VENTILATIVE COOLING AND ENERGY USE IN SUPERMARKETS

Zoi Mylona*, Maria Kolokotroni, and Savvas Tassou

RCUK National Centre for Sustainable Energy Use in Food Chains (CSEF)
Brunel University London
Kingston Lane, Uxbridge, UB8 3PH, UK
**Corresponding author: zoi.mylona@brunel.ac.uk*

ABSTRACT

Supermarkets are a category of non-domestic buildings with high energy use because of their operation. Recent work indicates that by improvements to the energy delivery systems through which internal environmental conditions are maintained such as thermal properties of external envelope including airtightness, HVAC systems and lighting, substantial energy savings can be achieved. Work to date has focused on typical supermarkets while the present paper examines frozen food supermarkets which include more refrigeration cabinets and therefore result in higher energy use per sales floor area. The work is based on measured energy and environmental data from a newly built supermarket in South London that was used to create and optimise an energy and thermal model of the supermarket using EnergyPlus. With the calibrated model, a parametric analysis was carried out to determine strategies for improved energy performance. Results indicate that changes in the operational times of the existing HVAC system, as well as different temperature set points in the sales area can lead to energy savings of 6.5%. Night Ventilation has the potential for energy demand reduction across the majority of the operating systems and could save 81 kWh/m^{2}sales area annually and up to 51% cooling energy. Improved envelope airtightness is also being investigated and in combination with thermal insulation retrofits, a further reduction is predicted to the energy demand. Light intensity monitoring data have indicated that additional energy savings can be achieved by introducing a daylighting control strategy. Compared to the baseline supermarket model as it operates currently, the above changes can reduce the energy use and CO_2 emissions by 13.1% annually. Finally, the potential of the implementation of different HVAC systems (CAV and VAV) to the store indicated that the VRF system can maintain more efficiently the indoor air temperature of the store with the minimum total energy use. Night Ventilation strategies through r the different HVAC systems showed that the CAV system presents higher dependence on the air flow rates of night ventilation.

KEYWORDS

Supermarket, Energy Use, HVAC, Night Ventilation, EnergyPlus

1 INTRODUCTION

Supermarkets are energy intensive buildings and have a major impact on energy demand compared to other commercial buildings. In the USA they represent a 5% of total commercial building primary energy use (Clark, 2015). According to Enova statistics (2008), supermarkets consume nearly twice the energy of office buildings. Electricity used for heating, ventilation and air conditioning (HVAC), hot water and refrigeration covers about 4% of the country total in USA and France and 3% in Sweden. Currently, there are over 1 million supermarkets in Europe (CREATIV, 2014). Thus, just a small percentage reduction in energy use can result to substantial savings. A 25 % energy saving in supermarkets in Europe will result in 31 TWh of annual electricity savings which equates to carbon reductions of 16.2 million tons CO_2 (CREATIV, 2014).

Recent work in the UK indicates that supermarkets have improved energy efficiency resulting from improvements to the energy delivery systems. According to (Sullivan, 2013) the majority of the UK supermarkets achieved a reduction to their emissions from 2005 to 2010. Analysis results from NREL (2015) demonstrate significant energy savings with the implementation of advanced HVAC strategies.

Literature review reveals that there is limited information on the energy use by sub-systems in supermarkets based on operational data. Available information indicated that refrigeration uses the largest percentage of energy followed by lighting and HVAC (Mavromatidis, 2013) (Tassou et al., 2011). A recent study shows that refrigeration accounts for about 40% of total energy use and lighting for 25% (Pearson, 2014). Therefore, significant savings can be achieved by improving the efficiency of these systems.

Supermarkets operate in a way that is quite different from other building types and require unique HVAC strategies (Clark, 2015). In general, energy consumption for HVAC and lighting depends on several parameters such as size of sales area, construction, opening hours, products nature, occupancy levels and external weather conditions. Mavromatidis (2013) suggests that one of the main indicators for energy use by supermarkets is the ratio of food products against total products; the greater the ratio , the more energy is consumed.

This paper presents a study for the energy use reduction of the HVAC and lighting systems of a medium size frozen food supermarket with a high ratio of food product to other products (approximately 9:10) and a high percentage of chilled and refrigerated products (approximately 51% of total products). It will focus on the potential of night ventilation for energy savings through the existing HVAC system and will also examine the impact of external building envelope air-tightness. Few studies to date have considered ventilative cooling strategies for supermarkets (Li-Xia Wu et al., 2006) although the potential is high as will be discussed in this paper.

2 CASE-STUDY BUILDING

A newly built ground floor supermarket, opened in June 2013 is the case under study. The store (315m^2 sales floor area) belongs to a UK frozen food supermarket chain and is located in South London, in a commercial area. Its opening hours are from 8:30- 20:00 on weekdays and Saturdays and 10:00 to 16:00 on Sundays. The store includes the sales area (tills and display area), cold storage rooms and auxiliary spaces (storage, office, restrooms, staffroom) as well as a large roof void area. The building is constructed according to current building regulations (Part L) in the UK (Table 1) (Part L, 2014). The main entrance of the store (northwest) and the southwest side are glass while the northeast side is adjacent to another supermarket.

