Air quality in indoor swimming pools: associations with air distribution, water treatment, aerosols and airway symptoms

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ABSTRACT

Adverse health effects have been reported in indoor swimming pools. Contributing factors may include high air humidity encouraging microbial growth, ventilation, aerosols and volatile organic compounds, as well as microbiological and physico-chemical quality of water. These factors were analyzed in five indoor swimming pools, of which four were to be renovated in the near future and one was only two years old. In addition, technical investigation of building structures, ventilation system, and physical conditions indoors was conducted. The results emphasise the importance of ventilation arrangements in the design and engineering of indoor swimming pools.

1. INTRODUCTION

Among the most important factors in indoor swimming pools are air conditioning and air quality. Indoor swimming pool should be depressurized during every season to make structures invulnerable to potential moisture and microbial damage. Swimmers have been reported (Potts 1996) to complain of skin and eye irritation, throat pain, stuffy nose and in the more serious cases the respiratory allergy. The swimmer takes all the breathing air just above the water level.

The aim of the study was to investigate the effectiveness of the air conditioning system, (e.g. availability of fresh air at the water level), thermal conditions, by-products of water treatment and indoor air quality. The concentration and diversity of airborne microbes and volatile organic chemicals were used as indicators of indoor air quality. Questionnaire to evaluate the perceived air quality and symptoms was conducted among the swimmers. The technical questionnaire was provided for municipal workers in the pool buildings.

This is the third part of our comprehensive research project on indoor swimming pools. The earlier parts have been reported by Jauhiainen et al 2002 and Yli-Pirilä et al 2003.

2. SWIMMING POOLS

2.1 Structures and water treatment techniques

The indoor swimming pools located in the different areas of Finland. The four buildings (A, B, C and D) had the main concrete wall constructions quite similar and the building A had also the roof constructed from concrete. The structural descriptions are presented in Table 1. The swimming centre B was the largest and the newest one. Problems with dampness and leaks in the roof structures could be observed in each of the buildings.

Sodium hypochlorite was used for disinfecting the water in the pools A, C and D. Both the pools B and E utilized ozonation in addition to disinfection with sodium hypochlorite in water treatment.

Table 1: Technical information of the five swimming pools and water treatment cycles per day

	A	B	C	D	E
construction year	1968	1999	1970	1966	1980
wall /roof - concrete c - wood w	c/c	c/w	c/w	w/w	c / c+w
area m^2	400	1250	488	396	249
volume m^3	14700	57000	4500	8000	2900
disinfectant - chlorine c - ozone o	c	c + o	c	c	c + o
cycles of water treatment	5	4	7	2	6
recirculation of supply air	10%	80%	not known	*85%	*60%
study year	2001	2001	2001	2002	2002

*estimated by the ratio of formaldehyde content in supply and exhaust air. See section 4.4

2.2 Ventilation systems

The other old swimming pool A was equipped with an old HVAC system needing renovation. Problems caused by freezing, snow and rainwater had been with one of the outdoor air grilles. The filtering of the outdoor air was not effective, and there were leaks in the filters. Whole the ventilation system was dusty and dirty. The exhaust fan of the old swimming pool was not working. The use of air conditioning had been limited during wintertime because of the harmful decrease in temperature in the indoor swimming pool. The whole air conditioning system was not in accordance with present standards.

On the contrary, the new swimming and sport centre B was equipped with an HVAC system of the latest technology. The location of supply air grille prevented the penetration of water and snow into the grilles. According to visual estimation, the surfaces inside the air treatment system were clean. To minimize contamination of the unit, there was a filter (EU5) in the exhaust air before the heat recovery unit. The supply air unit was equipped with pre-filter (EU5) and a fine filter (EU7).

The supply air chambers were located in the basement of the pools C, D and E. The supply air units were equipped with pre-filter (EU5) and a fine filter (EU7). The pools C and D were equipped with displacement ventilation. The pool E had mixing ventilation. Supply air was prevailed in front of large windows by the water pools and the exhaust air vents located in the ceiling of the buildings C, D and E. The heat recovery unit in the pool E was a rotating wheel.

The portion of the recirculation air in supply air varied in different pool buildings (Table 1).

3. METHODS

Technical investigation of outer walls and ceiling was carried out. Air temperature, relative humidity and pressure difference between outdoors and swimming pool space were measured. The amounts of supply air and exhaust airflow rates of the ventilation system were measured in the ducts and in the air terminal devices. Air, material and surface samples were taken for microbiological analysis. Air velocity was measured just above water surface. Pool water samples were analysed for volatile organic compounds. Indoor air samples were taken to determine the concentrations of particles, total concentration of VOCs and halogenated organic compounds.

