Energy Impact of Ventilation and Air Infiltration
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Ventilation of Public Swimming Pools

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Synopsis

Ventilation codes for swimming pools are based on preventing condensation. To save energy, air recycle with dehumidification is common. This successfully controls moisture, but does not remove airborne contaminants arising from evaporation of chemically treated pool water. This contamination may cause discomfort, irritation or even harm.

Environmental conditions and energy consumption were monitored at two public swimming pools over one year to identify the critical factors affecting bather comfort, to relate these to proportions of recycled air, and to show how to achieve acceptable bather comfort while minimising energy costs.

Questionnaire surveys showed that even under the most comfortable conditions, 20 to 30% of pool users suffered irritation, mainly of the eyes, attributed both to the air and to the pool water. Over the range of fresh air conditions available using the existing plant, discomfort experienced by pool users was not found to relate to the ventilation conditions, but rather to the level of chlorine compounds ("combined chlorine") in the water. High combined chlorine levels in the water are expected to result in high levels of contamination in the air, but this proved difficult to measure. However, increasing the fresh air ventilation rate when the combined chlorine level in the water is high is desirable in order to dilute airborne contaminants, and it is proposed that the combined chlorine level in the water should be used as a fresh air ventilation control parameter, along with humidity and carbon dioxide, to minimise energy use and maintain acceptable air quality.

1 Background

Ventilation rates for swimming pool halls have traditionally been determined by the need to limit condensation on the building structure. Comfort requirements of bathers and staff are then satisfied by choosing acceptable air and water temperatures.

The need to reduce energy consumption has encouraged the installation of heat recovery systems which dehumidify and recirculate a large proportion of pool hall return air[1]. These systems are economically attractive and the humidity can be controlled without the need for any fresh air at all. Consequently, there now exists the possibility of progressive build up of airborne contaminants in the pool hall atmosphere which may be corrosive, uncomfortable or even unhealthy.

The possible consequences of recirculating a high proportion of the air were discussed in The Lancet[2] in 1979 and by Penny[3] in 1983. They suggested that respiratory and eye irritation caused by chlorine compounds in the air may be more severe when an air recycle system is installed.

2 Objectives

The Sports Council in the UK commissioned ***EA Technology*** to undertake a study of the "the reliable measurement of the quality of swimming pool hall atmospheres and the specification of acceptable standards for recirculated air as a proportion of total ventilation, aimed at achieving satisfactory levels of bather comfort while minimising energy costs."

The project aimed to identify the critical factors in pool air which affect bather comfort, to determine quantitative limits for these critical factors, and thence to determine and recommend a practical and reliable monitoring and control system for pool air quality to maintain acceptable bather comfort with minimum energy usage.

3 Method

3.1. General

Two pools were studied, both with air recycle systems:

POOL A, selected as representative of a modern leisure pool with ozone water treatment, is a free form pool with flume, waves and a whirlpool spa which was opened in August 1986. The pool area is 490 metres^2 in a square building 49 x 49 metres (minus a triangular area forming the entrance concourse) with a ceiling height that varies between 6 and 11 metres. Ventilating air is supplied, vertically downwards, from registers in the underside of exposed circular ducts near the ceiling; air is extracted through openings in a similar set of ducts also at ceiling level.

POOL B is a conventional rectangular pool with hypochlorite water treatment, measuring 25 x 10 metres (= 250 square metres) in a pool hall 33 x 18 metres by 5.7 metres high. There is a full length spectator gallery along one side, and a large glazed wall along the other side. Air supply and extract to the pool hall is through rectangular registers in the ceiling. The air flow pattern is downwards along the long sides of the pool with extract along the centre line.

The specific information collected at each pool included:

- the nature and quantity of air contaminants
- the nature and quantity of water contaminants
- levels of pool usage
- bather comfort responses
- energy usage
- effectiveness of operational control

Following initial interviews with pool staff to find out how the pools were operated and the degree of cooperation and access to records which would be forthcoming, procedures for measurement and collection of physical and subjective data from pool users and staff were set up.

3.2. Physical conditions

Continuous logging of indoor and outdoor environmental conditions was carried out at 10 minute intervals comprising:

- pool hall air dry bulb temperature
- pool hall air wet bulb temperature
- return air dry bulb temperature
- return air wet bulb temperature
- supply air temperature
- return air carbon dioxide concentration
- air flow rate in fresh air duct
- air flow rate in recycle air duct.

