

## **Appropriate indoor climate for environmentally sustainable Supermarkets – Measurements and Questionnaires**

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### **SUMMARY**

Half the electricity use in supermarkets derives from the display of refrigerated food. 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. This work is an interdisciplinary study of perceived comfort in relation to measured local climate. The aim is to define an appropriate climate and to improve energy efficiency with maintained or even better climate for goods, staff and customers. Perceived comfort depends on thermal balance of the whole body. ISO7730 is valid only for situations where people spend a longer time. This study involves temporary situation of supermarket shopping. Perception data have been obtained by means of a questionnaire based on ISO10551. The results show that according to ISO7730 people should be dissatisfied with their thermal comfort. The questionnaires (ISO10551), however, indicate that the thermal conditions are acceptable.

### **INTRODUCTION**

In supermarkets there are three different categories that must be considered when a good climate should be established; goods, staff and customers. They are three different categories with 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 is harmonized within the EU. 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. Customers on the other hand are and will be dressed in accord to the outdoor conditions which means that during summer while they are light-dressed they can be too cold in the supermarkets. However, the customers are in transit and are spending a shorter periods of time in the supermarkets compared to the goods and staff. 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.

Supermarkets are large energy users and energy savings can be done through energy efficient equipment and systems but that is not enough as an argument for the merchandiser. There is a need of further arguments for the merchandisers and people involved when choosing the systems and technical solutions for supermarkets so that the energy use can be lowered with a result of less impact on the environment. An interdisciplinary analysis provides further arguments for the merchandiser to select energy efficient systems in the supermarket. The analysis highlights from an environmental and a financial point of view, advantages of energy efficient systems, improved thermal comfort and improved temperature quality of the food in

the supermarkets. As defined by ANSI/ASHRAE Standard 55-2004, Thermal Environmental conditions for Human Occupancy, thermal comfort is “that condition of mind which expresses satisfaction with the thermal environment” [1]. The hypothesis is that energy efficient display cabinets and system solution, as well as increase knowledge, results both in an improved thermal comfort and better temperature quality of the food. The thermal comfort problem in supermarkets especially in front of display cabinets have been studied by several researchers by using CFD-modelling, e.g. Foster [2] and Foster and Quarini [3]. Their results also show that cold air spillage can be a problem. Cold air from the cabinet falls out of the cabinet on to the floor, causing the customer's feet to become cold, commonly known as the 'cold feet' effect. Local discomfort can be caused when one particular part of the body is exposed by unwanted cooling. A high vertical temperature difference between head and ankle is an example of local discomfort. Fang et al [4] studied both in 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, the acceptability of air increased linearly with decreasing enthalpy of 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%).

This paper presents measured air temperatures along with questionnaires answered by mainly customers in front of vertical cabinets during summer and winter. The objective of this paper is to present results from field measurements and describe how staff and customers are judging the thermal environment (temperature and overall indoor environment) by variations, summer and winter, in front of open vertical display cabinets. The long-term aim of the project is to define the desired indoor climate that would satisfy both people (staff and customers) and the quality requirements of the food. When the desired indoor climate is declared the aim is to improve energy efficiency in supermarkets with a maintained or even better climate for goods, staff and customers.

## **METHODS**

Field measurements have been carried out in three different supermarkets, denoted A, B and C in Sweden. The size of the three supermarkets differs where A is the largest and C the smallest supermarket. In the three different supermarkets questionnaires have been collected in order to find out how the indoor climate was judged by the people in the supermarket. On the same time as people have responded to the questionnaires physical measurements on indoor parameters have been performed continuously. Questionnaires and measurements have been collected during a whole day (opening-hours) for summer (2005) and winter (2006) conditions in front of vertical display cabinets. In supermarket A, 425 people (34 staff) responded in supermarket B, responded 378 people (47 staff) and in supermarket C responded 405 people (49 staff). Totally 532 responded during the summer and 676 during the winter. Answers received were from 48% male and 52% female.

Presented in this paper is from physical measurement air temperatures in front of display cabinets. Together with questionnaires have people answered how they perceive, evaluate and prefers the temperatures. The presentation from the questionnaire also includes answers on how the overall indoor environment is judged.

