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Supermarkets, indoor climate and energy efficiency – field measurements before and after installation of doors on refrigerated cases

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ABSTRACT

Supermarkets are large users of energy and approximately half the electricity use derives from the display of refrigerated food. Ambient climate influences the performance of the cabinets and their energy use as well as the thermal comfort of people and the temperature quality of the food. An increase in temperature and humidity will raise the energy requirement for display of chilled and frozen food. Energy savings through energy efficient systems should not affect people or foodstuffs negatively.

This paper presents field-measurements on the indoor climate, energy and impact on people and foodstuffs before and after glass doors have been installed on vertical display cabinets (retrofit). The results show that if the systems were optimized the installation could be even more energy-efficient. Less power consumption is possible for the refrigeration system as well as the other systems.

1. INTRODUCTION

Approximately half the electricity use in supermarkets derives from the display of refrigerated food. Display cabinets are often concentrated in certain areas, hence affecting the local thermal climate. This climate influences the performance of the cabinets and their energy use as well as the thermal comfort of people and the temperature quality of the food. An increase in temperature and humidity will increase the energy use. Energy in supermarkets can be saved through the use of energy-efficient equipment and systems, but this alone is not sufficient to sway the merchandiser to invest in energy efficient systems. There is a need for further arguments for the merchandisers and others involved when choosing the systems and technical solutions for supermarkets, so that energy use can be reduced, with a corresponding reduction in environmental impact. An interdisciplinary analysis provides further arguments to select energy-efficient systems and to improve the systems (heating, ventilation and refrigeration systems) in supermarkets.

The merchandiser's primary objective is selling of food and earlier experiences from the field as shown by Lindberg *et al.* (2007a, b) suggest that energy savings alone is not a sufficient reason for extra investments in efficient display cabinets, technical solutions and efficient energy systems for supermarkets. There are different options to keep the cool air inside the cabinets where it should be when cooling refrigerated foodstuffs. One technical solution could be to cover with glass doors. Faramarzi and Kemp (1999) and Axell (2002) have shown that infiltration accounts for approximately 70-80% of the cooling load. An open design makes the display cabinet sensitive to infiltration. Installing glass doors on open vertical display cases can reduce the infiltration load, and hence the power consumption of the refrigeration system. Axell and Lindberg (2005) concluded that local comfort often can be poor in areas where open display cabinets are located. Foster (1996) and Foster and Quarini (1998) have used CFD when analysing their work on problem of cold aisles between display cabinets. Their results also show that cold air spillage can be a problem. Cold air from the cabinet spills out of the cabinet on to the floor, causing the customer's

feet to become cold, commonly known as the 'cold feet' effect. Fang *et al.* (2000) studied - both in the laboratory and in controlled field experiments in an office room - the effect of temperature and humidity on the perception of indoor air quality. Conclusions were that air temperature and humidity have a significant impact on both the immediate and the adapted perception of indoor air quality. Decreasing the indoor air temperature and humidity improved the perceived air quality significantly, with the acceptability of air quality increasing linearly with decreasing enthalpy of the air. The study included different combinations of three levels of temperature (18 °C, 23 °C and 28 °C) and three levels of humidity (30 %, 50 % and 70 %).

The objective of this paper is to present measurements on the indoor climate, energy and impact on costumers, personnel and foodstuffs displayed in vertical display cabinets for storage of dairy- and meat foodstuffs. Measurements were performed before and after glass doors have been installed (retrofit) on refrigerated cases.