Table 1: Limiting fabric parameters

	U-value (W/m^{2}K)
External Wall	0.35
Ground Floor	0.25
Roof	0.25
Windows	5.7*
*Single Glazed Windows	

Table 2: Refrigeration Equipment

	RefrigerationEquipment	
	No	**Power / unit (W)**
Open front multi-deck chilled food	7	1460
Lift up lid frozen food	58	200
Open top case frozen food	3	1345
Coldroom Chiller	1 (29.4m^2)	
Coldroom Freezer	1 (5.8m^2)	

The store is all electric from grid electricity. The annual energy consumption is 1102.8 kWh/m^2 sales area which is within the range identified for stores with sales area 180m^2-1400m^2 in the UK (850 to 1500 kWh/m^2 per year) (Tassou et al., 2011). The refrigerated display fixtures consist of three different refrigeration cabinets; (a) chilled food open front multi-deck cabinets, (b) lift up lid and (c) open top case frozen food cabinets. One freezer

(29.4m^2) and one chiller (5.8m^2) coldrooms are used for storage purposes. Lighting is provided by fluorescent lamps during opening hours and LED strips in the sales area during the night. The HVAC is a Variable Refrigerant Flow (VRF) system used for both heating and cooling. Two equally sized outdoor condensing units provide total heating output of 113kW and cooling output 101kW which are delivered to the tills and display areas only, through 7 ceiling cassettes and 1 door heater. The design cooling duty requirements of the store was estimated at 60kW sensible. The HVAC system is operated 24h with 20-21^{o}C set-point temperature for both cooling and heating. Ventilation rates have been set at 6ach for tills and display area, 10ach for restrooms and 1ach for storage area. The airtightness is designed at 15m^3/h m^2 @50Pa according to the current UK building regulations.

3 BASELINE MODEL DEVELOPMENT

3.1 Software and operational data

Half hourly energy data is available since the opening of the store (June 2013). Moreover, additional sub metering of different systems has been acquired from similar stores of the same supermarket chain.

Environmental conditions (air temperature, relative humidity, light intensity and CO_2 levels) have been monitored at 15mins interval for one year at different locations and heights in the store using 21 HOBO data loggers (Tempcon Instrumentation Ltd.). In addition, data were collected of air temperature of the 7 diffusers using i-button data loggers (Measurement Systems Ltd). For the present paper these data were used to calibrate the Energy Plus model developed.

EnergyPlus (Version 8.1) (U.S. Department of Energy, Energy Efficiency & Renewable Energy) was used to model the energy and environmental performance of the store. EnergyPlus is based on the most popular features and capabilities of BLAST and DOE-2 (Crawley et al., 2001). It also incorporates many advanced features, such as multi zone airflow and extensive HVAC specification capabilities (Coakley et al., 2014) including refrigeration systems. The refrigeration system capability within EnergyPlus focus on properly accounting sensible and latent energy exchanges between the refrigerated cases and the building HVAC systems. It also includes a model for walk-in coolers (coldrooms) exchanging energy with multiple conditioned zones. Secondary loops, shared condensers and sub coolers are also included as well as a library of data for different refrigerants (Stovall et al., 2010)

External conditions were simulated by using an *.epw weather file custom created with data from Gatwick airport weather station and year specific data from Weather Underground (www.wundergound.com) to correspond to the period of available operational data.

3.2 Model parameters input

Mechanical and architectural design details were available through the energy manager of the building with descriptions of the fabric properties, electrical, refrigeration and HVAC services distribution, control strategies and customer occupancy. In addition, in-store observations were carried out by the authors for typical weekdays and Saturdays during July 2013 to determine customer flow numbers. This varies between 15-120/hour with an average of 90/hour. Figure 5 presents the daily schedules for lighting, electrical equipment, customers' activity created in combination with the in store observations and refrigeration schedules. A summary of the parameters imported in EnergyPlus is shown in Table 4. The 3D construction model of the store designed in Google Sketch Up and through Open Studio Plug-in was transferred to EnergyPlus. The store is separated in 9 thermal zones.

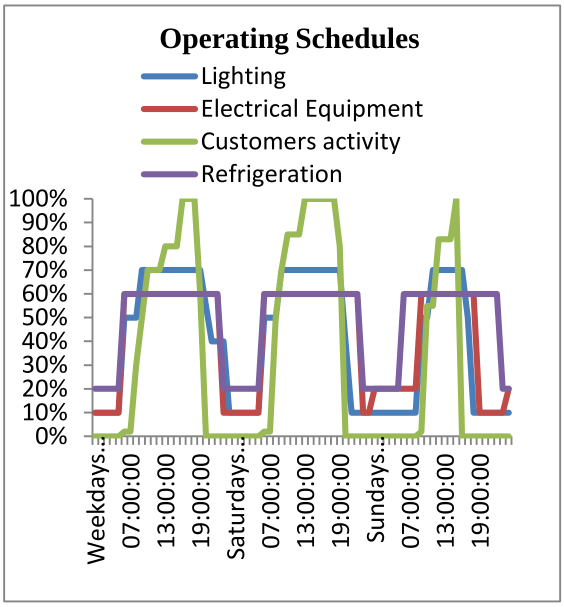

Figure 5: Operating Schedules (Lighting, Electrical Equipment, Customers activity, Refrigeration)