3.1 Differential air pressure

Differences in the air pressure inside and outside the swimming pools were measured. The air pressure inside the swimming pool was measured at floor and ceiling level. The reason for taking measurements for several days was to map out the average pressure difference, with reference to the structures of the swimming pool and leakages in them. The measurements were carried out using differential pressure transmitters, Setra 264 and 267 models, with a pressure measurement range of ±25 Pa, capable of measuring low pressure differences. Their respective errors are ≤1% and ≤0.4% of the full reading. At the beginning of the measurement period, the constancy of the transmitters' zero differential pressure was checked, and when necessary, the result was corrected by calculation.

3.2 Temperature and relative humidity

The temperature and relative humidity of air at the swimming pools was constantly measured during the measurements of the differential pressure. The temperature and relative humidity was measured using humidity transmitters, Vaisala RH/T HMP143 A and HMP 233 A models, which were calibrated at the outset. Measurement readings were recorded at 30-minute intervals using a Grant data collection device.

3.3 Air current velocities

The air current velocity was measured above the pool at the height of approximately 30cm, at a distance of one meter from the edge of the pool. Measurements of the air current velocities were carried out using a SwemaAir 30 thermoanemometer (error ±6% of the reading, minimum 0.05m/s). The velocity of the airflow was measured both longitudinally and across the pool at the same measurement point.

3.4 Microbes

Cultivable microbes were determined from the air, surface and material samples to evaluate the microbial contamination. Mesophilic fungi were cultivated on Rose Bengal malt agar (Hagem agar) and dichloran glycerol agar (DG18), and bacteria on tryptone yeast glucose agar (TYG) for 7 days at +25 ^{o}C. Microbes were identified using common mycological procedures.

3.5 Water quality and volatile organic compounds

Water samples were taken and field measurements were carried out in connection with the air quality measurements, during the last day of the each study period. The samples were collected at the point where the pool water was directed to the treatment system. The physicochemical quality of the water was assessed by measuring the free, combined and total chlorine concentrations in the water. The analyses were carried out using standard methods set by the Finnish Standards Association. For the analysis of the trihalomethanes (THMs), 250 ml of water was taken in a Teflon-capped glass bottle containing thiosulphate to quench the free chlorine. The compounds were analyzed by adapting the proposed standard CEN/prEN 30301. Water samples were extracted into hexane and analyzed by gas chromatography, using an electron capture detector (HP 5890II). The internal

standard was 1,2-dibromoethane.
The concentrations of volatile organic compounds (VOC) and halogenated hydrocarbons (HHC) were measured above the pool, 15cm above the water level and by the pool 1.2m meters above the floor level, as well as from the incoming and extracted air. VOCs were determined by collecting air samples in tubes containing Tenax GR/Carbosieve S3 or Tenax TA/Chromosorb 106 absorbents. Each sampling time was approximately 75 minutes. The samples were analyzed by gas chromatography, using the thermodesorption technique for sample feed and the GC-MS combination for analysis.
Air samples of carbonyl compounds as formaldehyde were collected into DNPH-Silica cartridges. Each sample-taking time was approximately 75 minutes. The aldehyde and ketone samples eluated in acetonitrile were analyzed using HPLC equipment and the GC-MS combination.

3.6 Particles
The total particle concentration and particle size distribution in the indoor air were measured above the pool, 50cm above the water surface, as well as by the ventilation inlet and outlet grilles. The particle measurements were carried out using a SMPS (Scanning Mobility Particle Sizer, TSI Model 3934) particle measurement device and. The measured particle size ranges were 15–710nm with the SMPS.
The technical questionnaire was delivered to the workers in 81 municipal swimming pools. Questionnaire to evaluate the perceived air quality and symptoms was conducted among the swimmers in all the five pools studied.

4. RESULTS AND DISCUSSION

4.1 Differential air pressure
At the beginning of the measuring period, the old indoor swimming pool *A* was depressurised, and during the second half of the measuring period, the pressure difference (dp) was balanced or fluctuated. The mean value for the pressure difference between the floor level indoors and the outdoor air was –3.8 Pa, and the mean pressure difference between ceiling and the outdoor air was –2.3 Pa. The mean values averaging pressure differences at the floor and ceiling levels during the whole measurement period are presented in Table 2.

