# PERFORMANCE OF VENTILATION SYSTEM AND PERCEIVED AIR QUALITY IN A SUPERMARKET AND A DEPARTMENT STORE

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## ABSTRACT

In this study the performance of air-conditioning system was evaluated in a suburban supermarket (5000 $m^2$) with a large food market and having two storeys and in a large department store (12000 $m^2$) in the centre of Helsinki. A self-administrated questionnaire where indoor air quality problems were asked was distributed to the employees. The main indoor air quality problems were dry air, dusty air and draught in both buildings. In the supermarket the proportion of employees complaining of too low room temperature was very high. Also the air quality in the supermarket was judged more often poor than in the department store. Perceived indoor air quality was evaluated in both buildings. The air quality was poorest in areas having leather or wood products, shoes and perfumes.

**KEYWORDS:** department store, supermarket, perceived air quality, air conditioning, thermal environment

## INTRODUCTION

Shop environment is different from office environment in many ways. In countries of a cold climate like Finland, there are problems during winter to meet the thermal comfort requirements of customers and employees because of differences in clothing. Pollution loads from goods varies between different areas. Goods are new with high emission rates. Loads from customers depend also on the time of day. The lay-out of sales area changes also often which makes it difficult to select the outdoor air rates according to the pollution loads.

## METHODS

This study was conducted in two buildings. The performance of air conditioning systems were analysed, thermal environment measured, a questionnaire for employees was distributed and perceived air quality was judged by an odour panel.

### Supermarket

This supermarket was part of a large shopping centre located 6 km north-east from the centre of Helsinki. The store built 15 years ago had two floors, with floor area of 2100 $m^2$ and 2600 $m^2$. The main entrance was located in the first floor where the food and daily consumer products and a bakery were situated. The second floor consisted of a wide selection of different consumer products like clothes, shoes, music, home products, sports etc. The average floor height was 5-6 m.

The design outdoor air flow was 3 l/sm$^2$. The main supply air rates were checked by duct measurements. The air distribution was mixing type. The air conditioning system had heat recovery, economizer with air recirculation, air filtration, heating and cooling. Both floors were divided into two control zone. The supply air temperature was controlled by the indoor air temperature. The outdoor air rate was controlled by the outdoor air temperature during winter and by the outdoor air enthalpy during summer.

The proportion of outdoor air in supply air was decreased when outdoor temperature decreased. At -18$^o$C the percentage of outdoor air was 40% (1.2 l/s,m$^2$). The percentage of outdoor air could be decreased even more when the outdoor temperature felt below -18$^o$C and could be as low as 20% (0.6 l/s,m$^2$).

No return air was used when the supply air temperature after the heat recovery was 10$^o$C or more. The design value of the supply air temperature was 17$^o$C. When the outdoor air enthalpy was higher than indoor air enthalpy, the return air rate was increased to 80%.

**Department store**

The building located in the city of Helsinki and built in 1952. The building has 11 floors above ground level and two underground floor. The department store was located in five first floor above the ground the 5th floor. In the upper underground floor there was large food department which was not included in this study. The department store has been renovated and expanded in the years 1985 and 1995. The total sales area was 14 000 m$^2$. There was a glazed atrium (height 15 m) inside of the building. Room heights varied from 2.5 to 5.6 m.

Three main air conditioning systems supplied different floors and zones of department store. The air conditioning system had heat recovery, air filtration, heating and cooling coils but not return air. There were 8 cooling units in the 4$^{th}$ and 5$^{th}$ floors. The design supply air flow was 3-4 l/sm$^2$. The air flows were checked and the ventilation system was balanced before measurements. The fans had variable speed control, 50-100%. The air distribution system was mainly mixing type. The room temperature control principles were in order of ; Control of heating coil and heat recovery rotation speed. If the room temperature is still rising then the cooling coil will be opened and finally increase of fan speed.

In each floor there was at least $CO_2$-sensor per air-conditioning unit, minimum of five sensors per unit. If the $CO_2$-level exceed's 1000 ppm even in any sensor the fan speed will be increased until the target value was been reached. This means the supply air rates was increased in all the five floors equally.