Table 3: Summary of parameters input

Input parameters	Value
HVAC System	VRF with 7 heat pump cassettes and door heater
Heating	
Heating Setpoint Temperature	20°C (non-operating hours) 21°C (opening hours)
Cooling	
Cooling Setpoint Temperature	20°C (non-operating hours) 21°C (opening hours)
Ventilation	6ach, Tills area, Sales area,
Infiltration	15m^3/h m^2 @50Pa
Lighting	16 W/m^2 Tills area 32.9 W/m^2 Display area
Electrical Equipment	16 W/m^2 Tills area 274.2 W/m^2 Kitchen 137.3 W/m^2 Restrooms 25.3 W/m^2 Office
Customers	7.6 m^2/person Tills area 16 m^2/person Sales area

3.3 Accuracy criteria

Due to complexity of the building and the dependency of independent interacting variables, it is difficult to achieve an accurate representation of the store. By calibrating the model to measured data, a more accurate and reliable representation of the building is achieved (Coakley et al., 2014). Kaplan et al. suggest calibrating models to short typical periods and not to annual data, for example to monthly data (Kaplan et al., 1990).

ASHRAE Guideline 14-2002 defines the evaluation criteria to calibrate a simulation model. Monthly and hourly data, as well as spot and short term measurements can be used for calibration. Mean Bias Error (MBE) and Coefficient of Variation of the Root Mean Squared Error (CVRMSE) are used to evaluate the model uncertainties (ASHRAE, 2002).

$$MBE = \frac{\sum_{i=1}^{N}(y_i - \hat{y}_1)}{\sum_{i=1}^{N} y_i} \qquad (1)$$

$$CVRMSE = \frac{\sqrt{\sum_{i=1}^{N}(y_i - \hat{y}_1)^2 / N}}{\overline{Y_s}} \qquad (2)$$

$$\overline{Y_s} = \frac{\sum_{i=1}^{N} y_i}{N} \qquad (3)$$

where, y_i is the measured data; $\hat{y}_1$ is the simulated data; N is the sample size; and $\overline{Y_s}$ is the sample mean of measured data.

ASHRAE (2002) recommends an MBE of less than 5% and a CVRMSE of less than 15% relative to monthly calibration data. If hourly calibration data are used, these requirements could be 10% and 30% respectively

Monthly simulation results for the case study model have shown a MBE of 1% and CVRMSE of 3%. Table 5 presents the hourly simulation results evaluation. The estimated % error with negative values means that the results from modelling are higher than results from the measurements and vice versa for positive values, whereas CVRMSE values are always positive.

Table 5: Hourly Model calibration results

	MBE	CVRMSE		MBE	CVRMSE
June 2013	1%	14%	December 2013	1%	15%
July 2013	2%	15%	January 2014	0%	13%
August 2013	1%	13%	February 2014	0%	12%
September 2013	0%	14%	March 2014	-2%	14%
October 2013	2%	12%	April 2014	-3%	15%
November 2013	0%	13%	May 2014	-3%	14%

4 RESULTS AND DISCUSSION

4.1 Energy efficient retrofit analysis and ventilation features

The HVAC control strategy is changed to facilitate night ventilation as follows: operation between 6:00 to 23:00 for weekdays and Saturdays and 9:00 to18:00 for Sundays rather than 24h of the baseline model. This change alone would save 81 kWh/m^2 sales area per year. A previous study for night ventilation implementation to a supermarket has concluded that longer night cooling activation results to fewer hours of AC system operation and higher energy savings (Li-Xia Wu et al., 2006). However, studies for offices and other non-domestic building have indicated that three control aspects should be taken into consideration (Kolokotroni, 1998); duration, system initiation and system continuation in order to maximise energy savings. In this case study, the following rules were implemented:

(A) Initiation: $T_{out}<T_{in}$,

(B) Continuation: $T_{out}<T_{in}$ and $T_{out}-T_{in}<T_{offset}$,

(C) Termination: continuation rule and $T_{in}=T_{min}$,

The continuation rule ensures that the outside air that brought in is effective on cooling the building. When the temperature difference between inside and outside air is low, the air brought in will have little effect on cooling while the ventilation fan energy use will increase the total energy use. However, if the outside air temperature is significantly lower than the inside air temperature, T_{min} will be achieved fast and the duration of night ventilation is decreased (Aria & Akbari, 2007).

Figure 6 shows the total energy use after the implementation of night ventilation using the above rules. T_{offset} of 1, 2, 3, 4, 5 and 8 ^{o}C, T_{min} of 12^{o}C and 15^{o}C and air flow rates of 4, 6 and 10 ach were tested. 10ach results to the higher reduction in total energy use, increasing with higher T_{offset} until it reaches 5^{o}C. 6ach also results to the lowest energy use when T_{offset} is 5^{o}C; after that point cooling energy use increases and this leads to an increase of the total energy use (Figure 7). 4ach results to minor changes with T_{offset} changes 0^{o}C to 5^{o}C. As in the other cases total energy use increases with $T_{offset}>$ 5^{o}C. These results indicate that the optimum energy savings can be achieved for this system when T_{min} is12^{o}C, T_{offset} is 5^{o}C and the air flow rate during night ventilation is 6ach.

