CASE STUDY ON THE THERMAL COMFORT IN A SERIES OF STORES

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0. INTRODUCTION

This case study concerns a very extensive study of the thermal comfort in 6 Belgian establishments of an international store chain. Since years the employees complained about bad thermal comfort: globally too hot during summer and locally too cold and draught problems during winter. The internal heat gains are very high in all stores due to lighting, electrical equipment and the amount of clients. In none of the stores mechanical ventilation nor cooling was provided, except in the food section. There was only natural ventilation due to the air flows between the entrance and exit locks of the clients and the doors of the merchandise depots.
The research is divided in a study of the summer situation and a study of the winter situation [1-3].

1. DESCRIPTION OF THE BUILDING

All stores have a similar structure. The buildings consist of a ground floor with partly a high ceiling and partly a low ceiling. The food section and most of the non food sections are situated on ground level. Each building has also a first floor with a smaller floor surface than the ground floor and a low floor-ceiling distance (3.10m). Hi-fi, television, clothing and sport sections are almost everywhere located on this first floor, as are the offices. A restaurant is connected to the building at the ground level. Fig.1 gives a schematic plan of the buildings.

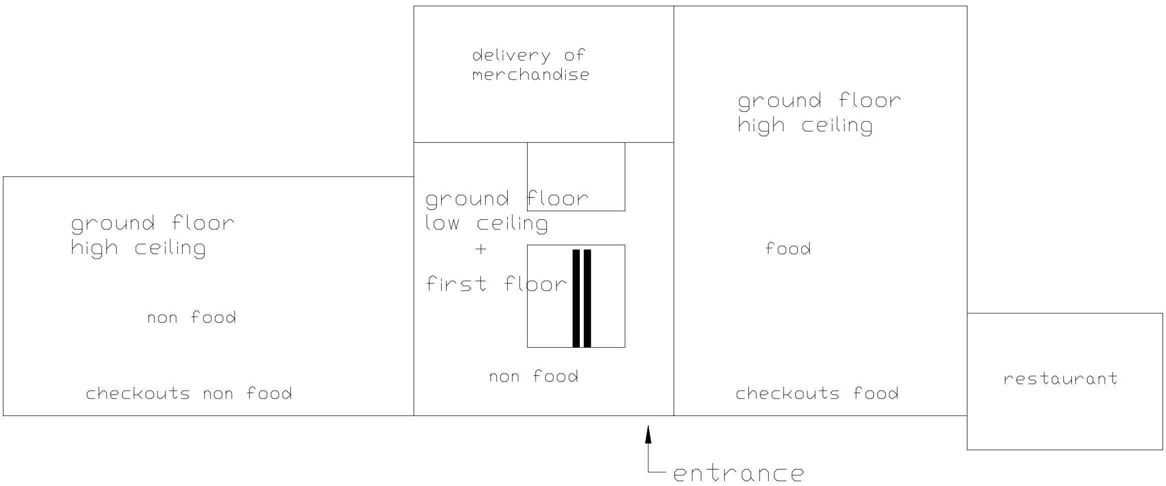


Fig. 1

2. CONCEPT OF THE RESEARCH

The research consists of a survey, measurements and building simulations. The survey is the most important part and forms the reference. With the results of the measurements thermal comfort values are calculated by using the comfort theory of Fanger. These comfort values are compared with the survey results. Furthermore the measurements and simulations are used to deduce the causes of the thermal discomfort. Considering these causes, solutions are proposed, which, after realisation, have been evaluated by a second series of measurements and simulations.

3. SURVEY

In June 1993 a survey on thermal comfort was held in all stores of the company. The aim was to get a complete picture of the complaints about thermal discomfort during summer and about cold and draught during winter. Nearly 51% of the 3500 employees filled in a questionnaire. The questions were divided in general questions and specific comfort questions. The general questions asked after the genus, age, education and seniority of the employee. The aim was to analyse the influence of these parameters on the comfort judgement through variance-analysis. We found out that in this case none of the parameters had a significant influence on the comfort judgement.
The specific comfort questions searched for the comfort judgement in summer and winter by means of the six following questions:

- general temperature impression during summer
- general temperature impression during winter
- sensation of draught at neck and back (winter)
- temperature at legs and feet (winter)
- temperature at the head (winter)
- temperature at the hands (winter)

For the judgement the psycho-physical voting scale of the ASHRAE comfort studies was used:

+3	hot
+2	warm
+1	slightly warm
0	neutral
-1	slightly cool
-2	cool
-3	cold

3.1 Summer results

During summer there are general complaints of strong overheating. In each store the differences between the sections are quite the same. Table 1 gives a summary of the results (mean value, standard deviation between brackets).

location	store1	store2	store3	store4	store5	store6
1	2.44	1.93	2.88	3.00	2.94	3.00
	(0.80)	(1.03)	(0.33)	(0.00)	(0.23)	(0.00)
2	1.14	2.45	2.08	2.39	2.59	2.24
	(1.18)	(0.74)	(0.91)	(0.82)	(0.47)	(0.88)
3	-0.11	0.07	0.00	-0.24	0.18	-0.06
	(1.59)	(1.69)	(1.21)	(0.74)	(1.52)	(0.98)

Table 1: general temperature impression during summer
(1=first floor; 2=non food ground floor; 3=food ground floor)

In the sections on the first floor the evaluation rarely indicates less than "hot". In the non food sections on the ground floor the complaints are similar, but less pronounced. The food sections are equipped with climatisation which explains the mean "neutral" evaluation. The high standard deviation is caused by the intrinsic differences between the different food sections (meat and fresh fish versus bakery).