## SUPERMARKETS

Refrigerated food can be displayed in horizontal or vertical display cases/ cabinets with different design. The vertical display cabinets are common but are however more sensitive to infiltration and are also large users of electrical energy. Two common open vertical display cabinets as shown in Figure 1 are included in the study; (a) A Vertical open display cabinets for roll-in and back-loading of goods. It is mainly for storage of refrigerated food, dairy-goods. The cool air is distributed as an air curtain in the front of the cabinet and the rear is closed by curtains. The cold room behind is separated by curtains, the cold room is used for storage of goods. From the back is the cabinet loaded with new goods. (b) A Vertical open display cabinet, front-loaded, for storage of refrigerated food. The cool air is distributed through perforated plates in the rear and as an air curtain in the front of the cabinet. New goods are filled up from the front. One way for the merchandiser to increase the sales area and display refrigerated food in a larger volume for the customers is to use Cold rooms, Fig. 2. The cooled air inside the room is kept separated from the warmer air outside the room. Customers are transported through the room while purchasing the food. Inside the Cold room refrigerated food can not only be stored in vertical display cabinets but also as examples be kept on shelves, boxes and pallets on the floor.

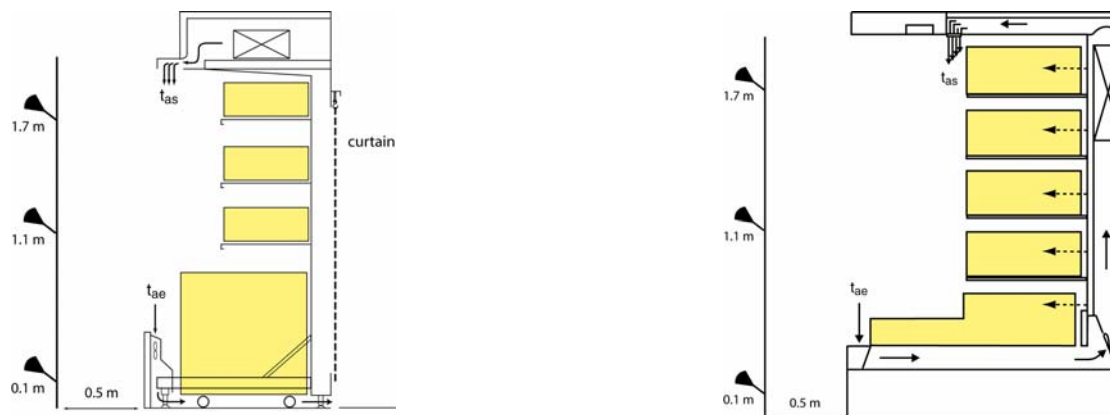


Figure 1: Open vertical display Cabinets and rack positioned 0.5m in front of the cabinet. The sensors are on levels 0.1m (ankle), 1.1m (abdominal) and 1.7m (head) (a) Roll-in and back loaded for Supermarket A, B and C ( denoted A1, B1 inside a Cold room and C1) and (b) Front loaded for Supermarket A, B and C (denoted A2, B2 and C2).

## OBJECTIVE MEASUREMENTS – PHYSICAL PARAMETERS

During the field measurements environmental parameters were collected from a rack with sensors vertical on three levels above the floor (Figure 1), recommended heights according EN ISO7726 [5]. The sampling intervals were 6 times/ hour and in each supermarket two different vertical display cabinets were measured. The refrigerated foods in the vertical cabinets were keeping temperatures between 0 °C and +8 °C. The Annual mean outdoor temperature for locations of the Supermarkets were 6 °C and during the measurements average temperatures for summer-condition was 15 °C and winter-condition around 0 °C. Supermarket B has a Cold room for displaying refrigerated food for customers. In previous work by Axell and Lindberg [6] measurements shows that supermarket B uses the energy most efficient, measures as total energy consumption per square meter total or sales area, A and C have similar energy performance using (energy/sales are).



a)



b)

Figure 2: Photos from the field study a) Cold room in supermarket B b) Supermarket A and questionnaires answered in front of vertical display cabinet, A1. It is a Roll-in and back loaded vertical display cabinet

## SUBJECTIVE MEASUREMENTS - QUESTIONNAIRES

The thermal sensation can be predicted but existing thermal comfort standards, e.g. ISO7730 [7] are based on experiences where people spend longer time. The standard ISO10551 [8] covers the construction and use of judgment scales and proposes a set of specifications on direct experts assessment of thermal comfort/discomfort expressed by persons subjected to various degrees of thermal stress. This approach has been done in order to supplement the objective measurements with the aim of receiving reliable and comparative data on the subjective aspects of thermal comfort/discomfort. Judgment scales as proposed in the standard have used and questioned in following order;