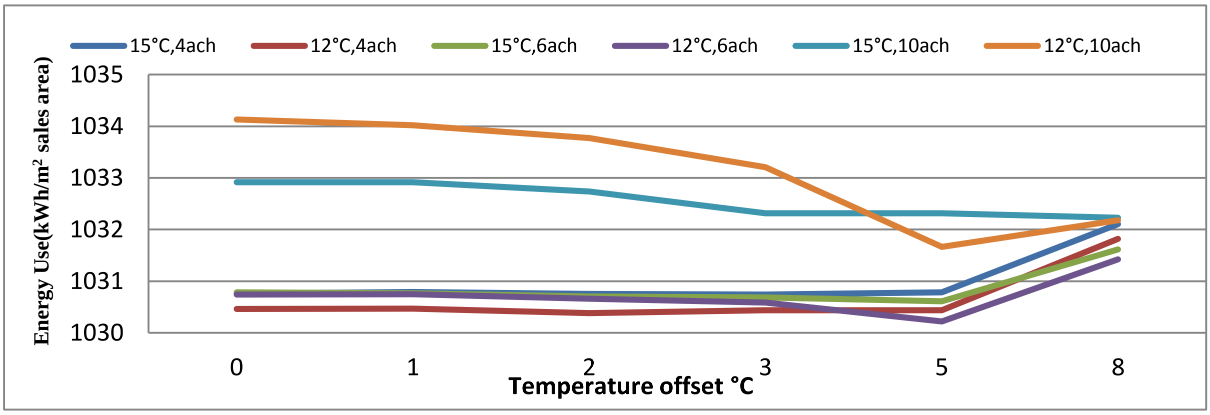

Figure 6: Annual Energy Use per sales area for different minimum indoor air temperature setpoints and different air flow rates of night ventilation in relation to the temperature offset

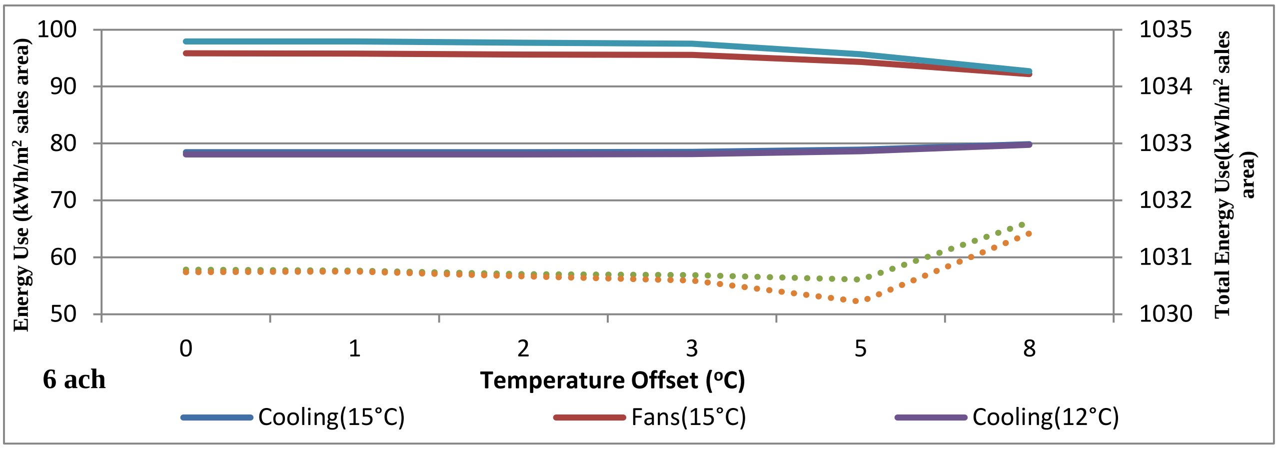

Figure 7: Annual Energy Use per sales area for cooling, fans and total for different minimum indoor temperature setpoints in relation to the temperature offset and 6ach air flow rate

Figure 8 presents the energy use reduction for each system due to different air flow rates of night ventilation. HVAC is mostly affected (around 40.1 %) because of the cooling demand reduction. Although night ventilation leads to added energy consumption of fans, this addition is smaller than the energy use reduction of the cooling demand.

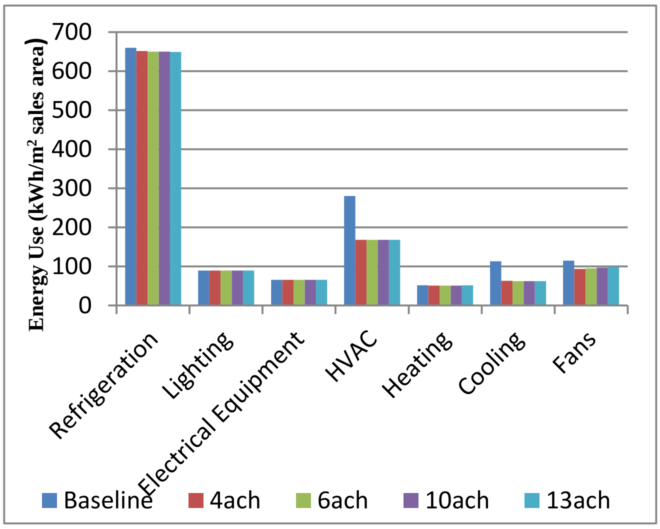

Figure 8: Annual Energy Use per sales area changes of the systems of the store due to different air flow rates of night ventilation