3.2 Winter results

The survey gives a pronounced correlation (correlation coefficient = 0.95) among the answers for the four specific questions and for the general temperature question. So these specific questions give little new information.
In winter the complaints are mainly about cold and draught. Table 2 gives a summary for all stores for the general temperature impression. Table 3 gives a summary for the draught impression.

location	store1	store2	store3	store4	store5	store6
1	-1.45	-1.03	-1.37	-1.23	-0.63	-1.21
	(0.70)	(0.69)	(0.54)	(0.62)	(0.59)	(0.45)
2	-0.62	0.40	-0.18	0.05	0.05	0.00
	(0.77)	(1.02)	(0.86)	(1.29)	(0.74)	(0.56)
3	0.28	-0.64	1.04	0.95	0.33	0.59
	(0.83)	(1.65)	(0.93)	(1.22)	(0.67)	(0.69)

Table 2: general temperature impression during winter
(1=food, checkouts and merchandise delivery; 2=general services and non food ground floor; 3=first floor)

location	store1	store2	store3	store4	store5	store6
1	-1.34	-1.35	-1.37	-1.29	-1.05	-1.05
	(0.63)	(0.62)	(0.59)	(0.57)	(0.57)	(0.54)
2	-0.42	-0.07	-0.31	-0.12	-0.10	-0.32
	(0.94)	(0.98)	(0.84)	(1.36)	(0.66)	(0.61)
3	0.40	-0.46	0.63	0.64	-0.28	0.47
	(0.94)	(1.27)	(0.86)	(1.07)	(0.87)	(0.92)

Table 3: draught impression during winter
(legend see table 2)

In the food stores, the food checkouts and the merchandise delivery the general temperature impression is problematic: “slightly cool” to “cool”. The temperature impression at feet, legs and hands gives the same judgement. Only the head temperature is judged less problematic. For the general services and in the non food sections at the ground floor the mean evaluation indicates “neutral”; at the first floor it indicates “slightly warm”. There are complaints about draught in the food sections, at the food checkouts, at the merchandise delivery and in nearly all the stores at the non food checkouts and the entrances of the restaurants.

The results of the survey expressed a problematic comfort situation, both in summer and winter. The locations with strongest complaints differ for both seasons.

4. MEASUREMENTS AND CALCULATIONS

4.1 Measurements

Through measurements of the indoor climate we looked for a confirmation of the survey and a specification of the causes of the thermal discomfort.
The measuring campaign consists of two parts: continuous temperature measurements during a longer period in both seasons and short-term measurements with a comfort apparatus at different places.

continuous measurements

In summer the continuous measurements are made in establishment 3 and 4 on the first floor (420m^2) during 7 to 8 weeks. It concerns measurements of surface temperatures on the floor, walls, false ceiling and roof, temperature gradients for two heights and air temperatures at 13 different places at the height of 1.80m (head level).
In winter the continuous measurements are made in establishment 1 and 6 at the checkouts during 10 weeks. Air temperatures are measured at foot level, back level, neck level and head level.
All temperatures are measured with thermocouples, connected to a data logger. To measure only air temperature and eliminate the radiation of the surrounding surfaces the thermocouples were protected with aluminium foil. All points are scanned every 3 minutes and averaged every 5 measurements.

short-term measurements

In each store short-term measurements are made with a comfort apparatus from Brüel & Kjaer: we measured in the summer period at 4 to 5 places each time during a day or a week and in the winter period at 10 to 11 places each time during a few hours. The apparatus consists of a portable tripod with 4 small measuring instruments. It registers every 10 sec. the air temperature, the radiant temperature of two hemispheres, the relative humidity and the air velocity (mean value and standard deviation over 10 sec).
In summer the measurements are averaged per 10 minutes. In each store we measured at the warmest places: on the ground level in the non food section, on the first floor, at some checkouts, in some offices and in the restaurant. The aim was to get a picture of the thermal comfort at the different zones in the store buildings. In the food section no measurements were made during summer, because of the climatisation.
In winter the measurements are averaged every minute to get a clear picture of the fluctuating character of the indoor climate. As the survey showed that during winter complaints are mainly situated at the checkouts, the merchandise delivery, the food sections and the restaurants, measurements are only made for these locations.

