3.3 Sensitivity to variation in rooflight fraction

For both sets of inputs, the models show optimization saddles for a rooflight fraction around 8%. However, while with NCM inputs, the potential energy saving offered by 8% rooflights is above 12% of the total demand, the Excel model with refrigeration cabinets modeled as cold only offers a saving of 2.5% of total demand from the inclusion of rooflights.

3.4 Multivariate optimization

Combining improvements of ventilation rates with insulation levels offers further energy demand reductions, as seen in Table 2, for which energy transfers were simulated on the Excel model with refrigeration included as cold cabinets, and the level of insulation was doubled, and the ventilation rate was halved. The energy demand reduction potential indicated by parallel simulations using the EnergyPlus model is rather higher. Models can be expected to differ, but with both showing the same linear relationships, they can be assumed to indicate savings within the range of both.

Table 2 Energy demand reductions available from halving ventilation rate and doubling insulation level, as shown by Excel and EnergyPlus models

| | Ventilation rate, ac/h | U value of insulation, $W/(m^2K)$ | Heating energy demand, MWh/a (Excel) | Total energy demand, MWh/a (Excel) |
|---|---|---|---|---|
| Unimproved design | 0.36 | 0.25 | 924 | 1781 |
| Possible improved design | 0.18 | 0.125 | 660 | 1519 |
| Energy demand reduction (Excel) | | | 29% | 15% |
| | | | | |
| *Energy demand reduction shown by simulation using EnergyPlus* | | | *50%* | *25%* |

A further 2% reduction in energy demand would be possible by further reducing ventilation rates to 0.1ac/h at times when store occupancy is low, and the need for fresh air is therefore less (15 hours/day).

## 4. Conclusions

This modeling process has established that the “process energy” heat exchanges within a supermarket retail floor have a significant impact on the heat balance in the building. The operational energy demand has been found for a store whose building parameters have been optimized firstly with, and secondly without, incorporation of (cold) refrigeration heat exchanges. The store optimized with refrigeration appropriately included is found to have a 15-25% lower energy demand. This causes less $CO_2$ emissions than the store “optimized” according to regulations, without refrigeration (“process energy”) appropriately included in the model. The energy cost reduction associated with this difference will be of the same order.

This indicates that Building Regulations, and the protocols imposed by the National Calculation Methodology are leading to significantly sub-optimized new-build supermarkets, to costly higher energy demand, and to unnecessary $CO_2$ emissions.

It is recommended that the Building Regulations and associated protocols should be revised to reflect the impact of process energy, where it is significant and directly affects the regulated energy, as in a supermarket, in order to minimize unwarranted $CO_2$ emissions.

Although the results presented in this paper relate specifically to the retail floor of a supermarket, the model could be extended to encompass the back portion of the store, with offices and storage space, some of which is chilled or frozen storage. The same principles apply to all buildings with significant process energy.

Further research is planned to assess the effects of stratification and of ventilation strategy on these findings. Additionally the impact of improvements in U values of refrigeration cabinets will be explored, along with a broader exploration of the impact of excluding process energy from design protocols for commercial buildings of different types.

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