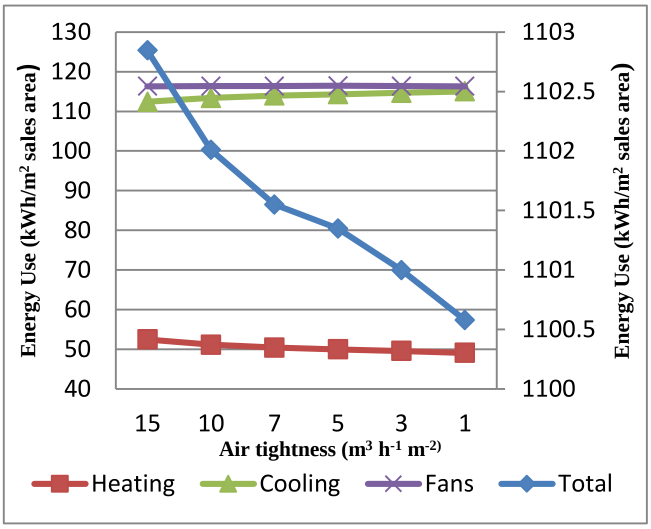

Figure 9: Annual Energy Use per sales area for heating, cooling, fans and total for different air tightness values

In the UK, air tightness tests are mandatory for buildings with floor are of more than 1000m^2 and should be less than a maximum air permeability of 10 m^3 h^{-1} m^{-2} at a test pressure of 50Pa. However for buildings less than 500m^2 total useful area, like the case study store, a test is not necessary; air permeability is taken as 15 m^3 h^{-1} m^{-2} at 50Pa (Part L, 2014). According to previous studies the desirable design value for low carbon supermarkets is 5 m^3 h^{-1} m^{-2} (Kolokotroni et al., 2014). Values of 15, 10, 7, 5, 3 and 1 m^3 h^{-1} m^{-2} were tested and presented in Figure 9. Increased air tightness results in a reduction in the total energy use but an increase in the cooling demand due to lower heat losses through the envelope.

Table 6 presents all changes implemented at the baseline model for optimum energy savings including high energy efficient lamps, daylight controls and envelope amendments.

Table 6: Summary of percentage energy savings of the total annual energy use per sales area

Input parameters	**Value**	**Energy Use savings**
HVAC System	6:00-13:00 weekdays and Saturdays 9:00-18:00 Sundays	
Heating Setpoint	19°C winter	
Cooling Setpoint	21°C summer	7.3%
Night Ventilation	Minimum indoor air temperature 12°C Delta temperature offset 5°C Air flow rate 6ach	6.6%
Lighting	Daylight control for 750 Lux	3%
	LED lighting in tills area and sales area 16 W/m^2 Tills area 9 W/m^2 Display area	4.5% **Total Lighting** 5.8%
Envelope	Double glazed windows Insulation of the interior ceiling	2.9%
Total		13.1%

It was found that a 60% reduction is achieved in the lighting system and 29% in the HVAC; the cooling demand is reduced by 29%, the heating demand by 25% and the fans energy use by 17%. A 4% reduction was observed in the refrigeration system. Figure 10 presents the annual energy breakdown of the store after the implementation of the energy efficient amendments. Considerable amounts of energy are consumed by the refrigeration (66%), while the HVAC system consumes approximately 22% of the energy with the cooling energy use to be the most demanding of the HVAC system.

Figure 11 presents a daily energy profile to demonstrate the interactions between the systems. It shows a reduction of the baseline hourly energy use after the implementation of the changes (Table 6) to the baseline model. When the store is closed, it operates at base load which is 10kWh lower than the baseline. At 6:00 a peak is observed due to systems start up (HVAC and lighting). After 8:30 that the store is open, the energy use remains relatively constant during trading hours and starts reducing when the store is closed until 23:00 when HVAC and lighting system are turned off.