2. SUPERMARKET DESCRIPTION

The measurements have been carried out in a Swedish supermarket, denoted Supermarket D. The size of the supermarket was 975 m² sales area, 1 333 m² total area. Opening hours are daily from 09.00 to 22.00. Approximately 50 m of vertical display cabinets and 17 m of horizontal freezers were covered with glass-doors. The analyse in this paper is focusing on the refrigerated vertical display cabinets for storage of dairy goods (D1) and meat (D2). The annual outdoor mean temperature for the supermarket of the area where it was located was 6 °C. The installations of the doors were performed during the cold season (week four and five year 2008). Measurements were performed mainly during week three and six, however more data have been collected for a longer period. Heating to the supermarket is included as a fixed cost in the rent and distributed from radiators and ventilation air. The supermarket is situated on the ground floor and above there are apartments in the building. In the basement is the engine room for the refrigeration system. The refrigeration systems are transcritical with CO₂. The condensing heat is rejected by dry coolers situated on the roof. The analysis on the refrigeration system is not included in this paper but will be published in future publications. For comparison on sales figures, outdoor conditions and occupancy week three and six are comparable.

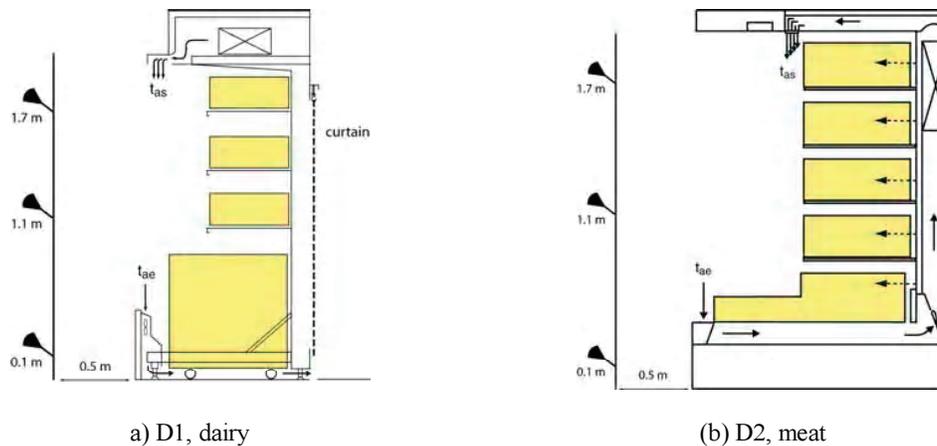


Figure 1: Measurements on heights 0.1 m (ankle), 1.1 m (abdomen) and 1.7 m (head). The distance for customers when displaying food was defined as 0.5 m in front of the vertical cabinet where also the rack has been positioned (a) Vertical cabinet for dairy foodstuffs, roll-in and back-loaded (denoted D1) (b) Vertical cabinet for meat, front-loaded for supermarkets (D2).

3. FOODSTUFFS, PERSONNEL AND COSTUMERS

The three different categories (foodstuffs, personnel and costumers) in supermarkets must be considered when a good climate should be established. Those categories have incompatible requirements depending on many diverse factors. When installing energy efficient systems or improving existing installations it is important that it will be done without affecting any instance of the categories negatively. Refrigerated food is to be stored according to temperature intervals given by legislation which in principle is harmonized within the EU. In Sweden the National

Food Administration (NFA) takes an active part in the development of new legislation in co-operation with the EU member states. Regulation (EC) No 178/2002 (2002) lays down general principles and requirements of food law. According the NFA regulations food must be stored within correct temperature intervals by the merchandisers. Staff in supermarkets is spending longer time in the environment and can adjust their dress-code according to the existing environment and their own activity. In Sweden legislation on the working environments is controlled by the Swedish Work Environment authority. In their statutes, AFS 1998:02 (2000) as example for the food industry, is +16 °C a recommended temperature. Customers on the other hand are and will be dressed depending on outdoor conditions which means that summer-time when light-dressed they can be to cold in the supermarkets. However, customers are in transit and are spending shorter periods of time in the supermarkets compared to the foodstuffs and personnel. The wish from the merchandiser on the other hand is to keep customers, as long as possible, within the sales area in order to sell as much as possible.

