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Energy use and perceived health in indoor swimming pool facilities

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Abstract. Swimming facilities are one of the most complex building categories with their high energy use and demanding indoor environment. A survey to collect information about user health and comfort, technical installations and operational strategies was distributed to pool facilities—from conventional swimming facilities to water parks—across Norway, and this article is based on the responses from 45 facilities. Using a multiple regression analysis, approximately 75% of the delivered energy can be attributed to the bather load and number of opening days. No correlation between delivered energy and user health and thermal comfort was obtained; however, a significant correlation between bathers and workers perceived health and comfort was found. Furthermore, bathers in the water parks reported to be significantly less satisfied with the indoor environment in comparison to bathers in conventional swimming facilities. The water parks also have a lower air change rate compared to the conventional swimming facilities.

1. Introduction

We spend almost 90% of our time indoors (1), and in many types of buildings, such as pool facilities, the exposure to certain contaminants is greater inside than in the outdoor environment. Norway has approximately 900 swimming facilities and water parks (2, 3) used for swimming education, recreation and sports. The energy consumption between different facilities differs significantly, and some of the variability can be attributed to the type, use and location of the facilities (4, 5). Swimming facilities also represent a building category with a challenging indoor environment with high temperatures and humidity levels. For example, high relative humidity (RH) is uncomfortable for the workers in the poolroom and increases the risk of mould and bacterial grows in the building constructions. On the contrary, too low RH increases the evaporation rate from the water and thereby the need for dehumidification of air and replenishing water to the pools, which are both energy-intensive processes. Another challenge is that the heat transfer coefficient between the skin and water is higher than that between the skin and air. In particular, the bathers experience one of the highest heat transfer rates of the human body (6). For this reason, the environmental condition that is experienced as too cold for a bather might be felt too warm for the lifeguards (7).

Another important aspect of the indoor environment is the air and water quality. When chlorine reacts with organic and inorganic contaminants present in the water, the formation of unwanted disinfection by-products (DBP) occurs. Long-term health effects such as asthma, adverse reproductive outcome, cancer and stillbirth have been associated with exposure to certain DBPs (8, 9), and dermal contact, oral ingestion and inhalation are considered important pathways of exposure (10).



Apart from the concentration of free and combined chlorine in pool water, no other chemical components are controlled in Norwegian pool facilities (11). No requirements concerning air quality in pool facilities exists: however, the Norwegian research institute, SINTEF, recommends to (12):

- Change the air between 4-7 times per hour,
- Have a maximum air velocity of 0.15 m/s above the water surface,
- Have an air temperature of 1-2 °C greater than the water temperature.

The work presented in this paper is a part of a larger project aiming to characterize whether there is a covariance between indoor environment and technology, and whether it's possible to establish a dose-response relationship between exposure and disease. The project is divided into three different parts where the status of parts one and two is presented in this paper:

- Part 1: Collection of statistics on energy and perceived air quality and user health from swimming pool facilities across Norway (n = 220),
- Part 2: Collection of information about health effects and user habits among professional swimmers above age of 18 across Norway (n = 1 109),
- Part 3: In-depth analysis of the air quality in 6-8 pool facilities. Determine whether there is a covariation between use of technology, ventilation strategy and user health and comfort, and if possible, establish a dose-response relationship.

2. Methods

2.1 Survey and study objects

The current study follows a cross-sectional study design where information was collected using a survey. The names of the facilities were collected from the facility register owned by the Norwegian Ministry of Culture. Swimming pools located in schools, hotels, rehabilitation centres and hospitals were excluded from the study since these pools are integrated in larger buildings where the primary aim is not to operate a pool facility. The survey was sent to the pool facilities by e-mail or distributed by ordinary mail through their municipalities owning the facilities. A total of 220 e-mail addresses received the survey including questions about user habits and thermal comfort, questions as to whether different energy saving measures have been installed (e.g., greywater recovery, heat recovery for air, automated filter flushing, upgrading of winds, walls and ceilings, etc.), energy and water use from the last five years (2013-2017), attractions, pool dimensions, disinfection technology installed in the facility. The survey was approved by the Norwegian Center for Data research (NSD). Forty-five facilities filled out the survey, and 17 facilities responded that they are unable to participate in the study due to lack of energy monitoring, lack of time, building and rehabilitation of the facility or new staff.

2.2 Climate correction of energy use

To compare the energy consumption of the pool facilities across Norway, the delivered energy (in kWh) was climate-corrected using the degree-day method, and the capital of Norway, Oslo, was used as the reference climate. According to the Norwegian energy foundation, ENOVA, 40% of the energy consumed in a pool facility depends on the outdoor temperature (13). The formula used for the climate correction was developed by ENOVA and is reported in equation 1.

$$E_{Pool\ Facility} \times \left(0.6 + 0.4 \times \frac{DD_{Oslo}}{DD_{Pool\ Facility}} \right) = E_{Pool\ Facility, Oslo\ Climate} \quad (1)$$

2.3 Multiple Linear regression model to predict the energy consumption

To propose a model to predict the energy consumption in a pool facility a multiple linear regression analysis was used because it allows to identify which few variables among a large set of independent variables have a significant relationship to the dependent variable, after adjusting for other variables (14). The climate-corrected delivered energy resulted positively skewed and was log transformed and tested for normality before the analysis was performed. The independence of the residuals was tested, and the residuals scattered with a mean of zero and without a specific pattern.