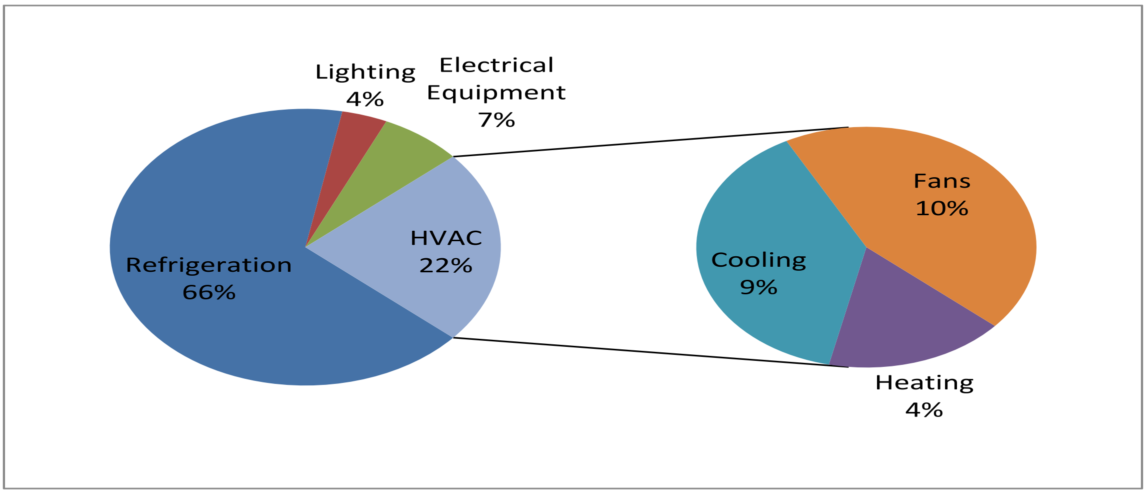

Figure 10: Percentage contribution of systems to the total annual energy use

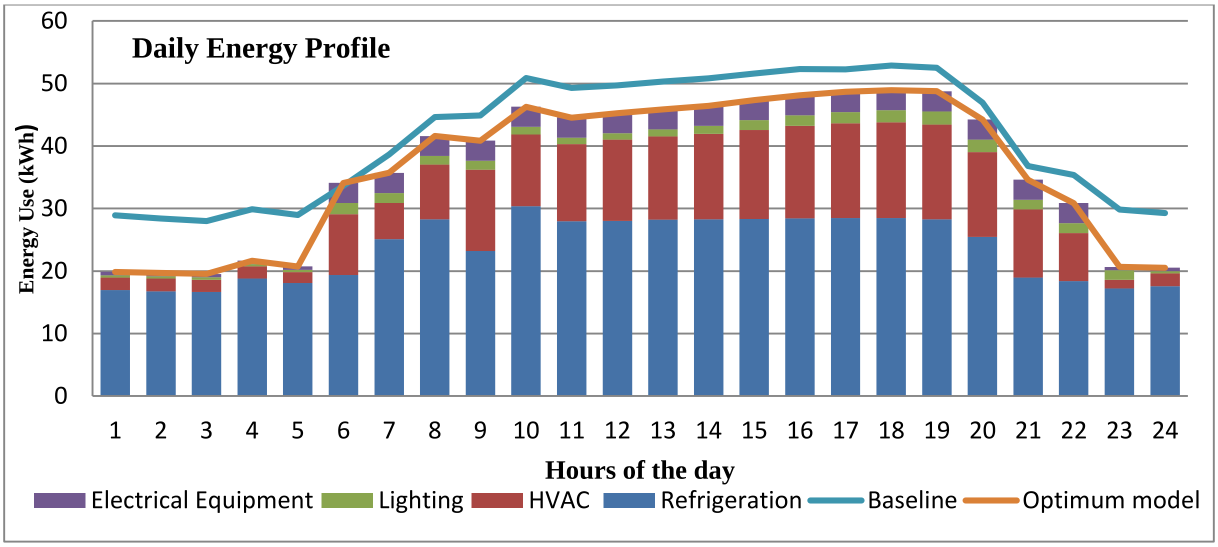

Figure 11: Typical summer weekday energy use profile of the store (Thursday 11/7)

4.2 Comparison of different HVAC systems

In general supermarkets present a challenge for air conditioning because of the interaction between the HVAC system and the refrigerated display cabinets which provide significant sensible cooling and increase the latent load fraction on the HVAC system (Tassou et al., 2011). According to the results presented in section 4.2, the HVAC system (VRF) energy use is between 22% and 24% of the total. However the most common system for supermarkets is the air constant volume (CAV). Apart from the CAV system, the variable air volume (VAV) HVAC system also simulated for the store under study.

Figure 12 presents a summary of the comparison between the different HVAC systems. The total annual energy use with a CAV HVAC system is higher by approximately 33% in comparison to the total annual energy use with a VRF system. A VAV differs at around 19% from the total annual energy use with VRF. However, if the optimal changes (Table 6) are implemented to the model with VAV, then the total annual energy use is approximately the same with the total annual energy use of the store as it is in operation today.