Table 2: Mean values of pressure differentials (Pa), temperature (^oC) of air and water, relative humidity (%) of air and air current velocities (m/s) in five indoor swimming pools

	A	B	C	D	E
pressure day/night	-2.7 / -4.0	-19.3 / -17.2	-3.4 / -5.6	+2.8 / +2.8	+7.2 / +3.1
temperature					
- air day/ night	28.4/ 27.1	26.9/ 26.8	29.7/ 29.4	24.4/ 24.1	26.2/ 25.3
-water	27.2	26.8	26.0	26.3	25.7
humidity day/night	43/41	55/53	25/32	53/52	46/44
velocity					
- longitude	0.08	0.17	0.13	0.16	0.24
- latitude	0.04	0.06	0.06	0.04	0.06

The indoor swimming pool B was extremely depressurised. The mean difference between the pressures at floor level and outdoors was greater than –20.0 Pa and the mean difference between the pressures in the ceiling and outdoors was greater than –16.3 Pa.
The swimming pool C had negative pressure for most of the time as planned (-3.4/-5.6 Pa); swimming pool D had positive pressure (2.8/2. Pa) and swimming pool E had considerable positive pressure (7.2/3.1) (Table 2). Obvious damage caused by dampness resulting from positive pressure and absence of moisture barrier was detected in the exterior walls of building E.

4.2 Temperature and relative humidity
The relative humidity in the indoor swimming pool A was not high, the mean value was 41 % RH (29 – 55 % RH), indicating that the amount of re-circulated air was minimal and the amount of fresh air and air drying caused by air change were maximal in the swimming hall. In the pool B, the average value of the water content of the supply air was much higher than the one of outdoor air, which revealed that supply air consisted mostly of re-circulated air. This was caused by the air conditioning system utilizing only re-circulated air as supply air and exhaust fans during nights. The moisture in the air was not removed by the air conditioning. On the other hand, at night the production of humidity was minimal, and so the water content in the indoor air was lower than in daytime.
There were only small temperature differences between the air temperatures of the pool rooms of the three swimming pools C, D and E. In every building the temperature was more or less constant day and night.
Design values of 30°C and relative humidity of 50% are often used for calculating the ventilation rates for swimming pool rooms. The air temperature of the pool rooms should be 2...3°C higher than the temperature of the pool water. These conditions may be complicated to achieve, because these criteria were met only in one of the buildings (C). In buildings A, B and E the temperature difference should be greater. In building D, however, the situation was critical, because the pool water was approximately 2°C warmer than the indoor air.

4.3 Air current velocities
The air current velocities were very low above the main pool. Velocities measured along the length of the pool were greater (0.08-0.24m/s) than those measured across (0.04-0.06m/s). The results are shown in Table 2.

4.4 Water quality and volatile organic compounds

The physio-chemical and microbiological quality of the main pools mainly fulfilled the national criteria set for pool water. THM concentrations (Table 3) consisted mainly of chloroform. The minimum and maximum concentrations existed in the pool B and E, respectively, where the ozonation was utilized.

Table 3: Average concentrations of trihalomethanes (THM) in water (µg/l), average concentration of halogenated hydrocarbons (HHC) (µg/m³), formaldehyde HCHO (µg/m³) and total concentration of volatile organic compounds TVOC (µg/m³) measured in air above the pool and its surroundings in the morning and in the afternoon

	A	B	C	D	E
THM in water	20.2	8.4	27.1	28.9	38.2
(chloroform)	(18)	(7.5)	(22)	(27.4)	(25.5)
incoming /	20.8	7.3	26.9	28.5	34.7
outgoing	(18.5)	(6.6)	(22)	(27.3)	(22.5)
HHC in air					
- above pool	17.7	27.3	7.2	5.6	16.2
- surroundings	53.8	24.5	5.8	4.0	12.5
HCHO in air					
- above pool	6.3	5.6	9.3	13.7	11,0
- surroundings	7.6	9.3	4.7	17.2	14.7
TVOC in air					
- above pool	151.3	153.7	92.1	65.9	127.1
- surroundings	142.1	100.2	51.1	33.9	50.3

The THMs calculated as chloroform exceeded the DIN norm (DIN 19643-1), 20 µg/l, also in the treatment assisted with ozonation E. The levels of THMs did, however, conform to the Ministry of Health and Social Affairs decree on pool water requirements 315/2002 (≤ 50 µg/l trihalomethanes reported as chloroform). The content of halogenated hydrocarbons in the indoor air of the swimming pools was low. The maximum content (Table 3) existed at swimming pool B. The average formaldehyde concentrations in indoor air varied in the range from 5.6 to 17.2 µg/m³ and the maximum values existed in the pool D and the E, where both the supply and exhaust air included formaldehyde 5.6 µg/m³; 6.6 µg/m³ and 6.9 µg/m³; 11.8 µg/m³, respectively. The concentration of halogenated compounds in the indoor air depends on the concentration of the disinfection by-products in water, air exchange rate and movement of swimmers in the pool.