2.4 Non-parametric methods to analyze the contributions of the categorical variables

From the survey, several questions were coded on a categorical scale such as perceived indoor climate and health among the bathers and employees. The pool facilities were also categorized based on their size: “water parks” contain four or more swimming pools in addition to multiple aerosol generation activities such as Jacuzzis, spring boards, wave pools and fountains, and “conventional facilities” contain up to 3 swimming pools and are typically owned by the municipalities. To analyze the difference between the two categories “type of facility”, the non-parametric test Kruskal-Wallis H test was used.

3. Results & Discussion

3.1 Variables effecting the delivered energy

Figure 1 compares the water use and the climate-corrected delivered energy between the facilities, ranging from 0.04 m³/bather to 0.35 m³/bather and 6.7 kWh/bather to 35 kWh/bather.

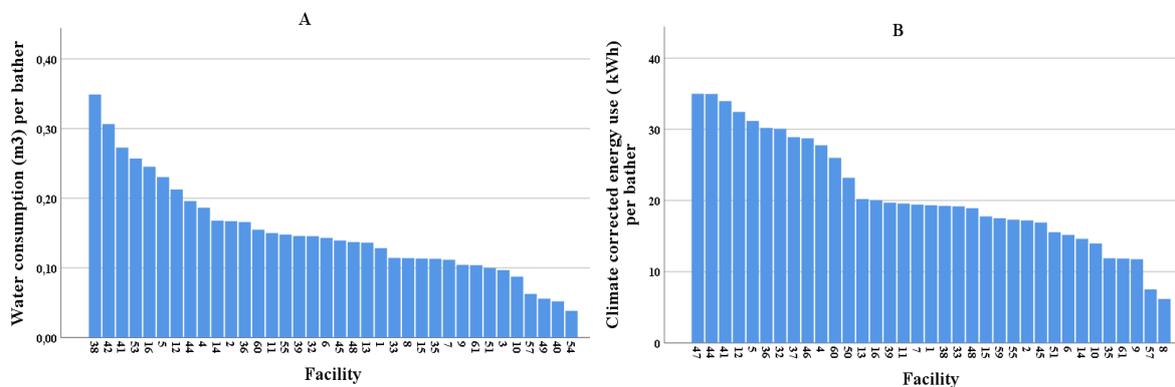


Figure 1. Water consumption per bather (A) and climate corrected energy use per bather (B) by pool facility

Correlation and multiple regression analyses were conducted to examine the relationship between the log-transformed climate-corrected delivered energy and potential predictor’s variables. Table 1 summarizes the significant variables found to correlate with the climate-corrected delivered energy and as shown in the table, the variables significantly correlating with the climate-corrected delivered energy is number of days open, construction year, number of bathers, air changes per hour (ACH), type of facility (binary variable), water use and pool water surface. As shown in the table, a positive correlation between type of chlorine and delivered energy was found, meaning that the facilities using onsite-production of chlorine by electrolysis consume more energy than those which use liquid sodium hypochlorite and calcium hypochlorite (granulated).

Table 1. Variables significantly correlating with the climate corrected energy use

Variable	Spearman's correlation coefficient
Number of open days	0.74**
Year of building	0.45*
Bathers	0.90**
ACH	-0.48**
Type of facility	-0.57**
Type of chlorine	0.37*
Water use (m ³)	0.89**
Pool water surface	0.86**

*p≤0.05, **p≤0.01

In general, the water surface in the water parks is three times greater compared to the water surface in the conventional pool facilities and the mean age of the water parks (2006) is also lower compared to the mean age of the conventional pool facilities (1983). This might explain the positive correlation between the construction year and energy use. Even though not statistically significant ($p = 0.21$), the climate-corrected energy use per bather is lower in the water parks (19.1 kWh/bather) compared to the conventional swimming facilities (27.1 kWh/bather). New facilities are more frequently equipped with apparatus such as grey-water heat recovery, on average, use 27% less energy per bather and 25% less water per bather compared to the facilities without grey-water heat recovery. Even though the pool-area normalized energy use seems to be decreasing, the size of the newly constructed facilities is increasing and thereby their overall energy use. Building flexible facilities that enable different user groups to utilize the same water surface for different purposes might result an effective strategy for reducing the overall energy consumption of the facility.