- Perception scale - the scale of Perception is a 7-degree two-pole scale, comprising a central indifference point and two times 3 degrees of increasing intensity. The central point of indifference corresponds to the absence of hot and cold. Neutral = 4, very cold = 1 to very hot = 7.
- Evaluative scale - the Evaluative scale is a 5 degrees scale with a point of origin indicating the absence of the effect, and 4 degrees of increasing intensity of the comfort. Comfortable = 1 and 4 degrees of increasing intensity of the effect, extremely uncomfortable = 5 and
- Scale of preference - the Thermal preference scale is a symmetrical 7-degree scale bipolar comprising a central point of indecision and two times 3 degrees of increasing intensity. Preference scale 1-7, where neutral = 4, much colder = 1 to much warmer = 7.

The questionnaires have been answered by staff and customer standing 0.5 m in front of the vertical cabinet where also the rack has been positioned (Figure 1 and Figure 2). The persons interviewed have been informed briefly about reasons for the questionnaire. Together with backgrounds parameters such as activity, clothes, age etc other physical parameters concerning indoor environment have been collected from the responders. A total of five indoor environment parameters (e.g. air temperature, humidity and air velocity ) with above three judgments scales have been questioned. Answers from questionnaire in this paper concerns the temperature and an overall question on how the acceptability is of the indoor environment (local climate) on a personal level.

## RESULTS

Depending on the outdoor conditions during the year there will also be an influence on the indoor environment. Ambient temperatures are depending on where and when it is measured as shown in Figure 3 with different levels presented during summer and winter conditions. The ambient temperature in front of the vertical cabinets is lower at all levels in all supermarkets during summer compared with winter. For supermarket B, B1, measured in a Cold room the temperature is keeping 8 °C on all three levels during summer and winter. In supermarket A there is a larger difference between summer and winter measurements compared with supermarket B, which also is using the energy more efficient.

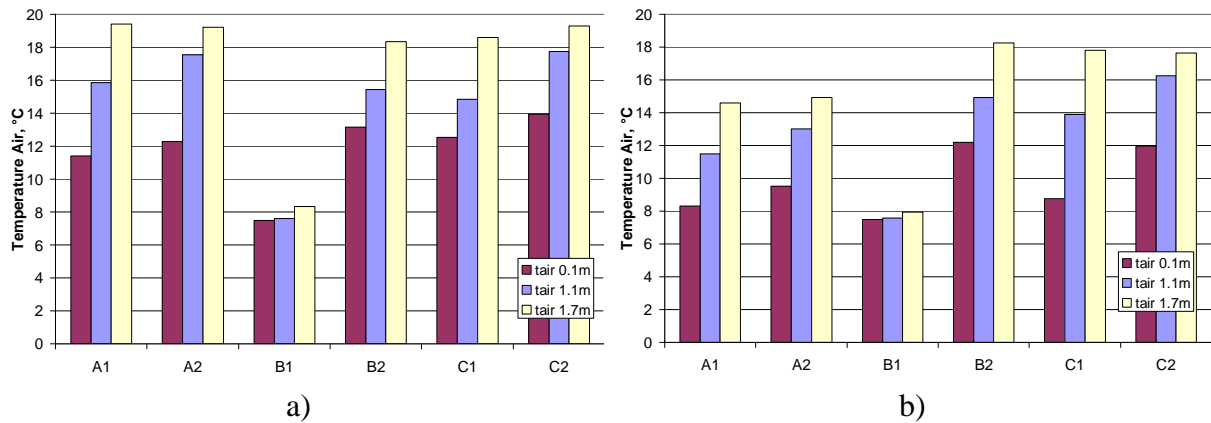


Figure 3. Average values, air temperatures (tair), during a) Summer and b) Winter. Levels on measurements 0.1, 1.1 and 1.7 m above the floor. For positions, A1-C2, see Figure 1.

The temperature is felt colder for the staff compared with the customers. For example when evaluated in front of A2 the average value for staff was 0.3 colder compared with the customers. Position A2 is measured where two vertical display cabinets are facing each others, during winter the temperature is perceived colder for staff (3.27) compared with customers (3.0). Inside the cold room, B1, lowest temperatures is evaluated from all positions for summer and winter.

