Survey of indoor air quality in three indoor swimming pools

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ABSTRACT
The survey concerned three swimming pools using a similar type of basic water treatment, but having different structures and ventilation systems. The survey included measuring air current velocities above the pools and studying the microbiological and physico-chemical quality of the pool water. In addition, microbes were determined from the indoor air, structures and ventilation systems, and airborne particles and volatile organic compounds from the indoor air samples. The total particle concentration of the indoor air and their size distribution varied between the swimming pools. The trihalomethane concentrations in the water were similar in all the swimming pools surveyed, the greatest concentrations in both the air and water having been found in swimming pool E. The principal problem was that in the swimmers' breathing zone, above the pool's surface, the air flow velocities were minimal. This emphasizes the importance of ventilation arrangements in the design and engineering of indoor swimming pools.

INDEX TERMS
Air movement; Pressure difference; Temperature; Relative humidity; Particles

INTRODUCTION
Swimming Pools Surveyed
This is the second part (Jauhiainen *et al.*, 2002) of a more comprehensive research project on indoor swimming pools. The swimming pools are located in the provinces of Itä-Uusimaa (built 1970) [C], South Karelia (built 1966) [D] and Satakunta (built 1980) [E]. In the case of all three buildings, a project plan for full refurbishment has been drawn up or is currently being drawn up. The structural descriptions described are based on archived drawings. Problems with dampness and leaks in the roof structures have been experienced in each of the buildings, and in swimming pool E damage caused by dampness, due to a missing vapour barrier, have also been detected in the wall structure above the windows.

Swimming pool C
In this swimming pool, minor repairs and alterations in the roof structure have been carried out due to damage caused by dampness. The vertical load bearing structures are reinforced concrete; the exterior walls of the pool room are glazed and the load bearing structure of the roof consists of glulam timber beams, supporting prefabricated plywood roof panels. The total volume of water in the treatment system is 1030 m^3. The water treatment includes coarse filtration, precipitation with a polyaluminium coagulant, sand filtration, disinfection with sodium hypochlorite and pH adjustment with carbon dioxide.

Swimming pool D
The load bearing structure of the swimming pool consists of glulam timber arches, carrying solid timber roof joists. One of the pool compartment walls is glazed. The total volume of

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water in the treatment system is 1200 m^3 having separate purification cycle for the main pool (approximately 1100 m^3). The water treatment system consists of electrochemical precipitation (ELECLEAN) combined with flotation and pressure sand filtration (hydroanthracite and quartz sand). Sodium hypochlorite is used for disinfecting the water and the pH is adjusted with carbon dioxide.

Swimming pool E
The vertical load bearing structures of the swimming pool are reinforced concrete. There is a tall window opening in one of the exterior walls of the pool room. The load bearing roof structure consists of prefabricated hollow slabs supporting a timber roof. The roof structures have been repaired because of problems caused by dampness in the original structure. The total volume of water in the treatment system is 450 m^3. The treatment includes coarse filtration, aluminium sulfate precipitation, sand filtration, ozonation, anthracite filtration, disinfection with sodium hypochlorite and pH adjustment.

METHODS

Differential Air Pressure

Differences in the air pressure inside and outside the swimming pool 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.

Temperature and Relative Humidity

The temperature and relative humidity of the swimming pools were 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. Measurements were carried out in swimming pool C between 11 and 18.12.2001, swimming pool D 30.9–8.10.2002 and swimming pool E 21–27.11.2002. Measurement readings were recorded at 30-min intervals using a Grant data collection device.

Air Current Velocities

The air current velocity was measured above the pool at a height of approximately 30 cm, at a distance of 1 m 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 0.05 m/s). The velocity of the airflow was measured both longitudinally and across the pool at the same measurement point.

Microbes

Culturable 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), bacteria on tryptone yeast glucose agar (TYG) for 7 days at +25°C. Microbes were identified using common mycological procedures.