4.2 Principles of the applied calculation method

For the analysis of thermal comfort it is important to make a difference between dissatisfaction with global thermal comfort (mostly because of too high or too low dry resulting temperatures) and dissatisfaction because of draught. The results of the survey showed that people are not always aware of this difference. Nevertheless for an extended investigation into the causes of the comfort problems it is necessary to take into account this difference.

global thermal comfort

To judge global thermal comfort we used the thermal comfort theory, developed by Fanger [4]. He deduced a comfort equation based on experiments, which takes into account the most important parameters that influence the sensation of thermal comfort:

- air temperature
- radiant temperature
- relative humidity
- air velocity: mean value and turbulence
- activity level (metabolism)
- clo-value: measure of the thermal quality of the clothing

With this comfort equation he derived a thermal index to ascertain the thermal sensation of persons in a certain climate for a given activity level and clo-value. This thermal index, the “Predicted Mean Vote” (PMV), is connected to the frequently used ASHRAE-scale (see above). It is an indication for the mean vote one can expect to be given by a group of persons in a certain climate, having a certain activity level and clo-value. Thus, it is an expression for the general degree of discomfort for the group as a whole. By measuring the climatic parameters and assuming the activity level and the clo-value for a certain situation the PMV can be calculated for that situation. Connected to the PMV-value, Fanger uses a more comprehensible index, the “Predicted Percentage of Dissatisfied” (PPD). It indicates the percentage of dissatisfied persons one can expect in a certain thermal situation. Each PMV-value corresponds to a PPD-value. It is important to notice that even for optimum thermal conditions (PMV = 0, neutral) the corresponding PPD equals 5%. Due to slight differences between individuals in their sensitivity for thermal conditions, it is impossible to satisfy everyone in a large group of persons sharing the same climate and having the same activity level and clo-value. A situation is considered acceptable if it does not exceed a maximum of 10 % of dissatisfied persons (PMV = -0.5 to +0.5).

The climatic parameters can be measured. For the clo-value and the metabolism Fanger made lists with values depending on the type of work and the type of clothes. Nevertheless the metabolism differs from person to person, even when doing the same job. Also the clothing differs from person to person, although working in the same indoor climate. Therefore it is important to keep in mind that the PMV and PPD, calculated from the measurements, are only directive values, not absolute, exact values, valid for all employees.

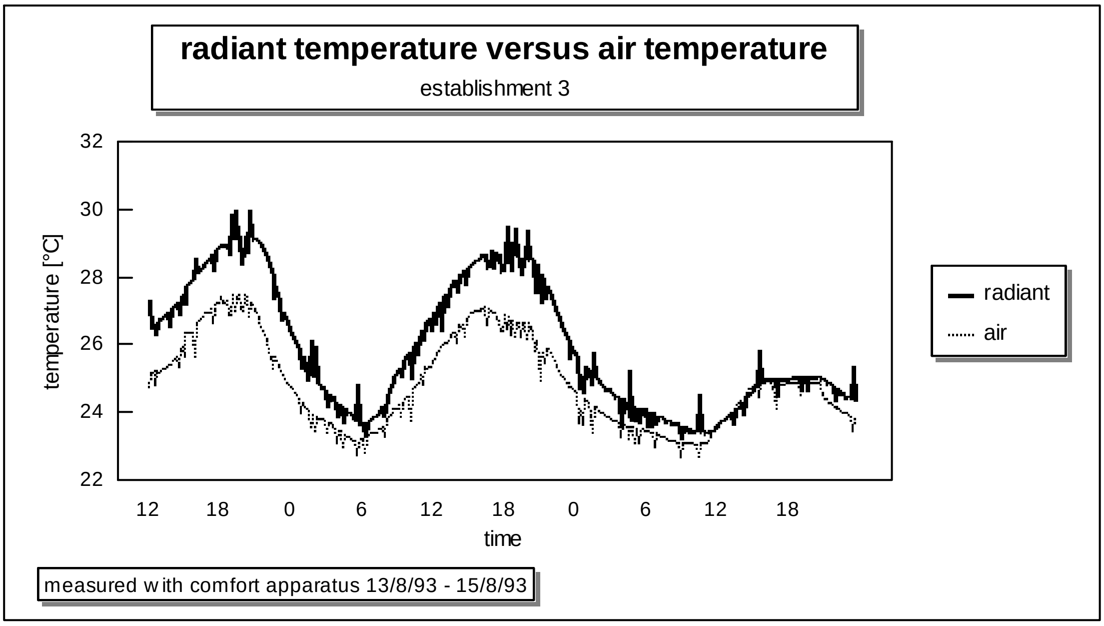
draught

Draught is defined as an unwanted, local cooling of the human body. Fanger et all [5] also developed a model to quantify the draught risk. From this model he derived a thermal index DR (Draught Rating) to ascertain the sensation of draught and to predict and control the percentage of dissatisfied because of draught. Determining parameters are the air temperature, the air velocity and the air turbulence, from which the air turbulence is the most important. Studies showed that a fluctuating air velocity, although with a low mean value, is experienced as much more uncomfortable than a constant, higher air velocity due to the constantly fluctuating cooling of the body [5]. Some particular spots of the human body (neck, back, ankles) are very sensitive for these fluctuations, especially with higher air velocities [6-8]. Therefore it is possible that based on the mean air velocity thermal comfort seems to be acceptable, but that due to too high fluctuations the percentage of dissatisfied because of draught is unacceptably high.
As mentioned above we found out that people are not always able to distinguish between the sensation of high fluctuating air velocities and the sensation of low temperatures, because of their similarity (a local cold feeling).