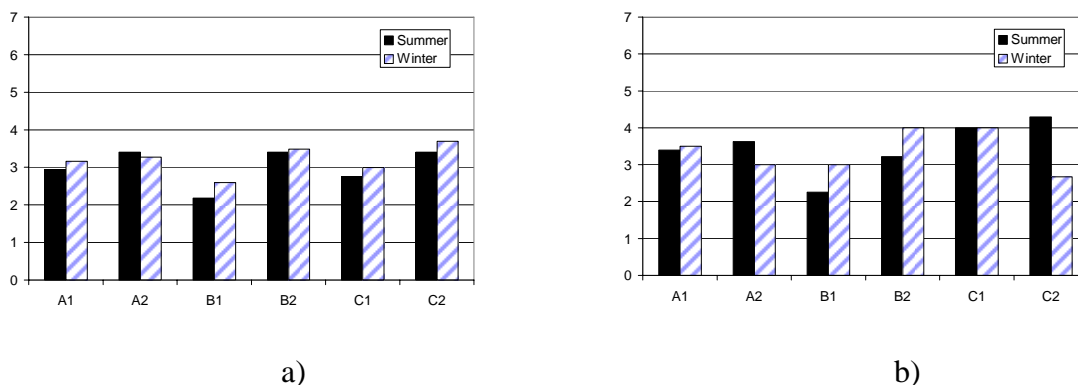


Figure 4. Average values during Summer and Winter. For positions, A1-C2, see Figure 1. a) Customer and b) Staff.

Question answered regarding the Temperature “How do you feel at this precise moment?” Perceptions scale 1-7 where neutral = 4, very cold = 1 to very hot = 7.

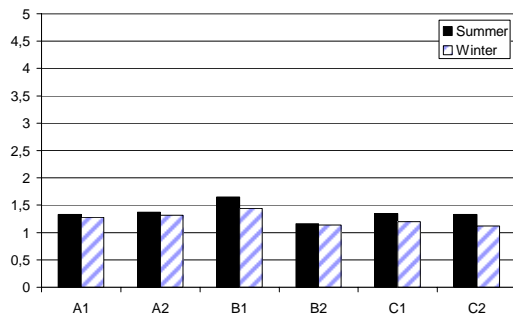
The temperature, see below Table 1 and diagrams in Figure 5, is found to be more uncomfortable for staff than customers (comfortable = 0). During summer and winter more

than 60 % of the customer and staff answered comfortable, an exception is B1, inside the cold room where 57 % answered comfortable during summer conditions. During summer 57 % of the customers answered comfortable compared with 70 % during winter conditions.

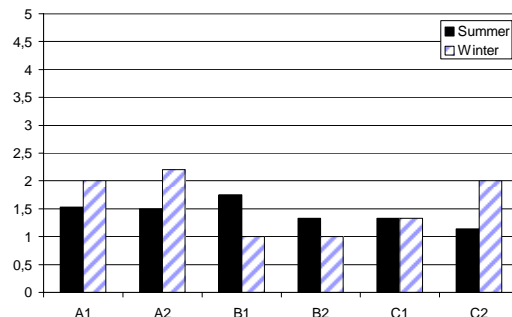
Table 1. Average values of preference scale for Customer and Staff during Summer and Winter (s/w). For positions, A1-C2, see Figure 1.

Question answered regarding Temperature “Do you find it...?” Scale 1-5, where comfortable = 0 and 4 degrees of increasing intensity of the effect, extremely uncomfortable = 5)

|          | A1<br>s/w  | A2<br>s/w  | B1<br>s/w  | B2<br>s/w  | C1<br>s/w  | C2<br>s/w  |
|----------|------------|------------|------------|------------|------------|------------|
| Customer | 1.33/ 1.28 | 1.37/ 1.32 | 1.65/ 1.44 | 1.16/ 1.14 | 1.35/ 1.20 | 1.33/ 1.12 |
| Staff    | 1.53/ 2.00 | 1.50/ 2.20 | 1.75/ 1.80 | 1.33/ 1.00 | 1.33/ 1.33 | 1.14/ 2.00 |



a)



b)

Figure 5. Average value during Summer and Winter. For positions, A1-C2, see Figure 1.