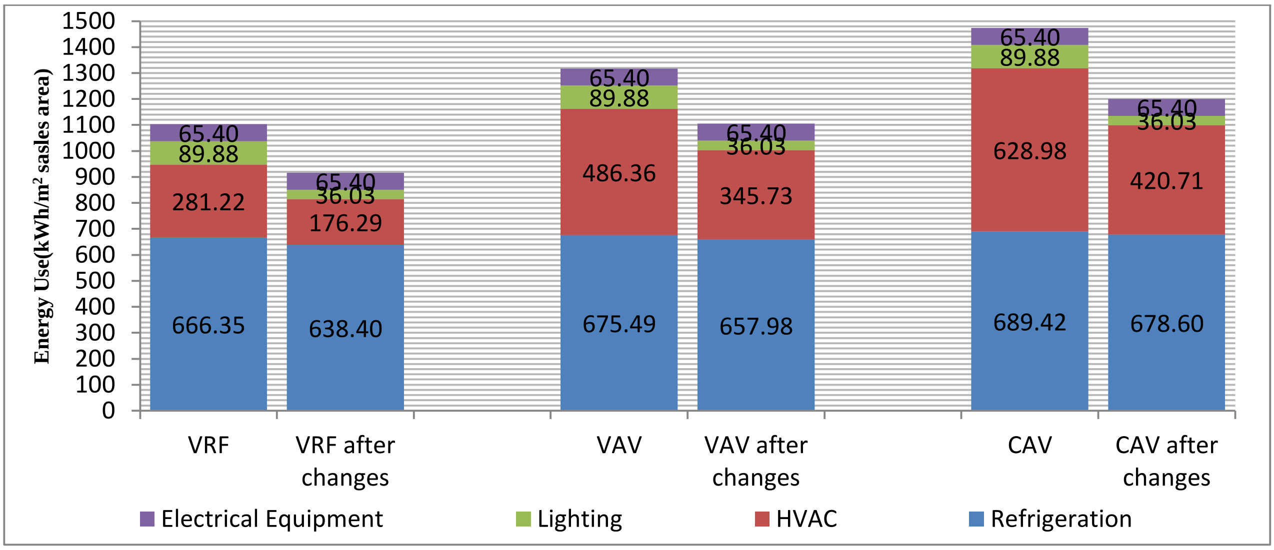

Figure 12: Annual Energy Use per sales area breakdown of electrical equipment, lighting, HVAC and refrigeration for total energy use of each HVAC system before and after the optimal changes of Table 6

Figure 13 presents the indoor air temperature annually for the baseline system models before the energy efficiency changes. It shows that indoor air temperature of the tills and display area is better maintained by a VRF system with the minimum total annual energy use per sales area.

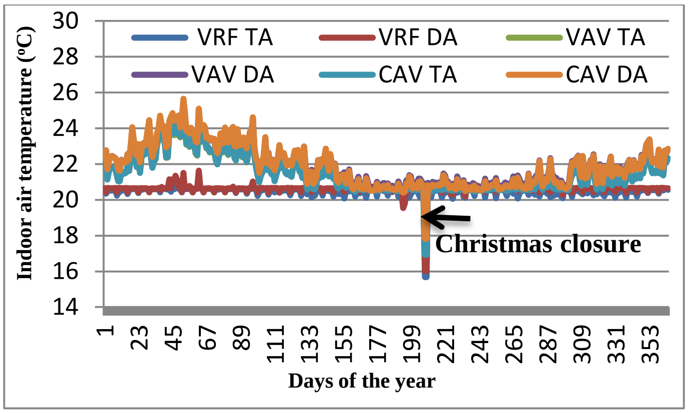

Figure 13: Indoor air temperature for Tills area(TA) and Display area (DA) during 1 year (1/6-31/5)

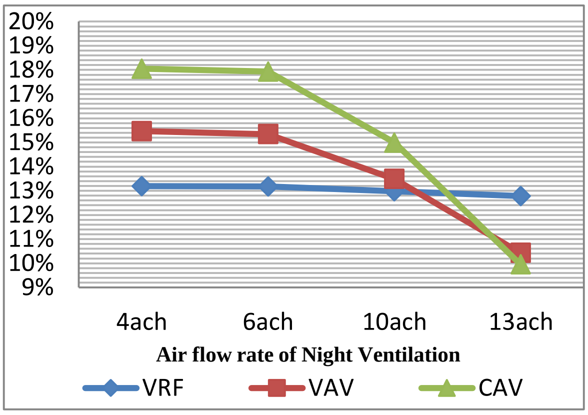

Figure 14: Percentage reduction of the total annual energy use per sales area of the different HVAC systems in relation to air flow rates of night ventilation.

Night ventilation was also investigated for CAV and VAV in comparison to VRF. Figure 15 presents the percentage reduction of the total annual energy use per sales area due to the night ventilation and its correlation to the air flow rate. The total annual energy use with the VRF system is observed to be approximately independent (13.2%-12.87%) of the air flow rate of night ventilation with 4 or 6 ach the best options, while the higher the air flow rate, the smaller the total energy use reduction is. 4 ach also achieve the higher energy savings for CAV and VAV; the higher energy use reduction is achieved with CAV (18.1%-10%). Figure 15 also indicated that CAV and VAV present a higher sensitivity to the increase of the air flow rates of night ventilation.

5 CONCLUSIONS

This paper presented results of energy use of a UK frozen food supermarket store which is used as a baseline for the investigation of energy efficiency measures for building fabric, lighting and ventilative cooling. EnergyPlus was used for the simulation of all scenarios with the baseline model calibrated using energy and environmental operational data from the case-study store. The papers focus in more detail on the HVAC system and night ventilation strategies. Parameters such as air flow rate, temperature offset and minimum indoor air temperature were investigated. The results for different air flow rates showed that total energy use is fairly flat in the range 0-6 ach with optimal flow rate to be around 6 ach in the case study building model with VRF system while cooling energy demand decreases with the increase of night ventilation air flow rate. Night ventilation can lead up to 6.6% total energy savings. Simulations also showed that the temperature offset for achieving highest energy savings is 5°C.