Questionnaire surveys of pool users were carried out at appropriate intervals.

Relative humidity was measured by wet and dry bulb thermistors because commercially available capacitative thin film humidity sensors were rapidly poisoned (within days) in a swimming pool hall atmosphere.

Air flow rates in ventilation ducts were monitored by permanent vane anemometers in both the air supply duct and in the fresh-air-from-outside duct, calibrated by anemometer traverses. Carbon dioxide concentration in the return air duct was recorded continuously as an index of the fresh air ventilation rate and occupancy.

3.3. Ventilation conditions

The fresh air entering the swimming pool hall and diluting the contaminants is a combination of the fresh air delivered through the ventilation system plus weather dependent air leakage into the building by infiltration, augmented also, when the building is in use, by air interchange through external doors.

The total effective fresh air ventilation rate was measured by a tracer decay technique, using sulphur hexafluoride injected into the supply air duct. The rate of tracer decay was then measured in the return air duct to give an average fresh air ventilation rate for the pool hall.

3.4. Water chemistry

The water chemistry analysis for the substances present in swimming pool water is reasonably straightforward and well documented. Chlorine (introduced as solutions of sodium or calcium hypochlorite) reacts with water to form hydrochloric acid (HCl) and hypochlorous acid (HOCl) which reacts with organic and nitrogenous compounds (mainly ammonia NH_3) in the water to form "combined chlorine" - chloro-organics, chloramines (NH_2Cl, $NHCl_2$, NCl_3) - and a residue of hypochlorous acid ("free chlorine"). Typical concentrations of 'free chlorine residual' are between 1 and 3 mg/litre (=ppm); free and total chlorine are checked routinely by the pool staff using DPD (diphenyldiamine) colorimetric tests, giving combined chlorine by difference. pH is controlled within the recommended range of 7.4 to 7.6, normally by adding acid.

3.5. Air chemistry

The air chemistry represents an altogether different problem. The main odorous and irritant contaminants in the air originate in the water where they are present at concentrations of a few parts per million. The concentrations of these substances in the pool atmosphere are likely to be one or two orders of magnitude less than in the water - perhaps 0.001 ppm[4]. These low airborne concentrations cannot be measured directly; and established sensitive methods of chemical analysis of gases such as infra-red gas analysers cannot measure chlorine or chloramines at all.

Concentration of the sample by passing the air over a suitable absorbent for a long time (e.g. 30 minutes pumped or several hours passive) followed by rapid desorption in the laboratory and measurement using a gas chromatograph + mass spectrometer was used, but unfortunately the nature of the desorption precludes detection of chlorine and chloramines, although chloroform is readily detected.

An alternative procedure based on absorbing the airborne chlorine compounds into pure water in a bubbler and then analysing the water by the usual DPD chemistry was moderately successful.

3.6. Subjective surveys

The survey form presented to pool users was self-completion on both sides of an A5 card and designed to resolve the subjective factors likely to influence feelings of comfort in a swimming pool environment. Questions were asked about:

- time spent in water
- time spent in different areas of the building
- feelings about the water: temperature, discomfort
- feelings about the air: temperature, discomfort
- irritation of eyes, nose, throat, skin

A pilot survey was carried out first at both pools by intercepting pool users as they left the building, asking them the questions on the survey forms, and writing down the answers.

Subjective surveys of the perceived conditions were thereafter carried out by intercepting pool users as they left the building, and asking if they would complete a questionnaire. Cooperation was good when the card distribution was supervised in this way. When pool users were approached in the cafeteria, as well as at the exit, a much better response rate was achieved. The response rate was usually 30 to 40%.

4 Results

4.1. Physical conditions

The pool return air temperature, taken as representing the mean pool hall air temperature was generally in the range 28°C to 30°C, but at both pools there were days when the temperature reached 32°C to 34°C. Relative humidity was generally 60% to 70%.

Total air flow rates were $19m^3/s$ (=4 air changes/hour) equivalent to 0.02 m^3/s per m^2 of wet area at Pool A, and 3.7 m^3/s (= 4.4 air changes/hour) equivalent to 0.008 m^3/s per m^2 of wet area at Pool B. The current CIBSE and Sports Council recommendations are for a mechanical ventilation rate of $0.01m^3/s$ per m^2 of wet area. The proportion of fresh air was varied by resetting the dampers in the air-handling units. Including infiltration, the proportion of fresh to total air flow was varied in the range of 39% to 61% of total flow at Pool A, and 33% to 53% at Pool B.

