Energy use and indoor air quality in Norwegian swimming pool facilities

Therese Bergh Nitter 1,2,3, Kristin Svendsen 2,3 , Salvatore Carlucci 1,3 and Bjørn Aas 1,3

1 Department of Civil and Environmental Engineering, 2 Department of Industrial Economy and Technology management,
3 Norwegian University of Science and Technology (NTNU)

1. Introduction

Norway has approximately 900 swimming facilities and water parks (1) 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 (2,3). Swimming facilities also represent the building category with the most complex indoor environment. High relative humidity (RH) is uncomfortable for the workers in the poolroom and increases the risk of mould and bacterial growth in the building construction. 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 consuming processes. The heat transfer coefficient between the skin and water is higher than between the skin and air and the bathers therefore experience one of the most extreme activities from the view point of heat transfer of the human body (4). Another important aspect of the indoor environment is the air- and water quality. Long-term health effects such as asthma, adverse reproductive outcome, cancer and stillbirth have been associated with exposure to certain chlorinated disinfection by-products (DBPs) (5,6).

This project is divided into three different parts where the status of part one is presented on this poster;

Part 1: Collect energy statistics and statistics of perceived air quality and user health from swimming pool facilities across Norway (n=220),

Part 2: Collect information about health effects and user habits among professional swimmers above 18 across Norway (n=1200),

Part 3: In-depth analysis of the air quality in 6-8 pool facilities. Determine if 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

Survey and study objects

This study follows a cross-sectional study design where information was collected using a survey that was sent to the pool facilities by mail, or distributed by mail through the municipalities owning the facilities. In total, 220 e-mail addresses received the survey including questions about user habits and comfort, energy saving measures, energy- and water use and attractions, pool dimensions, disinfection technology and ventilation strategy. So far, 37 facilities have filled out the survey, and 13 facilities have responded that they are unable to participate the study due to lack of energy monitoring, rehabilitation or new staff. The data collection will end in August 2019.

Climate correction of energy use

The energy use was climate corrected, using equation 1, and the capital of Norway, Oslo, was used as reference climate. According to the Norwegian energy foundation, ENOVA, 40% of the energy consumed in a pool facility depends on the outdoor temperature (7).

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

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.

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

The pool facilities were categorized based on their size, where "water parks" containing ≥ 4 swimming pools and smaller facilities, containing of a ≤ 3 swimming pools, owned by the municipalities was categorized in its own categories. To analyze the difference between the two categories "type of facility", the non-parametric test Kruskal-Wallis test was used.

3. Results and Discussion

Variables effecting Energy use

As shown in Figure 1 and 2, there is a significant difference in water use and climate corrected energy use between the facilities, ranging from 0.05 l/bather to 0.35 l/bather and 6.7 kWh/bather to 35 kWh/bather. There is a negative correlation between climate corrected energy use per bather and year of building which means that new buildings consume less energy per bather compared to older buildings (r=-0.437, p≤0.05). New facilities are more frequently equipped with apparatus such as grey water heat recovery. However, based on the preliminary analysis no covariation between choice of technology and energy use could so far be found.