4.3 Summer results

influence of the radiant temperature

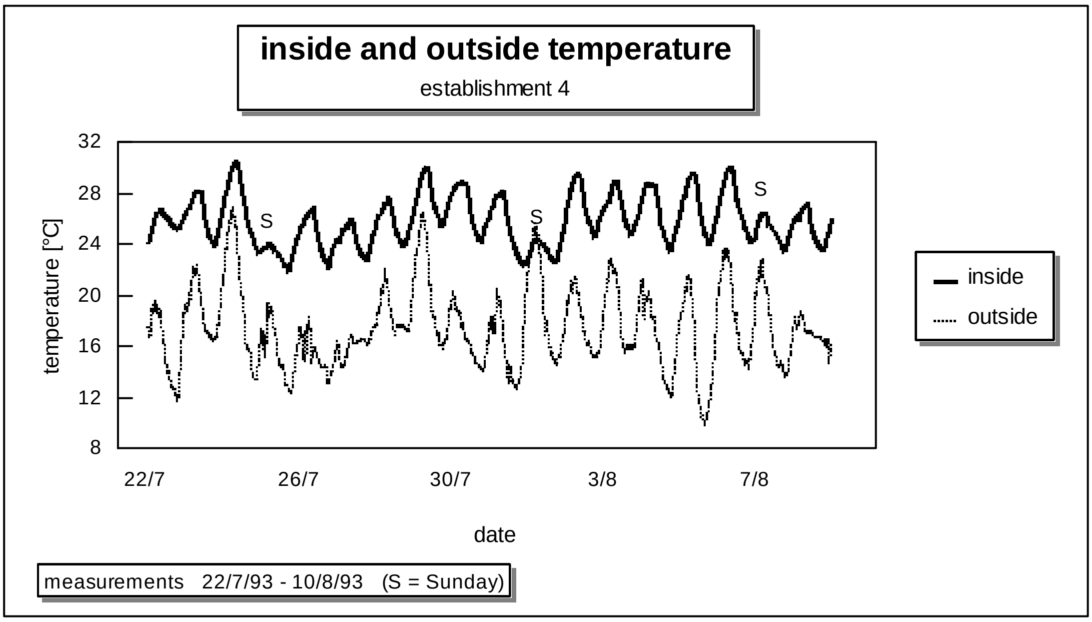
Graph 2 shows that during working hours the inside radiant temperature, as measured with the comfort apparatus, is nearly always higher than the air indoor temperature.
This radiant temperature can be seen as the average of the floor and ceiling surface temperature, as the viewfactors between the sensors and the ceiling or floor nearly equal one, due to the extent of both in comparison with the height of the first floor. It may be assumed that the radiant temperature of the ceiling is much higher than the floor temperature due to the great amount of lamps. By calculation we found for the ceiling a mean radiant temperature of 29.4°C, whereas we measured a mean radiant temperature of 26°C to 27°C. The effect of this higher radiant temperature of the ceiling is not included in the calculated PMV values, but will affect the thermal comfort negatively, especially with the low floor-ceiling distance. It may also explain the complaints about headache, tiredness, etc., as chiefly the head is very sensitive for high temperatures and most exposed to the radiation.



graph 2

influence of the outdoor climate versus internal heat gains

Graph 3 gives the indoor and outdoor air temperature for establishment 4 for the whole measuring period. The not-working days (Sundays) are marked with an S.



graph 3

On first sight it seems that during working hours the inner temperature does depend on the outer temperature, as the peaks inside coincide with the peaks outside. Nevertheless table 4 shows that for establishment 3 the mean indoor air temperature is 8 to 9°C higher than the mean outdoor air temperature. Similar results are found for all six stores. This can only be explained by the high internal heat gains (see table 8).

15/7/93 -	INSIDE			OUTSIDE		
13/8/93	min. [°C]	max. [°C]	mean [°C]	min. [°C]	max. [°C]	mean [°C]
total period	22.2	30.1	26.2	9.0	27.0	17.1
working hours	22.5	30.1	26.7	10.2	27.0	18.3
Sundays	24.1	27.2	25.8	11.9	25.7	18.3

Table 4: Comparison between inside air temperature at establishment 3 (min, max, mean) and outside air temperature (min, max, mean)