Other energy efficient measures examined indicate that lighting system can achieve the biggest reduction (60%) when using LED lighting fixtures. Significant is the reduction of the HVAC system energy use (29%) due to night ventilation and the change of the indoor air temperature setpoints for summer and winter periods due to a cooling demand reduction.

The comparison of three HVAC systems (VRF, VAV and CAV) indicated that VRF results in the lowest total annual energy use per sales area with better maintenance of indoor air temperature. However, the VAV system could reach the same performance after the energy efficient measures discussed in the paper with the VRF system that is currently in operation. A further investigation of the influence of night ventilation on the performance of the different HVAC systems indicates that percentage highest savings can be achieved with the CAV system as it is the most inefficient of the three examined in this paper.

6 ACKNOWLEDGEMENTS

This work is carried out as part of the RCUK Centre for Sustainable Energy Use in Food Chains (EP/K011820/1) project. Thanks are due to Rick Jenkins for providing energy data and facilitating access to the case-study store.

7 REFERENCES

Aria H & Akbari H. (2007). A predictive Nighttime ventilation algorithm to reduce energy use and peak demand in an office building. *Energy and Power Engineering*,7,1821-1830.

ASHRAE. (2002). *ASHRAE Guideline 14-2002, Measurement of Energy and Demand Savings.*

Clark J. (2015). *Energy-Efficient Supermarket Heating,Ventilation, and Air Conditioning in Humid Climates in the United States.* NREL, National Renewable Energy Laboratory.

Coakley D, Raftery R, Keane M. (2014). A review of methods to match building energy simulation models to measured data. *Renewable and Sustainable Energy Reviews. Elsevier*,37, 123-141.

Crawley D B, Hand J W, Kummert M, Griffith B T. (2008). Contrasting the capabilites of building energy performance simulation programs. *Building and Environment, Elsevier*, 43, 661-673.

Crawley D B, Lawrieb L K,Winkelmannc F C, Buhlc W F, Huangc Y G, Pedersend C O, Strandd R K, Liesend C O, Fishere D E, Wittef M J, Glazerf J. (2001). EnergyPlus: creating a new-generation building energy simulation program. *Energy and Buildings, Elsevier*, 33, 319-331.

CREATIV, Industry Energy Efficiency. (2014, February 14). *The future energy effective supermarket.* Retrieved from SINTEF: http://www.sintef.no/projectweb/creativ/the-future-energy-effective-supermarket/

Geros V, Santamouris M, Tsangrasoulis A, Guarracino G (1998). Experimental evaluation of night ventilation phenomena. *Energy and Buildings, Elsevier*, 27, 141-154.

Kaplan M, Jones B, Jansen J. (1990). DOE-2.1 C model calibration with monitored end-use data. *ACEEE 1990 Summer Study Energy Efficient Building* , 115-25.

Kolokotroni M, Tassou S, Gowreesunker B L. (2014). Energy aspects and ventilation of food retail buildings. *Advances in Building Energy Research*, 9, 1-19.

Kolokotroni M, Webb B C , Hayes S D., (1998). Summer cooling with night ventilation for office buildings in moderate climates. *Energy and buildings, Elsevier*,27, 231-237.

Kolokotroni M. (1998, March 10). Night Ventilation for cooling: Field Tests and design Tools. *Low-Energy Cooling Technologies for Buildings: Challenges and Opportunities for the Environmental Control of Buildings, Professional Engineering Publishing, London,UK*,33-44.

Li-Xia Wu, Zhao J N, Wang Z J. (2006). Night ventilation and active cooling coupled operation for large supermarkets in cold climates. *Energy and Buildings, Elsevier*,38,1409-1416.

Mavromatidis G, Acha S, Shah N (2013). Diagnostic tools of energy performance for supermarkets using Artificial Neural Network algorithms. *Energy and Buildings, Elsevier*,62, 304-314.

Measurement Systems Ltd. Retrieved from https://www.measurementsystems.co.uk/data-logging/miniature_temperature_loggers/ds1922l__thermochron_data_logger_-40_to_85_c

Part L. (2014). *Building Regulations Part L2A Conservation on Fuel and Power in new buildings other than dwellings.*

Pearson A. (2014). *CIBSE Case STudy: Advanced Energy Efficient Supermarket.* CIBSE Journal.

Stovall T K, Baxter V D (2010). *Modeling Supermarket Refrigeration with EnergyPlus.* Retrieved from Oak Ridge National Laboratory:

Sullivan R, Gouldson A. (2013). Ten years of corporate action on climate change: What do we have to show for it? *Energy Policy, Elsevier*,60, 733-740.

Tassou S, Ge Y, Hadawey A, Marriott D. (2011). Energy consumption and conservation in food retailing. *Applied Thermal Engineering, Elsevier*,31, 147-156.

Tempcon Intrumentation Ltd. *HOBO Temp/RH 3.5% data logger UX100-003, HOBO U12 Temperature/Relative Humidity/Light/External Data Logger - U12-012*.

U.S. Department of Energy, Energy Efficiency & Renewable Energy. *EnergyPlus Energy Simulation Software*. Retrieved from http://apps1.eere.energy.gov/buildings/energyplus/