4. METHODS

The measurements have been designed in order to show how the installation of hanged double glass doors area affecting the indoor environment, energy use, products and costumers. Physical measurements (from a rack) and questionnaires in front of the cabinets were collected 2008.01.18 (no doors) and 2008.02.08 (doors). Other measurements and data have been collected for other periods as described below. After the installation of doors on the vertical display cabinets the intervals for defrosting was changed and one (the outer) air curtain for the vertical display cabinet was removed. Some additional light was installed in the cabinets and outside the cabinets.

Table1: Measurement program for different variables before and after the installation of glass doors.

Climatic condition: Dry bulb temperature (°C), Relative humidity (%)	Questions asked regarding thermal sensation and indoor environment collected in front of display cabinets (D1, D2)	Electrical energy supply (kWh)
<p>Outdoor air</p> <p>Indoor air (ambient condition in front of the display cabinets, in accordance with ISO 23953-2).</p> <p>Indoor climate, air and relative humidity (conditions 0.5 m in front of the display cabinets D1, D2).</p> <p>Measurements on cabinets D1 and D2 (supplied air in the air curtain and interior temperatures).</p>	<p>Questionnaires on how the;</p> <ul style="list-style-type: none"> - temperature is perceived, evaluated and preferred - overall indoor environment is judged and evaluated 	<p>Total electrical energy supply for the whole supermarket</p> <p>Total electrical energy supply for the storage in mainly vertical display cabinets (K2, dairy and meat)</p> <p>Total electrical energy supply for storage of refrigerated and frozen foodstuffs (K1, K2 and K3 including fans, pumps and dry-coolers).</p>

Temperature loggers (EasyLog) were used to continuously collect measurements. Each logger individually stored the measurements. Measurements for the ambient conditions (climate measuring point) in front of cabinets were according ISO 23953-2. The sampling intervals were 6 times/ hour. The logger has an accuracy of 0.5 K.

Measurements of the physical conditions in front of vertical display cabinet before and after the installation of the doors were performed and continuously collected during opening hours. A rack with sensors was used for measurements of environmental parameters vertical on three levels above the floor as shown in Fig. 1 above, recommended heights according ISO 7726 (1998). The sampling intervals were 6 times/ minute and in the supermarket two different vertical display cabinets were measured (D1 and D2). Measurements were also collected from the cabinets D1 and D2 with Easyloggers. They were collecting data from the supplied air in the air curtain and interior temperatures (under shelves). In parallel with the physical measurements in front of the vertical display cabinets questionnaires were distributed. The questionnaires are based on standard ISO 10551 (1995). In the questionnaires consumers have stated how they perceive, evaluate and prefer the temperatures in front of the vertical display cabinets. The questionnaires also included answers on how the overall indoor environment is perceived and evaluated before and after the installation of the doors. Thermal sensation can be predicted but the standard ISO

10551 (1995) covers the construction and use of judgment scales. The standard proposes a set of specifications for direct expert assessment of thermal comfort/discomfort expressed by persons subjected to various degrees of thermal stress. This approach has been applied in order to supplement the objective measurements with the aim of obtaining reliable and comparative data on the subjective aspects of thermal comfort/discomfort. Judgement scales as proposed in the standard have been used. Data on total electrical input used for the whole supermarket as well as for the refrigeration system was collected. Other indices in order to compare the use of energy have been calculated.

5. RESULTS

The results show how the technical solution “doors” are affecting the indoor climate (for costumers, personnel and foodstuffs) the energy performance for the refrigeration system and the sale-numbers. The relation between the subjective and objective data will be used in order to present the results. Results indicate that the retrofit glass-doors directly affect the supermarkets indoor environment, electric power consumption and storage temperature of refrigerated foodstuffs.

The costumers are not negatively affected by the installed doors and sales numbers have not been lower due to the installations. This comparison is done only for a shorter period and longer measurements are needed in order to see how and if the doors have affected the sales numbers. Conditions, air temperature and relative humidity, at level 1.1 m in front of the cabinets (D1 and D2) are shown in Table 2 below.