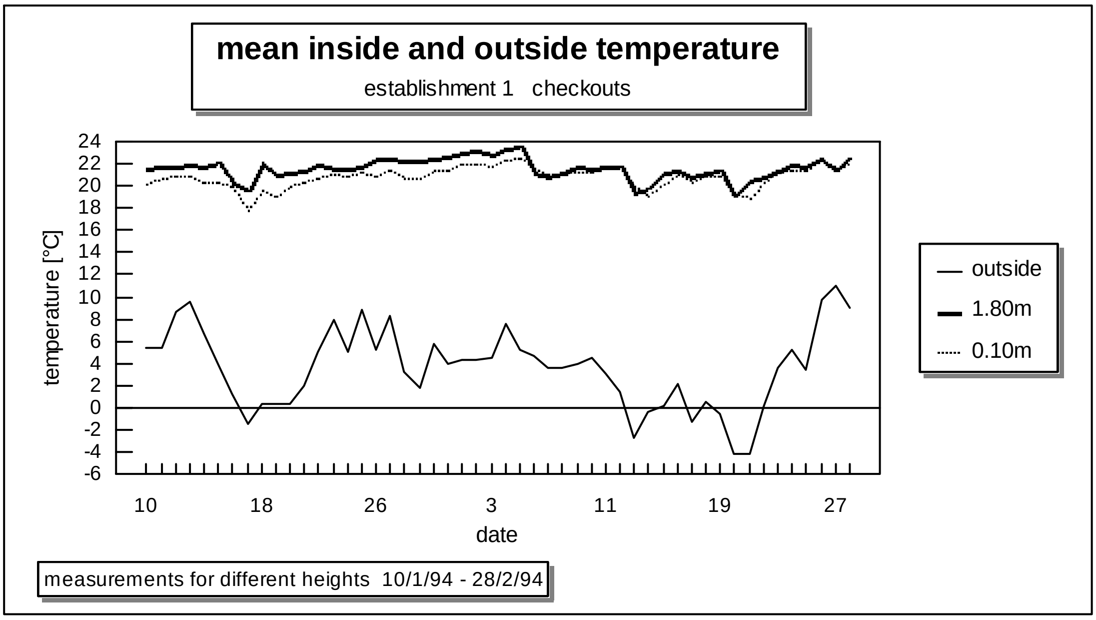
The fact that even outside the working hours high indoor temperatures are reached, can be explained by the short cooling down period and the lack of night ventilation. In the morning the building therefore is still warm and due to the high internal heat gains and the limited heat capacity of the building, automatically high temperatures are achieved during day. Even for days with low summer outdoor temperatures, high indoor air temperatures are reached. This can only occur because of the high internal heat gains and not because of the outdoor climate:

establishment 3 14°C<outside<20°C → 24°C<inside<29°C
establishment 4 17°C<outside<21°C → 26°C<inside<30°C

4.3 Winter results

influence of the outdoor climate

Graph 4 shows the daily averaged indoor and outdoor temperatures for the continuous measurement at the checkouts in establishment 1.

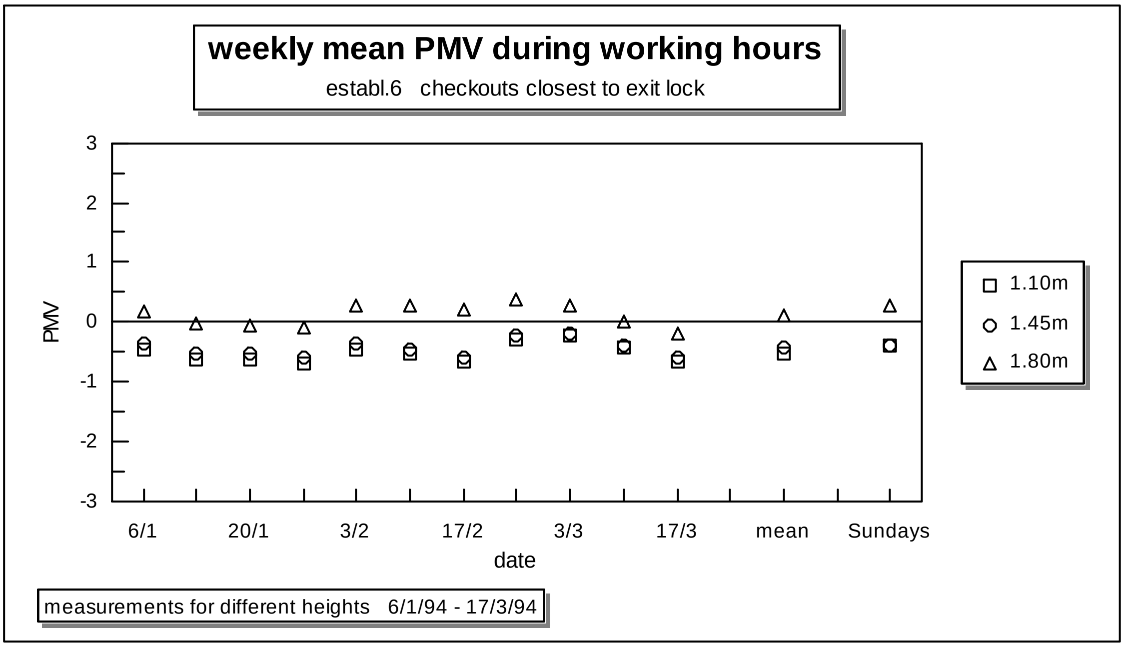


graph 4

Comparing indoor and outdoor temperatures we find a similar tendency. A strong temperature fall outside causes also a temperature fall inside. It has to be mentioned that the mean outdoor temperature during the winter of 1993-1994 was higher than in the reference year (monthly average 3 to 7°C in 1993-1994 in comparison with 3 to 4°C for the reference year). The magnitude of the temperature fall inside depends strongly on the height above the floor and the distance between the checkout and the exit lock. The lowest temperature is always reached at the checkout closest to the exit lock (difference of 2 to 4°C between the closest checkout and the furthest checkout).