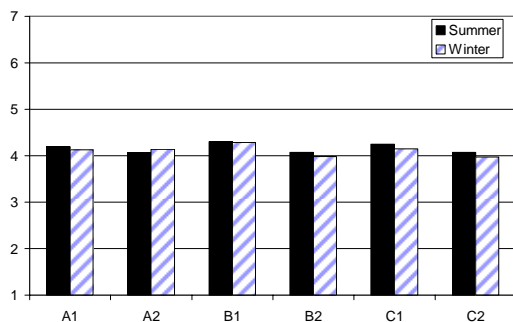
a) Customer and b) Staff.

Question answered regarding the Temperature “Do you find it ....?”

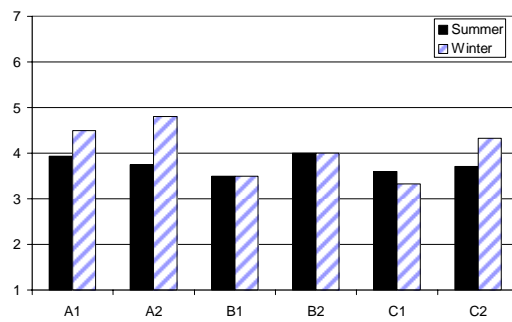
Evaluative scale 1-5, where comfortable = 1 and 4 degrees of increasing intensity of the effect, extremely uncomfortable = 5)

The temperature is preferred to be neither warmer nor colder (4=neutral) for customers.

Variation of the preferred temperature is larger for the staff as shown in b) Figure 6 below.



a)



b)

Figure 6. Average value during Summer and Winter. For positions, A1-C2, see Figure 1.

a) Customer and b) Staff.

Question answered regarding Temperature “Please state how you would prefer to be now...”

Preference scale 1-7, where neutral = 4, much colder = 1 to much warmer = 7.

When finally judgements about the indoor environment was asked in the questionnaire it was better during winter-conditions for customers as shown in a) Figure 7 below. Followed was the

question on how the indoor environment was found. Average value was below 1,5 for all cases (1= comfortable, 2= slightly uncomfortable).

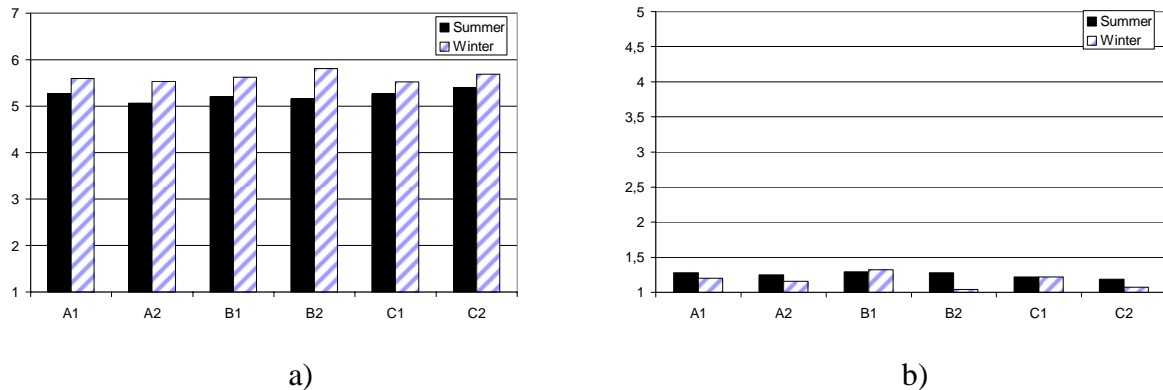


Figure 7. Average value during Summer and Winter. For positions, A1-C2, see Figure 1.  
 a) Question answered “How do you judge the indoor environment at this precise moment?” (Scale of 7 degrees from very bad = 1 to very good = 7, 4 = neutral)  
 b) Question answered “Do you find the indoor environment .....? (Scale 1-5, where comfortable 1 and 4 degrees of increasing intensity of the effect, extremely uncomfortable = 5