Water Quality

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 heterotrophic plate count of each sample was determined, as well as the yeasts and moulds growing in the malt extract medium. Water samples were filtered through a 0.45 µm membrane and cultured on THG and malt extract media. The physico-chemical quality of the water was assessed by measuring the free, combined and total chlorine concentrations in the water, the water pH, temperature, $KMnO_4$-value (COD) and turbidity. The analyses were carried out using standard methods set by the Finnish Standards Association. The dissolved ozone concentration in the pool water (swimming pool E) was measured using an ozone analyser (MOCA model 3600). For the analysis of the trihalomethanes (THMs), 250 ml of water was taken in a Teflon-capped glass bottle containing thiosulfate to quench the free chlorine. The compounds were analysed by adapting the proposed standard CEN/prEN 30301. Water samples were extracted into hexane and analysed by gas chromatography, using an electron capture detector (HP 5890II). The internal standard was 1,2-dibromoethane.

Particles

The total particle concentration and particle size distribution in the indoor air were measured above the pool, 50 cm above the water surface, as well as by the ventilation inlet and outlet grilles. The particle measurements were carried out using a SMPS particle measurement device and CLIMET Instruments CI-500 Innovation and Royco MicroAir 5230 particle counters. The measured particle size ranges were 15–710 nm with the SMPS and 0.3–25 µm with the CLIMET and Royco particle counters.

Volatile Organic Compounds

The contents of volatile organic compounds (VOCs) and carbonyl compounds were measured above the pool, 15 cm above the water level and, by the pool, 1.2 m above the floor level, as well as from 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 sample-taking time was approximately 75 min. The samples were analysed by gas chromatography, using the thermodesorption technique for sample feed and the GC-MS combination for analysis. Air samples of carbonyl compounds were collected into DNPH-Silica cartridges. Each sample-taking time was approximately 75 min. The aldehyde and ketone samples eluted in acetonitrile were analysed using HPLC equipment and the GC-MS combination.

RESULTS

Differential Pressure

The differential air pressure between the outside and interior floor level and the outside and ceiling level was measured in each swimming pool. Only 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 1). Obvious damage caused by dampness resulting from positive pressure and absence of moisture barrier was detected in the exterior walls of building E.

Temperature and Relative Humidity

There were only small temperature differences between the air temperatures of the pool rooms of the three swimming pools. In every building the temperature was more or less constant day and night. The technical data of the buildings surveyed and the mean values of measurements are shown in Table 1.

Air Current Velocities above the Pool

The air current velocities were very low above the main pool. Velocities measured along the length of the pool were greater (0.13–0.24 m/s) than those measured across (0.04–0.06 m/s). The results are shown in Table 2.

Table 1 The technical information and measured values of temperature, relative humidity and pressure difference across the outer wall in the three swimming pools (– = not measured)

Swimming pools	Construction year, repaired, (R)/ unrepaired, (U)		Disinfectant	Wall structures, (w) wood, (c) concrete	Roof structures, (w) wood, (c) concrete	Air volume of the pool site m^3	Area of the swimming pools m^2	Study period	Temperature °C / relative humidity % in air		day/night, presssure difference, Pa	Water temperature, °C	Treatment cycles/day
									Day	Night			
C	1970	U	chlorine	c	w	4500	488	10.–18.12. 2001	29.7/ 24.6	29.4/ 32.4	–3.4/ –5.6	26.0	7
D	1966	U	chlorine	w	w	8000	396	30.9.– 8.10. 2002	24.4/ 52.7	24.1/ 51.8	+2.8/ +2.8	26.3	2
E	1980	U	chlorine ozone	c	c	2900	249	21.– 27.11. 2002	26.2/ 45.7	25.3/ 43.5	+7.2/ +3.1	25.7	6

Water Quality

The physio-chemical and microbiological quality of the main pools mainly fulfilled the national criteria set for pool water. The water of swimming pool E showed in the evening measurement too low a level of free chlorine in proportion to combined chlorine (<1.5-fold). Any residual ozone was not detected in the pool water. THM concentrations are shown in Table 2.

Microbes

The indoor air samples and the ventilation systems contained mostly outdoor air microbes: *Cladosporium, Penicillium,* basidiomycetes, yeasts and bacteria. In the indoor air and on the surfaces, there were low levels of such microbes as *Aspergillus ochraeus* and *Aspergillus versicolor,* which thrive in moist conditions. *Mucor* and *Wallemia* were present both in the indoor air and ventilation structures, in which the number of species of abnormal microbes was highest. *Aureobasidium* was present in the ventilation systems of each swimming pool.