global thermal comfort versus draught

The measurements show a clear difference between the temperature situation and the draught situation. The PMV's calculated with the measured temperatures are nearly all situated in the comfort zone (graph 5).



graph 5

Thus, in general the thermal comfort is satisfactory, except for some specific points. The draught on the contrary creates an unacceptable situation. Especially at the entrance and exit locks and the delivery of the merchandise we measured high draught ratings. The checkouts appear to be the most problematic locations, especially those close to the exit lock. Table 5 gives a comparison between the draught ratings for the checkouts based on the continuous measurements and on the short-term measurements with the comfort apparatus.

Calculated draught rating [%]	short-term measurem.	continuous measurem.
checkout far from exit	5 to 20	15 to 20
checkout near exit	30 to 90	40 to 75

Table 5: comparison of draught rating between measurements with comfort apparatus and continuous measurements

The values of the short-term measurements can be seen as a picture at a given moment, whereas the continuous measurements give more averaged values. Generally it shows that far from the exit lock the draught risk is on the verge of acceptable, whereas near to the exit lock the situation is completely unacceptable.

5. COMPARISON SURVEY - MEASUREMENTS

Summer situation

Comparing the results of the measurements with the survey, we notice that similar trends are found in both calculations and survey: too warm at the first floor (calculated PMV = 2), meanwhile on the ground level comfort values vary between “slightly warm” to “warm”, with a higher tendency to ”warm”. For some sections the PMV from the survey is definitely higher than from the calculations. Those calculations were originally based on a clo-value of 1.2 and metabolism of 200W or 120W (see table 6). We looked which metabolism had to be used to receive the results of the survey. Values are given in the third column of the table between brackets.

PMV establishment n° and location	survey	measurem 200/1.2	simulation survey
1 first floor	2.44	1.94	2.47 (300W)
2 check out	2.51	1.68 (120W)	2.24 (300W)
3 ground floor	2.08	1.56	2.13 (300W)
4 ground floor	2.39	1.71	2.26 (300W)
5 check out	2.95	0.88 (120W)	2.80 (400W)
6 first floor	3.00	1.88	3.22 (400W)

Table 6: comparison between PMV survey and calculated PMV from measurements

Values of 300 to 400 Watt suppose heavier physical work than what normally is done at the store chain. This discrepancy probably can be explained by the fact that the employees wanted to emphasise the lack of thermal comfort of many years by giving a higher (more negative) vote than can be observed in reality.

Winter situation

Table 7 gives a summary of the percentages of dissatisfied due to temperature and draught for the survey and the measurements.

Comparison survey - measurements
% of dissatisfied due to temperature and due to draught

department	survey		measurements	
	temp	draught	temp	draught
ESTABLISHMENT 1				
food	°47.1	31.0	15.3	47.8
checkout food	°71.6	76.8	7.3	27.6
checkout non food	°47.7	52.5	5.2	48.2*
ESTABLISHMENT 2				
food	°53.1	32.4	8.2	37.2
checkout non food	5.2	40.8	5.0	52.8*
delivery merchand.	°29.2	48.7	9.2	11.6
restaurant	8.7	38.7	5.4	30.5*
ESTABLISHMENT 3				
food	°29.2	24.1	24.1	44.0
checkout food	°80.7	81.5	14.7	93.3
checkout non food	44.4	78.5	42.9	50.4
ESTABLISHMENT 4				
food	°37.2	19.9	11.8	27.9
checkout food	°87.3	78.5	12.8	26.8
checkout non food	7.5	52.0	12.5	21.5*
restaurant	13.3	16.5	5.1	38.2*
ESTABLISHMENT 5				
food	°44.4	32.8	8.5	14.4
checkout food	79.4	66.0	78.5	82.9
checkout non food	10.2	39.2	5.1	13.0*
delivery merchand.	°47.7	46.6	5.2	22.2
ESTABLISHMENT 6				
food	30.1	14.7	11.6	12.2
checkout food	°93.8	83.4	11.6	40.1
checkout non food	11.8	5.1	11.3	19.8*
delivery merchand.	°54.2	45.5	6.0	27.6

Table 7: summary of the percentages of dissatisfied for the survey and the measurements