**RESULTS**

**Thermal environment in the supermarket during winter and summer**

Measurements were made in February when the outdoor temperature was -10$^o$C. Thermal climate on the ground floor was strongly influenced by the cold outdoor air flowing through the main entrance to the cashier area and cold air currents from refrigerated display cases. The air temperature at the ankle level was between 11 and 15$^o$C. At the height of one metre the air

temperatures were between 13 and 16°C. There was a large vertical temperature difference between the ceiling and floor levels. The exhaust air temperature was about 20°C.
The temperature sensors on the ground floors were demanding warm supply air to the occupied zone. The supply air temperatures were 26°C in the cashier area and 31°C in the food area.

In the second floor the supply air was well mixed, the vertical temperature difference between the ceiling and the floor level was less than 1 K. There was some cooling need because the supply air temperature was 17°C and the exhaust air temperature 20°C. The ground floor was 3-7 K cooler than the second floor.

During the measurements in June the outdoor air temperature was 27-28°C and the relative humidity 40%. The cooling capacity of the air conditioning system was insufficient because the supply air temperatures were about 22°C during the maximum capacity. Due to internal sources of coldness the indoor temperature in the occupied zone of the ground floor was 16-21°C but in the second floor the air temperature was 26°C.

**Thermal environment in the department store during winter and summer**

Measurements were made in March when the outdoor temperature was -10°C and 0°C. The target value for indoor temperature was 19°C. The supply air temperature was 16-23°C. There were great variations in indoor air temperature depending on the location and type of department. The most common value was 20-21°C. The departments on the street level had lower room temperature, 18-19°C in spite of higher supply air temperature. In the light appliance department on the 5th floor with high heat loads the room temperature was even over 25°C. The relative fan speeds of the three main air-conditioning units were 68, 89 and 100%. The highest fan speed was in the unit serving also light appliance department.

During August the outdoor air temperature was 27°C and the outdoor air relative humidity 45-50%. The supply air temperatures were 15-18°C. The measured indoor temperatures varied from 22.5 to 25°C.

**$CO_2$-levels in the department store**

Continuously $CO_2$-levels were obtain from 15 locations in the department store by the control system of the air-conditioning system. During normal occupancy the measured $CO_2$-levels never exceeded 600 ppm. Before Christmas and sales days in October the highest $CO_2$-levels were 900 ppm in the street and second floor. In the 4th and 5th floor the highest $CO_2$-levels were a little bit over 500 ppm. Demand based control of ventilation seemed to be necessary only when the outdoor air temperatures falls under -10°C.

**IAQ questionnaire for employees**

A self administrated questionnaire was distributed to the employees working full or almost full time in these two stores. The questionnaire was modified from the Helsinki Office Environment Study [1]. The response rate was 50%. The amount of responded employees was 25 and 100. Table 1 shows the results from the questionnaire. For comparison the results from the Helsinki Office Environment study are also shown [1].

Table 1. The prevalence of indoor air quality complaints.

| Complaints | Prevalence, % | | |
|---|---|---|---|
| | Supermarket | Department store | Helsinki Office study |
| Too warm | 30 | 30 | 15 |
| Too cold | 56 | 30 | 7 |
| Draught | 60 | 40 | not measured |
| Dry air | 52 | 42 | 29 |
| Humid air | 0 | 2 | <1 |
| Dusty air | 52 | 50 | not measured |
| Static electricity | 18 | 2 | not measured |
| Unpleasant odour | 40 | 16 | 14 |

The analysis of the questionnaire and measurement resulted the following problems:

- the most serious air quality problems exist outside of the sale area; traffic and loading areas, waste management areas, stocks
- exposure to dust, smells and chemicals while managing of goods in stocks
- the street floors have problems with cold outdoor air penetrating inside during winter.
- too high temperatures in the areas with high heat loads like lighting appliances and areas with low ceiling height
- too low temperatures in food departments areas where refrigerated display cases are located
- poor placement of air distribution devices in the cashier areas
- transfer of odours from kitchen to sales area

**Perceived air quality**

The perceived air quality (PAQ) in the outdoor air intakes, supply air and several points inside buildings were evaluated with a trained panel with 8 (supermarket) or 14 persons (department store). The judgements were made during normal occupancy at 13 in afternoon in Mondays. The $CO_2$-concentrations during the measurements in the department store were between 400 and 600 ppm. No return air was used in the supermarket and fan speeds were set up to 100% in the department store. The outdoor supply air rate in the supermarket was 3 l/sm$^2$ and in the department store 3-4 l/sm$^2$. Between each measuring point the olfactory sense of panel members was refreshed with outdoor air.