Table 2: Vertical display cabinet and conditions at level 1.1 m during one hour for cabinets (D1 and D2)

Variable	Unit	No doors 2008.01.18		Doors 2008.02.08	
		D1, dairy	D2, meat	D1, dairy	D2, meat
$t_{a,1.1}$	°C	15.0	16.3	18.5	18.8
$t_{a,Rh1.1}$	%	43	38	41	41

Costumers are dressed depending on outdoor conditions. Outdoor conditions during the measurements were comparable (average week 3 was 4.9 °C and 3.9°C week 6) and as shown in Table 3 below. Maintaining food temperatures at correct temperatures is the key to maximizing high quality display life and maintaining the food quality. Temperatures measurements were performed on the ambient air (according ISO 23953-2) in front of the vertical display cabinets, the supplied air in the air-curtain and for the interior air in the cabinets. In Table 3 and 4 below are measurements from cabinets (D1 and D2) shown.

Table 3: Vertical display cabinet and mean (day and night) air temperatures for meat cabinet (D2) and outdoor.

Variable	Unit	No doors 2008.01.18		Doors 2008.02.08	
		Day	Night	Day	Night
$t_{a,o}$	°C	4.7	4.7	6.3	5.1
$t_{a,amb}$	°C	17.3	16.7	19.2	18.3
$t_{a,s}$	°C	2.2	1.7	1.0	2.3
$t_{a,int}$	°C	6.7	4.5	4.7	3.4

Table 4: Mean (day and night) air temperatures for dairy cabinet (D1).

Variable	Unit	No doors 2008.01.18		Doors 2008.02.08	
		Day	Night	Day	Night
$t_{a,amb}$	°C	15.9	16.0	19.4	18.2
$t_{a,s}$	°C	-3.7	-3.8	-4.6	-4.3
$t_{a,int}$	°C	7.2	6.7	3.6	1.5

For both display cabinets the interior temperature with doors was about 2 K colder (for both day and night), the cabinets were equipped with night curtains before the installation of doors.

Measurement results in front of the vertical display cabinets (D1 and D2) are shown in Fig. 2 below. The results on the gradient measured between ankle (1.1 m) and head (1.7 m) was before the installation 7 K after the installation of the doors the temperature difference was 5.5 K for D1. The local comfort has been better for people.