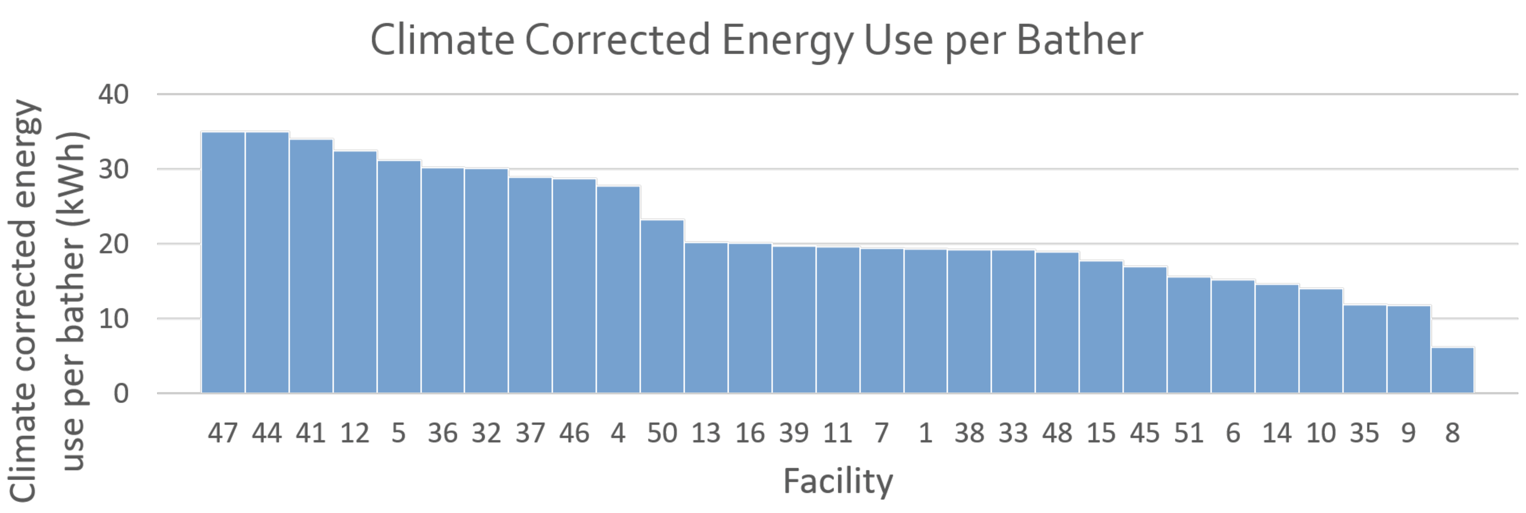

Figure 1: Water consumption (in m3) per bather and facility

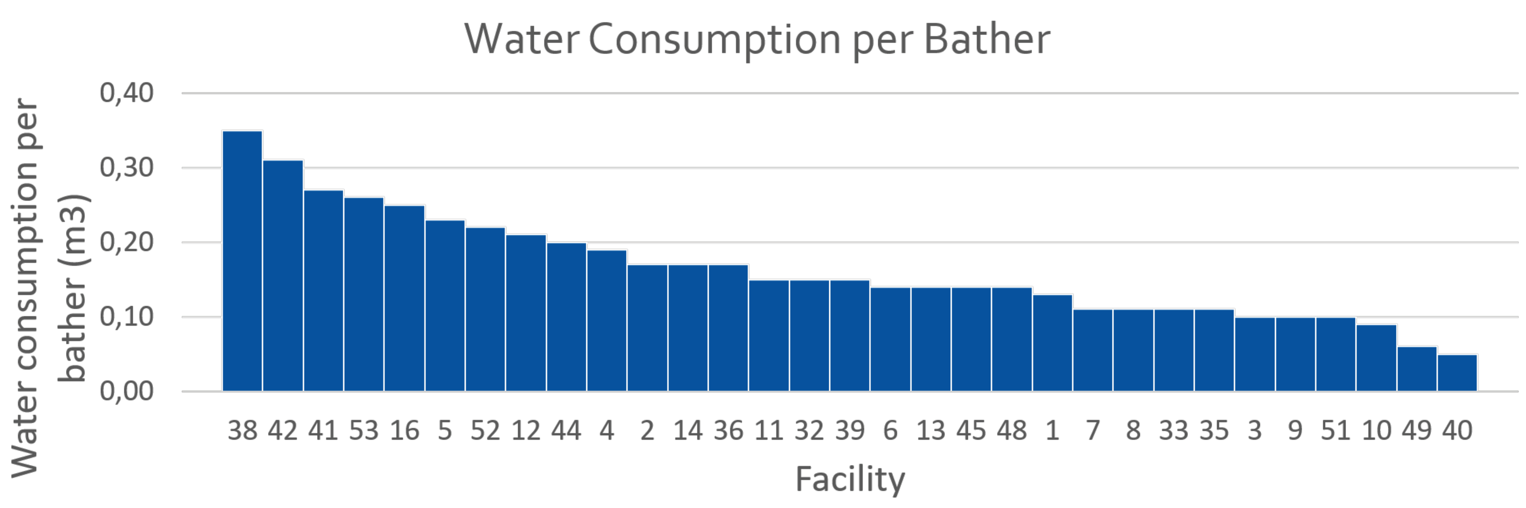

Figure 2: Climate Corrected energy use per bather (in kWh) and facility

Table 1 summarizes the significant variables found to correlate with the energy use. As shown in the table, the variables significantly correlating with the climate corrected energy consumption, is type of the facility (0=water park, 1= conventional pool facility), bathers, no of days open during 2017, water use, m2 water surface, air changes per hour (ACH) and type of chlorine.

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

Variable	Spearman's Correlation Coefficient
Type of facility	-0.46**
Bathers	0.74**
No. open days	0.53**
Water use (l)	0.71**
m^2 water surface	0.66**
kWh/opening day	0.99**
ACH	-0.46*
Type of chlorine	0.51**

In accordance with the standardized beta coefficient, bather load was the variable explaining most of the energy consumption. In Table 2, the result of the multivariate regression model is shown. In six of the 37 facilities, energy use for 2017 was not reported and was therefore excluded from the analysis. The two variables bather load and number of days' open during 2017 explains approximately 77% of the energy use.