4.2. Chemical conditions

At Pool A the free chlorine recordings showed a very regular cyclic variation of between 0.5 and 1.0 mg/l, at a frequency of about 2 hours peak to peak. At Pool B the free chlorine charts showed a low value in the morning (0.5-1.0 mg/l at 10am) rising to a maximum soon after midday (about 2.0 mg/l at 1pm) and then falling off again towards evening (1.0-1.5 mg/l at 6pm).

The air chemistry tests proved difficult and inconclusive. The GC/MS technique detected chloroform concentrations which were 20 to 50 times higher at the lowest fresh air rates compared with the higher fresh air rates. The water bubbler technique indicated that the chlorine compounds in the air are at concentrations of the order or less than 1/10,000 of the concentrations in the water i.e. 0.1μg/litre or less.

4.3. Irritation experienced

An aim of the survey was to measure the amount of irritation and discomfort experienced by bathers, staff and spectators using and working at the pool, in particular that caused by the indoor air quality in the pool hall.

Questions of the type "What did you think of the pool water today?" and "How comfortable did you find the air at the pool today?" with reference to eyes, nose and throat, were designed to differentiate between water- and air-induced symptoms. Four surveys were carried out at each pool and the results are shown in Figure 1. Correlation between symptoms attributed to air and water respectively was good at both pools for the same part of the body, suggesting either that people could not differentiate the cause (air or water?) or that highly contaminated water results in highly contaminated air.

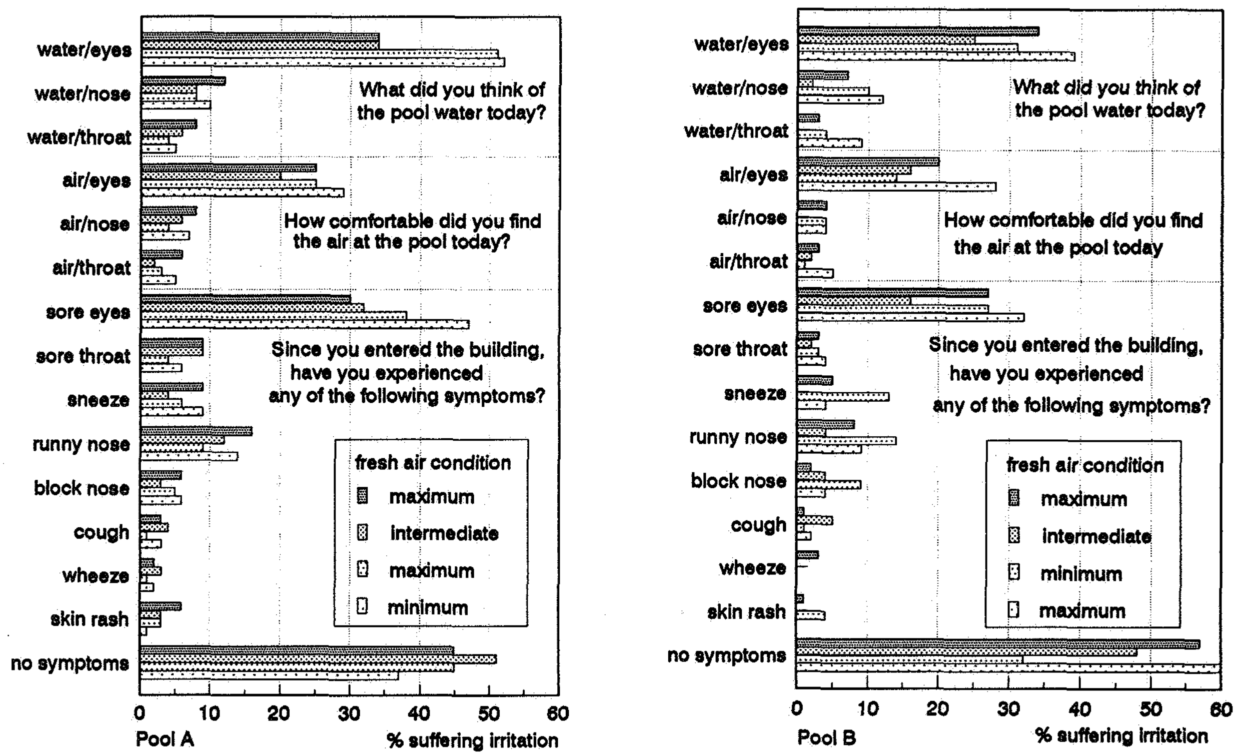

Figure 1 Questionnaire responses at the pools showing incidence of symptoms with different fresh air ventilation rates.