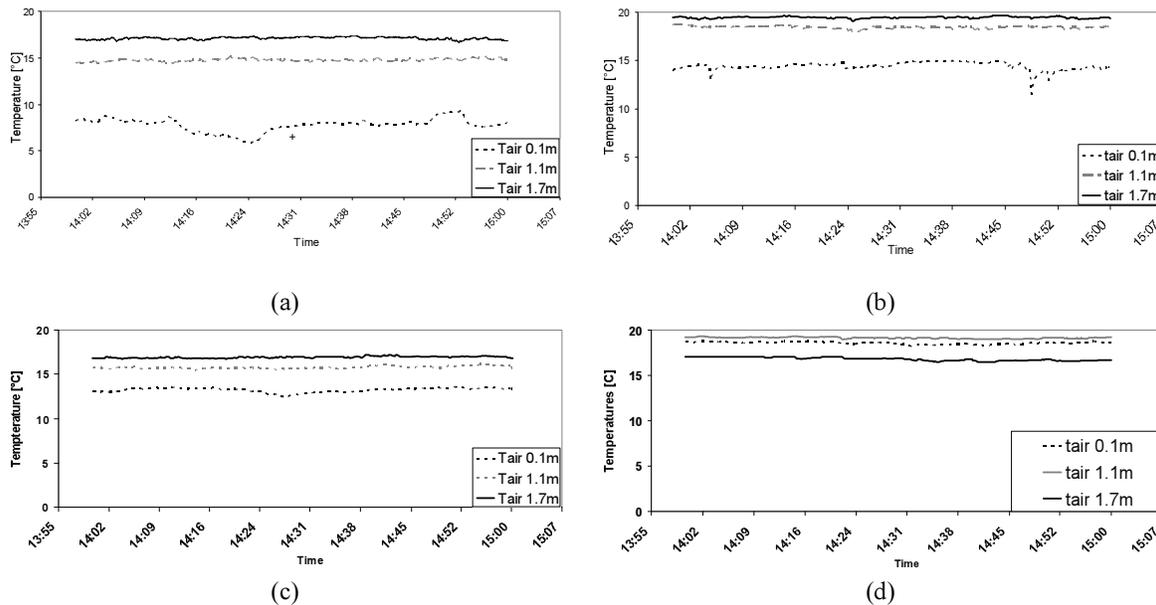


Figure 2: Measurements in front of vertical display cabinets (a) D1, dairy, no doors (b) D1, dairy, doors (c) D2, meat, no doors (d) D2, meat, doors

In total 120 persons (61 % female) responded the questionnaires before installation and 150 persons (64% female) after the installations, equally distributed over the 2 different cabinets.

The respondents are asked “How do you feel at this precise moment?”. The perception scale is a symmetrical 7-degree two-pole scale, comprising a central indifference point and two times 3 degrees of increasing intensity, cold, neutral, and hot. Respondents answers in % are presented in Fig. 3(a) below. The costumers in front of the cabinets perceive the temperatures as more neutral and warmer when the doors are installed.

The first question is followed by “Do you find it ...? The evaluative scale is between comfortable followed by four degrees of increasing intensity of the effect, to extremely uncomfortable. Respondents answers in % are presented in Fig. 3(b) below. The temperature is found to be more comfortable when the doors are installed.

The second question is followed by the third question when the respondents were asked “Please state how you would prefer it to be now...” The preference scale is a symmetrical 7-degree two-pole scale, comprising a central indifference point and two times 3 degrees of increasing intensity, much colder, neutral, and very warmer. Respondents answers in % are presented in Fig. 3(c) below. The temperature is preferred to be neither warmer nor colder by most of the consumers in front of both cabinets.