## DISCUSSION

The cabinets are cooled and kept cold by chilled air. The chilled air is circulating, through the cold cooling-coil and as an air-curtain in the front (sometimes also from the rear) of the cabinet. The air-curtain works as a barrier between the cold air in the cabinet and the warm ambient air outside the cabinet. The variations in the outdoor condition seem to have the strongest influence on the climate condition outside the display cabinet during summer. During summer are ambient temperatures and enthalpy higher and the air-curtain in the cabinet will be weaker. Due to frost growth on the cooling-coil, the air-flow will be lower, the air-curtain weaker and cold air falls easier out from the cabinet. The cold air will lead to colder ambient, higher temperature differences (head-ankles) and warmer temperatures in the cabinets so that the temperature quality of the goods will be influenced. In order to maintain the same temperatures for the cabinets the cooling-demand for the cabinets will be higher and in order to maintain the same ambient temperature outside the cabinets the heating demand will increase for the heating system which often is in combination with the ventilation system. It is of importance how the ventilation system together with the other systems in the supermarket is controlled in order to condition the air where and most needed. There exist a large need of knowledge and further arguments for the merchandiser and people involved with supermarkets in order to choose efficient systems, the systems in the supermarket includes both the system for storage of chilled and frozen goods as well as the heating and ventilation system. A lack of knowledge for people seems to exist since they believe that goods are kept cold when the ambient areas outside the refrigerated cases are cold. The cabinets are not suppose to cool the customers, the are supposed to keep the good cold. The physical measurements and questionnaires presented will be used in order to define a suitable indoor climate for goods, staff and customers in supermarkets. In this paper physical measurements (temperatures) are presented along with answers from questionnaires (regarding temperatures and indoor environment). Further physical parameters along with answers from the questionnaires concerning humidity, illumination, air velocity, background parameters (age, gender etc) are to presented in future publications. The relation between the subjective and objective data will be used to define a desirable indoor climate.

## **CONCLUSION**

The results show that according to ISO7730 people should be dissatisfied with the thermal comfort, especially during summer. Analysis from physical data, Figure 3, indicates that in all supermarkets especially customers during summer are dissatisfied. Temperature differences (between ankle and head) are higher than 5K. According ISO7730, local discomfort caused by vertical air temperature differences, at least 20% are dissatisfied. However customers in front of the cabinets perceive the temperatures to be in average 3.1 (3 = neutral). Inside the cold room, B1, for customers the temperature is perceived lowest (2,18 for summer resp. 2,59 for winter). During summer customers evaluated the temperature as more uncomfortable compared with the winter. Customers are wearing less clothes during summer compared with winter season which most probably is the reason for that answer. However as answer on how the overall indoor environment in the supermarkets during summer and winter was the average value higher than 5 (4 = neutral, 5 = slightly good). During winter the indoor environment was judged as better than summer conditions. However Customers answered 0.78 higher for summer and 0.45 higher for winter compared with staff. The staff answered an average value of 4.85 for summer respectively 5.18 for winter conditions. The questionnaires however, indicate that customers find the indoor environments as comfortable to slightly uncomfortable. When asked how the temperature is preferred an average of 4.1 was given from customers and 3.9 for staff, see Figure 6. Results from previous presentations on field measurement in this study shows that supermarket A, which use the energy less efficient, also have highest difference on the enthalpy measured in front of the display cabinet. With a lower temperature and humidity the energy use can be lowered. For appropriate indoor air climate and environmentally sustainable supermarkets it is of importance that all systems in the supermarket are optimized in order to run efficient.

## **ACKNOWLEDGEMENT**

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## **REFERENCES**

1. ASHRAE. 1992. ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy, Atlanta: American Society of Heating, Refrigerating, and Airconditioning Engineers, Inc.
2. Foster A. M. 1996, The benefits of computational fluid dynamics (CFD) for modelling processes in the cold chain, FRPERC University of Bristol, Langford, Bristol, BS18, 52 p.
3. Foster, A. M, Quarini G. L. 1998, Using advanced modelling techniques to reduce the cold spillage from retail display cabinets into supermarket stores, Proc. Cambridge Conf., IIR Refrigerated Transport, Storage & Retail Display Conference, IIR, 217-225.
4. Fang L, Clausen G et al. 2000, Temperature and humidity: important factors for perception of air quality and for ventilation requirements, ASHRAE Transactions, 106 (PA): 503-510.
5. EN ISO 7726, 2002, Ergonomics of the thermal environment - Instruments for measuring physical quantities, 51 p.
6. Axell M, Lindberg U. 2005, Field Measurements in supermarkets, Proc. Vicenza Conf., IIR / C. R. Conf. Vicenza, IIF, 8 p.
7. EN ISO 7730:2006 Ergonomics of the thermal environment - Analytical determination and interpretation of the thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, 52 p.
8. ISO 2001, SS-EN ISO 10551, Ergonomics of the thermal environment- Assessment of the influence of the thermal environment using subjective judgment scales, 18 p.