4.5 Microbes

The concentrations of airborne fungi were lower than in outdoor air, however, ranging from 2 to 711 cfu/m³. The samples contained mostly outdoor air microbes: Cladosporium, Penicillium, basidiomycetes, yeasts and bacteria. The air samples included fungi favouring moisture environments (e.g. Acremonium, Aureobasidium, Aspergillus (A.) versicolor, A. fumigatus, A. penicillioides, Eurotium, Fusarium, Tritirachium, Oidiodendron, and Wallemia). Surface samples included some additional fungi (Chaetomium, Rhizopus, Mucor, Ulocladium, Paecilomyces and Sphaeropsidales). Aureobasidium was present in the ventilation systems of each swimming pool. In addition, Streptomyces spp. were found in four ventilation systems. Several moisture indicating microbial species were not detected in outdoor air but they were present in air and in ventilation systems of all the buildings studied (Table 4).

Table 4: Presence of microbes in air, surface and material samples and in ventilation system (Yes, No) in five swimming pools and the number of the analyzed moisture indicating microbial species NOT found in outdoor air

	A	B	C	D	E
air	yes/ 6	yes/ 7	yes/ 5	yes/ 5	yes/ 3
surface	yes/ 6	yes/ 4	-	yes/ 7	yes/ 1
material	-	-	yes/ 2	-	no
ventilation	yes/13	yes/ 5	yes/15	yes/12	yes/8

4.6 Particles

The total particle concentrations of the indoor air varied between the swimming pools. The highest content of particles was detected in building B (total content 8,000 #/cm³). Above the pool, the particle content was approximately tenfold than that in building E. The distribution of particle sizes also varied (Table 5). The distribution of particles was bimodal in the pool buildings C and D where the proportion of ultra fine particles (D_p < 100nm) was high.

The particle concentration of the outdoor air affects the total particle content in the indoor air of the swimming pools. The particle content can also be influenced by the separation capacity of filters, ratio of recirculation air, air exchange rates and internal sources of particles, for example swimmers' movement in the pool.

Table 5: Concentrations of particles (particle size of 15-710 nm) in air (#/cm³) and particles geometric mean diameter (nm) measured above the pool

	A	B	C	D	E
conc., #/cm³	7000	8000	3100	1700	900
GMD, nm	80	70	50	70	100

4.7 Complaints and symptoms

In average 100 swimmers in each pool answered the questionnaire. They reported to have airway symptoms in the range from 14% to 60% during swimming (Table 6). Those who swam more often had more reported symptoms.

Table 6: The percentage of race swimmers, regulative swimmers and contemporary swimmers (%) who reported respiratory symptoms during swimming

	A	B	C	D	E
race swimmers	62	41	52	34	56
regulative swimmers	14	16	16	14	11
contemporary swimmers	8	13	19	20	7

5. CONCLUSIONS

The concentrations of airborne microbes were fairly low, although the microbes favouring moisture conditions were present. The total particle concentration of the indoor air and particle size distributions varied between the swimming pools. The splashing of pool water during swimming formed ultra fine particles to air. The content of these potential irritants will be studied further. The trihalomethane concentrations consisted mainly of chloroform in the water and they exceeded the DIN norm level of 20 µg/l in the four swimming pools surveyed. In addition, formaldehyde and acetaldehyde were emitted to indoor air from pool water. The principal problem was that in the swimmers' breathing zone the air flow velocities were minimal. The technical questionnaire performed in a larger set of swimming pools revealed that the half of the workers in 81 municipal swimming pools found the operation of ventilation system to be only satisfactory or worse. Questionnaire to evaluate the perceived air quality and symptoms showed the portion of reported airway symptoms to vary in the range from 10 % to 60 % among the swimmers. This emphasises the importance of ventilation arrangements in the design and engineering of indoor swimming pools.

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