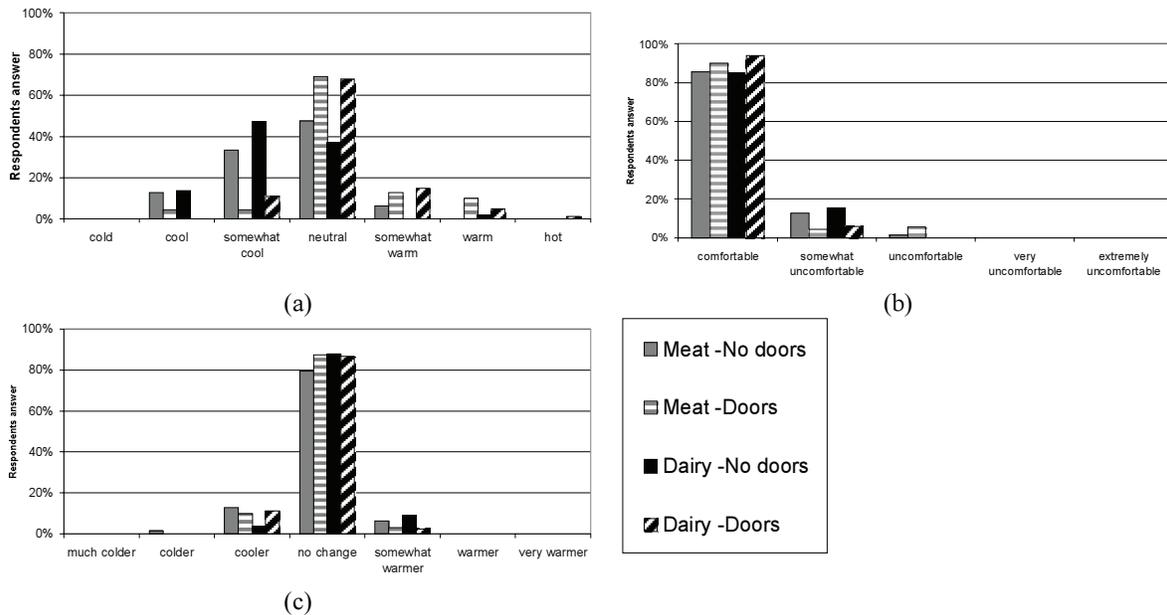


Figure 3: Questions asked regarding temperature in front of vertical cabinets D1, dairy, and D2 meat (a) “How do you feel at this precise moment?” Perception scale, 7-degree (b) “Do you find it ...? Evaluative scale, 5-degree (c) “Please state how you would prefer to be now...” Preference scale, 7-degree

An overall judgement about the acceptability of the indoor environment was asked “Please state how you judge the indoor environment at this precise moment”. Respondents answers in % are presented in Fig. 4(a) below. The costumers answered the conditions as better after the doors were installed especially in front of the meat products (D2). This was followed by the question on how comfortable they found the indoor environment. Costumers found the indoor environment as more comfortable after the doors were installed. The questionnaires indicate that more than 90 % of the consumers rate the indoor environments as 'Comfortable' to 'Somewhat uncomfortable' before and after the doors were installed.

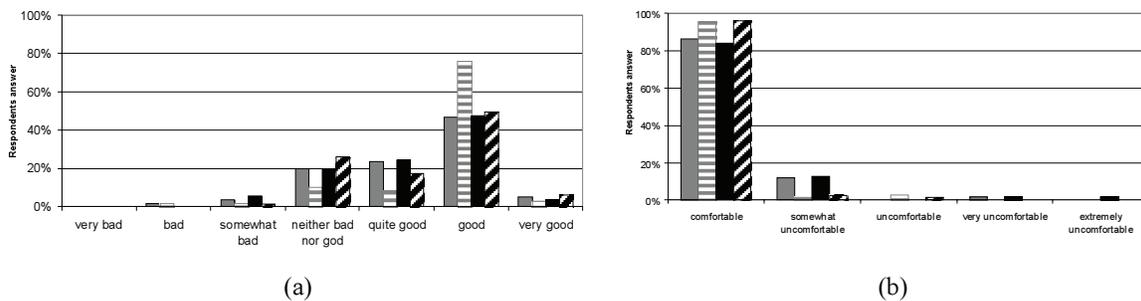


Figure 4: Questions asked regarding the indoor environment, labels as Fig. 3 above (a) “Please state how you judge the indoor environment at this precise moment...” 7-degree scale (b) “Do you find it ...?Evaluative scale,5-degree

The electric power consumption was measured separate for the refrigeration system on the three different plants for the refrigeration systems (K1, K2 and K3). K2 includes compressors (two) and dry coolers for vertical display cabinets supplying mainly dairy and meat cases, the comparison before and after the installation of the doors is presented in Table 5 below. The total electrical supply decreased 4 % for the whole refrigeration system (K1, K2, K3 and internal consumers for week 6-8 was compared with 1-3). For K2 the electrical supply decreased 26 % as shown in Table 5 below. The total electrical supply for the whole supermarket decreased 6 % after the installation of doors. Indices according Table 6 below indicates that supermarket D uses the energy as average supermarkets, more indices and comparisons are presented by Axell and Lindberg (2005) from earlier publications.