A general question, "Since you entered the building, have you experienced any of the following symptoms?", was also included followed by a list of possible symptoms. Sore eyes were by far the most common complaint and affected about 30% of pool users. About 10% suffered runny noses. About 50% of people reported no symptoms at all. A higher proportion of younger users reported symptoms. Susceptible individuals tended to suffer frequently.

The most common complaint of sore eyes correlated significantly only with age group: young people are more affected. The incidence of reported eye and nose irritation did not significantly relate to the fresh air quantity, relative humidity, or carbon dioxide concentration. A tendency was seen at Pool A (but not at Pool B) towards sore eyes at high actual and perceived air temperatures.

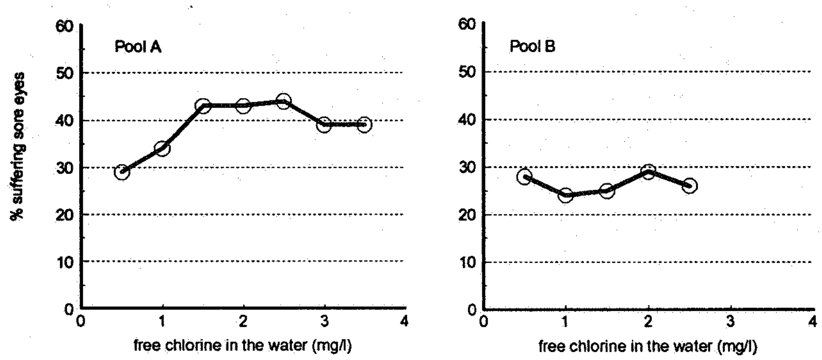

Figure 2 Incidence of sore eyes with varying free chlorine in the pool water.

At Pool A the incidence of sore eyes increased with all measures of chlorine in the water, but not at Pool B, see Figure 2.

4.4. Energy

The weekly energy consumptions obtained from the manual meter readings showed that the total annual energy consumption per square metre of water surface area is very similar at both pools: 19 GJ/m^2 at Pool A, and 20 GJ/m^2 at Pool B. This compares favourably with the average of 25 GJ/m^2 for indoor municipal pools[1].

Energy consumption increased linearly with decreasing outside temperature, Figure 3, but with a lot of scatter in the individual weekly figures, up to + 20%, which precluded correlation with other variables.

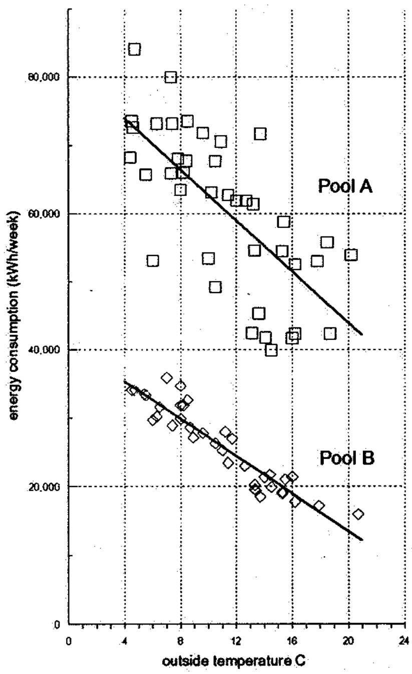

Figure 3 Weekly energy consumption

5 Conclusions

Under conditions which would be considered to be 'comfortable', 20% to 30% of bathers at swimming pools suffer discomfort, most commonly associated with the eyes.

Under the range of conditions experienced i.e. fresh air rates per m^2 of wetted area of 0.003 to 0.005 and 0.008 to 0.013 m^3/s, at total ventilating air flows of 0.008 and 0.02 m^3/s per m^2 respectively. The discomfort suffered by bathers was not related to fresh air ventilation rates. The most significant factor appears to be the amount of chlorine in the water.

6 Recommendation

Ventilation control should be based on the most demanding of the three factors:

- relative humidity,
- carbon dioxide concentration,
- "free" chlorine concentration in the pool water.

In this way, the ventilation rate and heat loss can be minimised while maintaining satisfactory indoor air quality.

Acknowledgements

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