As shown in Table 1, a negative correlation between ACH and type of facility was found. Apart from their size, the main difference between the two types of facilities is how they are managed. The water parks are organized in their own association where they exchange experience for better understanding of operational concepts and to increase their expertise. Most of the water parks are owned by the private sector and, for economic reasons, they also give more attention towards parameters such as energy and water consumption. The conventional facilities are owned by the municipalities and the focus on operational strategies concerning energy saving are often non-existing. In eight of the 45 facilities, delivered energy for 2017 was not reported and were therefore excluded from the regression analysis.

A high level of multi-collinearity was found between the number of bathers, water use and pool water surface, and only one of these variables was used into the regression model. In accordance with the standardized beta coefficient, bather load was the variable explaining most of the energy consumption (60%) and was hence used in the regression. In Table 2, the result of the multivariate regression analysis is shown. The two variables bather load and number of days' open during 2017 explains approximately 75% of the delivered energy.

Table 2. Predictor variables identified using multivariate regression model explaining the climate-corrected delivered energy in 2017

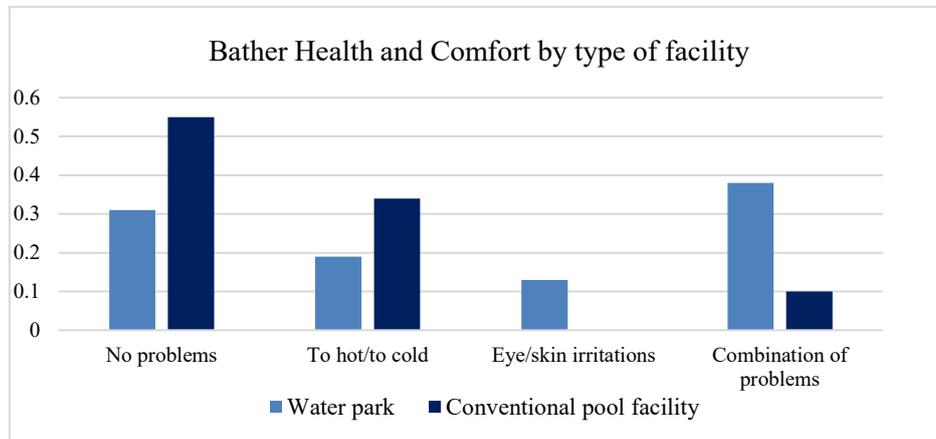
	B	SE B	Standardized Coefficient β
Constant	10.34	0.80	
Bather load	5.91×10^{-6}	0.00	0.60**
No. days open	0.010	0.00	0.38**

R = 0.87, R² = 0.76, Adjusted, R² = 0.75, n = 36

4. Reported user health and comfort

The bathers' health and thermal comfort, in percentage, reported in the water parks and conventional swimming facilities is shown in Figure 2.

Figure 2. Bather health and comfort by type of facility



Using the Kruskal Wallis test for independent samples, a significant difference between reported health effects amongst the bathers was found between the two types of facilities, where the problems was greater in the water parks compared to the conventional swimming facilities. A significant difference in the air change rate (ACH) was also found between the two types of facilities. The water parks reported an average ACH of only 2.65 h^{-1} , which is almost half of the conventional swimming facilities (4.86 h^{-1}) and well below the recommended values of between $4\text{-}7 \text{ h}^{-1}$.

In 38 out of 45 facilities, it was reported that the employees occasionally complain about their health and comfort due to their work environment and four out of the facilities, the employees have resigned their job due to the work environment. In 31% of the facilities, it was reported that employees occasionally complain about thermal comfort, and, in 49% of the facilities, the complains are more complex including dissatisfaction with several of the following problems: air temperature, relative humidity, respiratory and/or skin irritations. In 25 of 45 facilities, it was reported that the bathers regularly complain about the indoor environment and in 9 facilities the complains are more complex.

In Table 3, variables significantly correlating with the reported bathers' health and comfort is shown. In the facilities where the bathers are less satisfied, the employees are also less satisfied ($r = 0.32$, $p \leq 0.05$). Perceived indoor environment also significantly correlates with the type of pool facility, where the users of waters parks reported less satisfaction compared to the users of conventional pool facilities ($r = -0.34$, $p \leq 0.05$). This corresponds to the findings of previous studies where the air concentrations have been measured to be greater in larger facilities compared to smaller poolrooms (15, 16).

Table 3. Variables significantly correlating ($p \leq 0.05$) with bathers' health and comfort

Variable	Spearman's Correlation Coefficient
Type of facility	-0.34
Employees' health and comfort	0.32
Aerosol generating activities	-0.33

5. Conclusions

The multiple regression analysis shows that most of the delivered energy in pool facilities can be predicted knowing the approximate number of visitors and the number of opening days during the year. No correlation between delivered energy and users' health and comfort was obtained, however, the bathers in the water parks reported to be significantly less satisfied with the indoor environment in

comparison to the bathers in the conventional swimming facilities. The water parks also have a statistically significantly lower air change rate compared to the conventional swimming facilities and peoples complains might therefore be related to the indoor air quality in the water parks.

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