Table 5: Comparison of the electric power consumption (K2) before and after the installation

Total Electrical Supply for compressors and dry coolers	Total Electrical Supply for compressors and dry coolers	Difference
No doors	Doors	After installation
Week 1-3	week 6-8	-26 %

Table 6. Comparison of indices related to the building area (from June 2006 to July 2007)

Supermarket	Indices	
	Total Electrical Supply / Total area and year	Total Electrical Supply / Total sales area and year
	$w_{tot} = \frac{W_{e,tot}}{A_{tot}}$ eq. 1	$w_{sale} = \frac{W_{e,tot}}{A_{sale}}$ eq. 2
	kWh/(m ² and year)	kWh/(m ² and year)
D	504	689

6. DISCUSSION

In supermarkets are three different categories that must be considered when attempting to establish a good indoor climate: foodstuffs, personnel and costumers. Unfortunately, they have incompatible requirements depending on many diverse factors. When installing energy-efficient systems, or improving existing installations with a technical solution, e.g. glass doors, it is important to do so without adversely affecting any of the categories. The electrical supply for the refrigeration system (K2) decreased and the storage temperature for the refrigerated foodstuff has been improved after the doors were installed. The results has been shown that the storage temperature for the foodstuff have been lowered approximate 3 K with doors installed. A higher quality of the food was maintained. If the temperature was adjusted and the foodstuffs still could keep correct temperature it could be possible to save more energy. A 1 K lower (as a rule of thumb) evaporator temperature corresponds to 3 % savings on the electrical supply for the chiller(s). That indicates that for K2 (electrical supply for mainly vertical display cabinets for storage of dairy and meat products) more than 30 % on the electrical supply could be saved when doors are installed. It is often questioned by merchandisers if doors could be ha selling "hinder" or troubles for personnel. However, if it could be showed that energy efficient display cabinets and an improved thermal environment also result in an improved temperature quality of the food and an improved thermal comfort, which in turn affects the customer and personnel in a positive way, this would make a strong argument for such an investment. This project has been performed during winter conditions and for a short period. For conclusions on how the sales figures, indoor environment, energy performance and interactions with the refrigeration and HVAC system are affected are affected an analyse for a whole year is necessarily. During summer conditions the infiltration is higher which in turn would be more savings when doors are installed, also people wear less clothes during summer. Perceived comfort depends on the thermal balance of the whole body. ISO 7730 (2005) describes how this balance depends on environmental parameters, physical activity and clothing. The standard also describes how to predict a perceived comfort from the above data but this is valid only for situations where people spend a reasonably long time. This study involves people in the temporary situation of supermarket shopping, which has previously not been thoroughly investigated. Subjective measurements show that after the installation of doors the people perceived the temperature as more natural and warmer, evaluated it as more comfortable and more than 80 % answered that they do not prefer any change. The objective measurements shows that the thermal comfort is improved, the gradient measured in front of D1, dairy, was lower after the doors were installed.

7. CONCLUSIONS

The influence from retrofit installation of glass doors proved to be beneficial and it shows that if the different systems are optimized the energy usage could decrease even more. Field measurements and comparison before and after the doors were installed shows that doors:

- Reduced the electric consumption of the refrigeration's system (-26 % for K2, mainly dairy and meat foodstuffs).

- Reduced the total consumption for the whole supermarket use of electricity (-6 %)
- Reduced the temperature gradient between ankle and head in front of D1, dairy (2 K)
- The questionnaires indicates that the costumers are not negatively affected by the installations

The trade off between glass doors and indoor environment is an issue to be closely evaluated by supermarket operators. Using glass doors as an energy-efficient technology can reduce the power consumption for the refrigeration system. However in order to get the most out from it the systems must be optimized for the installation of glass doors. Another conclusion is that in order to evaluate the effects from the installation of glass doors controlled laboratory measurements are necessary as well as further field measurements based on a whole year. Such studies are planned as a follow up to the field measurements presented in this paper.

NOMENCLATURE

A	Area	(m ²)	ae	Air; air curtain; extract
t	Dry bulb temperature	(°C)	aint	Air; interior (shelf mean value)
V	Volume	(m ³)	ao	Air; outdoor
w	Indices	(-)	as	Air; air curtain supply
W	Energy input	(kWh)	e	Electrical
Subscripts			Rh	Relative humidity
aamb	Air; mixed ambient (ISO 23953-2)			

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