There is a greater difference between the results of the survey and those of the measurements for the winter situation than for the summer situation. For locations with higher temperatures (restaurant, checkout non food; marked with a *) both in the survey and the measurements the distinction is made between the thermal situation ("neutral") and the draught situation (mostly unacceptable: > 10 to 15%). For locations with lower temperatures this distinction is less clear in the survey, whereas based on the measurements we do find a clear difference between the thermal situation and the draught situation. In 60% of the locations the PPD of the survey is much higher than that of the measurements. This means that for these places in general the judgement of the employees on the global thermal comfort is more negative than what is found with the measurements. For the judgement on the draught situation the agreement between survey and measurements is better (60%). For some locations the measurements show an acceptable thermal situation and an unacceptable draught situation, whereas the employees consider both the thermal and the draught situation as unacceptable (marked with a °). It is notably that for 60% of these locations the percentage of dissatisfied due to temperature from the survey does agree with the calculated draught rating. This confirms the assumption that people not always can distinguish the discomfort due to too low temperatures and the discomfort due to draught.

The research shows that during winter there is a draught problem and not so much a temperature problem. Especially near the entrance and exit locks of clients and merchandise the air velocities and turbulences are so high that they create an unacceptably strong draught. So solutions have to be searched in stopping these turbulent draught flows.

6. BUILDING SIMULATIONS

With the building simulation program CAPSOL [10] we simulated the thermal indoor climate during summer for the non food sections of the different stores. For the outdoor climate we took the month of July from the TRY-year for Ukkel (near Brussels). Simulations are made for the first floor, the part of the ground floor with high ceiling and the part with low ceiling. Aim was to analyse the influence of the internal heat gains due to lighting, electrical equipment and clients, the influence of solar gains and of the location in the building.
The winter situation is not simulated. The constantly changing interaction between indoor and outdoor climate through the entrance and exit locks creates a very complex situation that hardly can be simulated in a correct way.

influence of the internal heat gains

Table 8 gives the internal heat gains for the different stores with the distribution for the different zones. It includes the gains due to lighting and electrical equipment. The table also gives the mean daily amount of clients per store. Each client represents on average 120 Watt. For the simulations the mean daily amount of clients is transformed into a mean hourly amount that, dependent on the moment of the day, is multiplied by a weight factor.

establishment	ground floor high ceiling [kW]	ground floor low ceiling [kW]	first floor [kW]	clients [amount/day]
1		68.1	108.9	5100
2		95.2	61.4	5050
3	100.2	54.6	83.1	5600
4	55.7	43.3	91.6	3300
5	115.5	96.9	53.7	5600
6	92.1	62.1	81.4	2400

Table 8: internal heat gains with distribution over the different zones and daily amount of clients per establishment

The simulation has investigated the effect of the internal heat gains by first simulating each building without internal heat gains. The results are given by percentages of the working hours that certain temperatures are exceeded (>26°C, >28°C, >30°C). Although there are differences between the stores, a global tendency can be observed: when there are no internal heat gains (IHG), there is a very strong fall of the indoor temperature:

- ground floor, high ceiling: temperature almost never >24°C
- ground floor, low ceiling: temperature never >20°C
- first floor: very strong fall: temperature almost never >26°C, whereas with IHG the temperature often >30°C

influence of solar gains

Some stores have very few windows in the shopping zone, others have much more windows. Comparing them for IHG = 0 does not show a considerable difference. This demonstrates the minor role of solar gains on the indoor climate.

The simulation of the buildings for the summer period including the internal heat gains gives high to very high indoor temperatures. The highest values are found at the first floor, whereas at the ground floor also high temperatures are reached but less pronounced. So in general the simulation shows the same tendencies as found in the survey.

7. SOLUTIONS

7.1 Summer situation

To improve the thermal comfort during summer we analysed the possibilities of mechanical ventilation and a limitation of the internal heat gains.

7.1.1 Ventilation

The preferential solution is forced and controlled ventilation with fresh air. By simulation we analysed the effect of night-ventilation, of day- and night-ventilation and of the magnitude of the ventilation rate.

the magnitude of the ventilation rate

To avoid complaints of draught the ventilation rate has to be restricted during working hours. Outside the working hours this problem does not count, so normally high rates can be applied. Simulation shows that for night-ventilation the efficiency increases very slowly once the ventilation rate exceeds 3.5/hour. Furthermore a higher rate includes higher energy use. So for further calculations we only considered the following ventilation rates:

day-ventilation	2.5/hour
night-ventilation	3.5/hour

night-ventilation

Night-ventilation already improves the thermal comfort, but not sufficiently. Due to the high internal heat gains and the lack of heat capacity in the building, the building heats up quickly during the day.

day- and night-ventilation

Day-ventilation contributes much more efficiently to the decrease of the indoor temperature. A disadvantage is the restriction of the ventilation rate to avoid draught during working hours. The simulation showed a remarkable improvement of the thermal comfort by a combination of day- and night-ventilation. On the ground floor acceptable temperatures can be achieved in this way. Nevertheless on the first floor even with day- and night-ventilation we still get temperatures above 28°C. So additional cooling has to be considered.