Results are shown in Tables 2 and 3. In the supermarket is shown also the predicted proportion of dissatisfied with air quality (PPD) calculated from the decipol values.

Table 2. Perceived air qualities (PAQ) in the supermarket.

| Space | PAQ (decipol) min - max | PAQ (decipol) mean | PPD (%) |
|---|---|---|---|
| Outdoor air intake | 1-3 | 2.1 | |
| Supply air | 1-4.7 | 2.5 | 11 |
| Exhaust air | 3-8 | 4.9 | 30 |
| Fish | 2-16 | 6.5 | 36 |
| Bakery | 1-13 | 5.7 | 32 |
| Vegetables | 1.5-10 | 4.8 | 28 |
| Cash desks | 2-6 | 4.2 | 24 |
| Toys | 3-6 | 3.9 | 22 |
| Music | 2-8 | 3.9 | 23 |
| Gardening | 4-15 | 8.1 | 47 |
| Home appliances | 2-7 | 3.9 | 23 |
| Sport shoes | 2.5-17 | 8.2 | 47 |
| Pillows, towels | 2-5 | 4.1 | 25 |
| Carpets | 5-13 | 7.7 | 47 |

Table 3. Perceived air qualities in the department store.

| Space | PAQ (decipol) min - max | PAQ (decipol) mean | Outdoor supply air rate $l/sm^2$ |
|---|---|---|---|
| Underground service tunnel | 9-20 | 13.7 | unknown |
| Outdoor air (street level) | 0-7 | 2.7 | --- |
| Outdoor air intake $7^{th}$ Floor | 0-2 | 0.8 | --- |
| Supply air $5^{th}$ floor | 0-3 | 1.4 | --- |
| Perfumes | 1-8 | 4.5 | 4 |
| Bags | 0-5 | 3.0 | 4 |
| Coats | 0.6 | 2.5 | 4 |
| Leather coats | 1-5 | 3.1 | 4 |
| Shoes | 0-4 | 2.3 | 4 |
| Children's cloths | 1-5 | 2.1 | 3 |
| Toys | 2-4 | 2.5 | 3 |
| Sports | 0-4 | 2.0 | 3 |
| Young fashion | 1-12 | 4.4 | 3 |
| Videos and records | 0-4 | 1.9 | 3 |
| Books | 1-6 | 2.9 | 3 |
| Glassware | 1-6* | 3.3 | 3 |
| Light and electricity | 1-5 | 2.1 | 3 |
| Home wares | 0-4 | 1.6 | 3 |
| Interior decoration | 1-5 | 2.8 | 3 |

* temporary odours from the coffee room

## DISCUSSION

During the wintertime it is difficult to find such indoor air temperature which would fulfill both customers and employees because the former group are dressed in outdoor clothes and the latter group in indoor clothing. In order to keep customers' thermal sensation during winter at acceptable level, room temperature in shops should be as low as 14-15$^{o}$C. This requires a supply air temperature less than 5$^{o}$C. So there are few possibilities to use lower indoor set value lower than 18$^{o}$C. Local heater can be used in such a points where employees are working permanently.

The indoor climate in the department store was judged equally or better than in the supermarket by the employees. Shops were judged more often too warm, which was partly as a result of higher activity of employees and very high internal heat loads in some areas. Shops were also cooler than other indoor environments because of cold food department and workplaces nearby entrances. High air change rates and problems with air distribution increased the percentage of employees complaining draught. During low occupancy periods the outdoor air rates per person are very high, which makes the indoor relative humidity very low.

The control of cold air currents from refrigerated display cases and entrances should be improved. The air distribution efficiency while supplying warm air must be improved. The use of local cooling units rather than use of very high supply air rates in the areas with high heat loads like lightning appliances is preferable.

There were great differences in perceived air quality between different locations in the supermarket and the department store. The supply air rates should be controlled much more based on internal pollution sources. The control of room temperature in stores requires much higher outdoor supply air rates than the control of the indoor air quality by the $CO_2$-control.

## ACKNOWLEDGEMENTS

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## REFERENCES

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