Table 2 Concentrations of halogenated hydrocarbons, microbes and particles in air, of THMs in water, of microbes on surfaces and in ventilation systems, and air velocities above the pool (– = not measured).

Swimming pools	THMs in water calculated as chloroform (µg/l)	Halocarbons in air (µg/m^3)	Microbes in air, surface and material samples and in ventilation system (Yes, No) The number of the indicator organisms NOT found in outdoor air				Particle concentration (D_p 15- 710 nm) (1/cm^3)	Particle count median diameter (nm)	Air velocity above the pool (m/s)
	Water	above the pool surroundings	air	surface	material	ventilation	above the pool		long direction width direction
C	25.5	7.2	Yes	–	Yes	Yes	3200	50	0.13
		5.8	5		2	15			0.06
D	28.2	5.6	Yes	Yes	–	Yes	1700	70	0.16
		4.0	5	7		12			0.04
E	30.9	16.2	Yes	Yes	No	Yes	900	110	0.24
		12.5	3	1		8			0.06

Particles

The total particle concentrations of the indoor air varied between the swimming pools. The highest content of particles was detected in building C (total content 3200 1/cm^3). Above the pool, the particle content was approximately double that in building D and approximately 3.5 times greater than that in building E. The distribution of particle sizes also varied (Table 2). In building C, the proportion of ultrafine particles (D_p < 50nm) was high; in building D the mean size was 70 nm, and 110 nm in building E.

Volatile Organic Compounds

The content of halogenated hydrocarbons in the indoor air of the swimming pools was low. In building E, the content was approximately 2.5 times greater than in the other two (Table 2). The carbonyl compounds content, particularly formaldehyde and acetaldehyde, in the indoor air differed in the following way, the lowest counts being in building C (4.3–11.5 µg/m^3 of formaldehyde and 5.9–14.8 µg/m^3 of acetaldehyde) and the highest in building D (4.6–18.0 µg/m^3 of formaldehyde and 6.3–18.8µg/m^3 of acetaldehyde).

DISCUSSION

Design values of 30°C and relative humidity of 50% are often used for calculating the ventilation rates for pool rooms. The air temperature of the pool rooms should be 2–3°C higher than the temperature of the pool water. Creating of these conditions may be complicated, because these criteria were met only in one of the buildings (C). In building E the temperature difference should be greater. In building D, however, the situation was critical, the pool water being approximately 2°C warmer than the indoor air.

Shortcomings were found in the ventilation of each of the swimming pools. The positive pressure in the buildings exerts great strains upon the exterior wall and roof structures. No damage was detected in the load bearing structures of any of the indoor swimming pools, and the microbial analyses support this finding.

There are no standard values for air current velocities in swimming pools. In this study, air current velocities were mostly below the mean of the recommended values (0.20 m/s) in dwellings given in the Classification of Indoor Climate (FiSIAQ 2001).

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.

Water treatment practices were found to be adequate in producing pool water that meets national criteria set for the physio-chemical and microbiological quality of pool water. The THMs calculated as chloroform exceeded the DIN norm (DIN 19643-1), 0.020 mg/l, also in the treatment assisted with ozonation. The levels of THMs did, however, conform to the Ministry of Health and Social Affairs decree on pool water requirements 315/2002 ($\leq$50 µg/l trihalomethanes reported as chloroform). The levels' measurements were within the range of the average concentrations measured in pools in conjunction with a larger survey, 35.4 µg/l (Vesihydro, 1998). 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.

CONCLUSION AND IMPLICATIONS

The principal problem is that the airflow velocities are very low in the swimmers' breathing zone, above the pool's surface.

In indoor swimming pools, the significance of the comfort factors (temperature and air flow velocity) is great, because those moving in pool facilities usually have wet skin and little clothing. Therefore, a certain overheating of pool facilities must be accounted for to avoid draughts.

Our results elicit the importance of ventilation design of indoor swimming pools.

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