7.1.2 Restriction of the internal heat gains

All results show that especially the high internal heat gains cause the strong heating up of the building. We proposed some possibilities to restrict the heat gains so that the ventilation flow needed could be lowered and the necessity of a cooling system could be avoided.
Possibilities are:

- to extract the ventilation air through the lamps, so the convective part of the heat emission by the lamps is removed directly; this requires special lamps
- to use lamps with lower power
- to decrease the amount of lamps

Especially the last two proposals are not at all evident, because of the very strict requirements for colour reproduction and light intensity, asked by the company.

7.2 Winter situation

The measurements showed that the problems during winter are caused by too strong draught flows near the entrance and exit locks. The checkouts are the most problematic locations. The proposed solution consists of rebuilding the locks to break the draught current towards the checkouts.

8. EVALUATION OF THE SOLUTIONS

Both for the summer and the winter situation a store was chosen as pilot-project to realise the proposed solutions and to evaluate them before the application in all other stores.

8.1 Summer situation

For the summer situation establishment 6 was chosen as pilot-project because of its averaged position concerning the thermal climate compared to the other stores.

ventilation system

Two types of ventilation systems are installed on the first floor: split-groups that suck in indoor air, cool it and blow it back into the room and air-groups that, dependent on the outside temperature, mix fresh air with indoor air to minimise the cooling load. The aim was to analyse the improvement of the thermal comfort and to compare both ventilation systems by continuous measurements and short-term measurements.

Based on our results an independent consultancy office worked out a ventilation configuration for both the ground floor and the first floor. The space is divided in different zones, each with one or more split- or air-groups with one suction opening and several blow-in openings. The split-groups are cheaper to install, but use more energy than the air-groups. For the air-groups they used existing groups that were passed into disuse. By using outside air the energy use will be reduced, but the installation and maintenance costs are higher than for the split-groups.

measurements

The continuous measurements are done from 2 October 1995 to 18 October 1995 on the first floor in one zone with a split-group and one zone with an air-group. In each zone we measured the air temperature under a blow-in opening, between two blow-in openings and on a location as far as possible from a blow-in opening. All points are scanned every 3 minutes and averaged every 5 measurements.
In the same period we measured on the first floor on 23 locations with the comfort apparatus. Measurements are made every 10 sec. and averaged every minute.
The aim was to get a picture of the variation of the thermal comfort in each zone for different heights and of the variations between the zones.

results

The ventilation system realises a decrease of the PMV and PPD. In table 9 a summary is given for the first floor.

	present situation	original situation	difference
PMV [-]	1.14 - 1.47	1.63 - 1.83	0.36 - 0.48
PPD [%]	33.7 - 49.7	57.3 - 67.5	17.8 - 23.6
DR [%]	7.2	4.5	-2.7

Table 9: Comparison between original and improved comfort situation

Both systems are adjusted for a blow-in temperature of 21°C. The mean air temperature decreases from 27°C to 22.3°C. The radiant temperature decreases from 27°C to 23.3°C. As table 9 shows the PMV decreased with 0.42. So comfort improvement has been realised, but it is still not optimal due to the rather high radiant temperature and the rather high activity level of the employees.

Analysing the homogeneity of the zones we find that the temperature difference over the height never is more than 1°C and over the zone never more than 1.5°C. So we can conclude that both ventilation systems create a very homogenous temperature field.

Comparing both ventilation systems from a comfort point of view, we find very little difference. Table 10 gives a summary of the air temperature, the PMV, PPD and DR, averaged for the zones with split-groups and the zones with air-groups.

210W/0.8clo	air-group		split-group	
	on top	on floor	on top	on floor
temp [°C]	23.0	22.3	22.1	22.0
PMV [-]	1.39	1.33	1.32	1.29
PPD [%]	44.2	41.9	41.8	40.6
DR [%]	10.0	10.5	10.3	11.0

Table 10: averaged comfort values for the air-groups and the split-groups

As can be seen in table 10 both systems realise an equivalent thermal comfort, with a similar temperature homogeneity and air velocity.

8.2 Winter situation

For the winter situation establishment 5 was chosen as pilot-project as they were already doing renovations there. They installed new entrance and exit locks, so that there is never a direct connection between the indoor and outdoor climate. They did not ask us to do new measurements, which probably means that there were no complaints anymore.

9. CONCLUSIONS

A very extensive comfort research was done by means of a survey, measurements and building simulations. The survey formed the most important part of the research. The measurements however confirmed the results of the survey: strong overheating during summer and local draught problems during winter. The measurements and building simulations were necessary to deduce the causes of the thermal discomfort. It showed us the importance of the internal heat gains for the overheating during summer, the influence of the ceiling radiant temperature and the need for a ventilation system. It also proved the difficulty for people to distinguish between temperature problems and draught problems.
The proposed solutions were evaluated after installation in one store. They realised an improvement of the thermal comfort, but did not give complete satisfaction for some problems. It is up to the company now to apply the improvements in the other stores and to evaluate the judgement of the employees on the new situation.

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