Table 2: Predictor variables identified using multivariate regression model explaining the climate corrected energy use 2017

	B	SE B	β
Constant	10.15	0.82	
Bather load	5.44×10^{-6}	0.00	0.61**
No. days open	0.010	0.00	0.41*

R= 0.89, Adjusted R2 = 0.77, dependent variable: Ln_ClimaCorr_2017, n=30

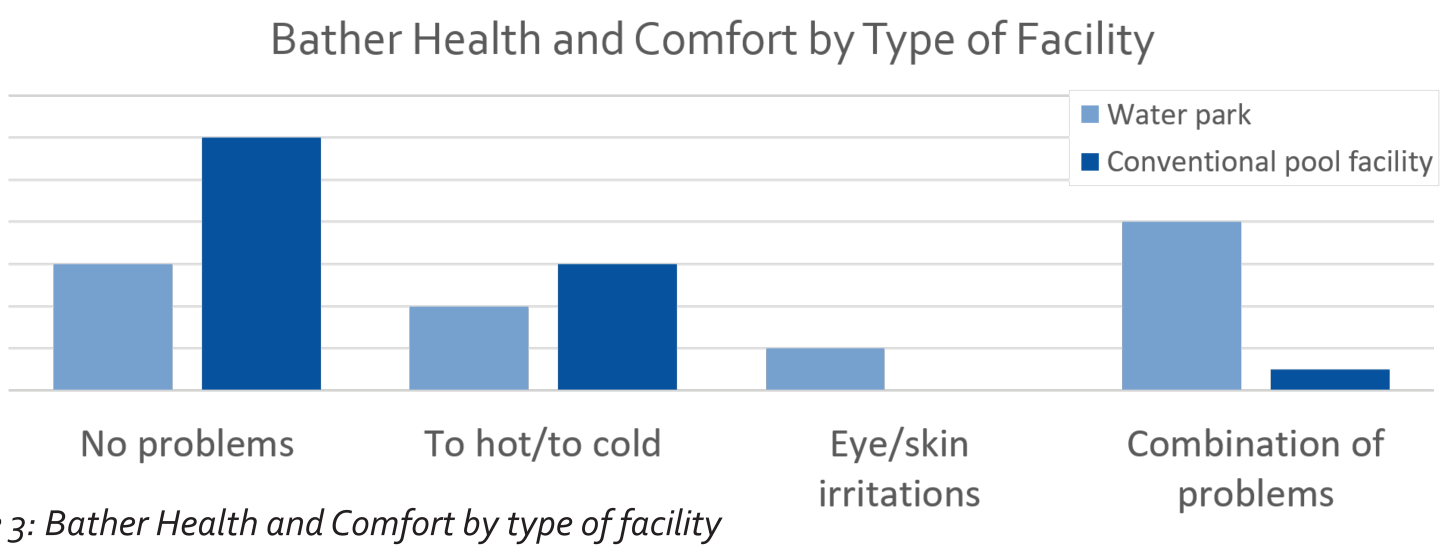

Figure 3: Bather Health and Comfort by type of facility

Bather health and comfort

In Figure 3 the bather health and comfort reported in the water parks and conventional pool facilities is shown. 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. Between the two categories of swimming pools, a significant difference in climate corrected energy use per bather and ACH was also found, where the water parks use less energy per bather and have an ACH of only 2.65, which is almost half as much as the conventional swimming facilities (4.81) and well below the recommended ACH of between 4-7.

The non-parametric Spearman's correlation test shows that, in the facilities where the bathers are less satisfied, the employees are also less satisfied (r=0.44, p ≤ 0.05). Perceived indoor environment also significantly correlate with type of pool facility, where the users of waters parks are reported less satisfied compared to the users of smaller pool facilities (r=-0.43, p≤ 0.05).

4. Conclusion

This study is not finished yet so no conclusions can be made. However, our preliminary analysis shows that most of the energy consumption in pool facilities can be predicted knowing the approximate number of visitors and number of opening days during the year. No correlation between energy use and user health and comfort was obtained, however, the bathers in the water parks was reported to be significantly less satisfied with the indoor environment in comparison to the bathers in the conventional swimming facilities. Even though the waterparks don't use more water per bather than the conventional swimming facilities, they do consume significantly less energy and have a lower ACH.

References

1) Norwegian Ministry of Culture. (1996). *Regulations for swimming facilities, pools and saunas.*
2) E. Trianti-Stourna, K. Spyropoulou, C. Theofylaktos, K. Droutsa, C.A. Balaras, M. Santamouris, . . . Papanikolaou, N. (1998). Energy conservation strategies for sports centers: Part B. Swimming pools. *Energy and Buildings,* 27, 123-135.
3) W. Kampel, B. Aas., A. Bruland. (2013). Energy-use in Norwegian swimming halls. *Energy Build*, 59(0), 181-186.
4) Abdul Munir, Satoru Takada, Takayuki Matsushita, & Kubo, H. (2009). Prediction of human thermophysiological responses during shower bathing. *Int J Biometeorol*, 54, 165-178. doi:10.1007/s00484-009-0265-9
5) Rivera-Núñez, Z., Wright, J. M., & Meyer, A. (2018). Exposure to disinfectant by-products and the risk of stillbirth in Massachusetts. *Occupational and Environmental Medicine*, 0, 1-10. doi:10.1136/oemed-2017-104861
6) World Health Organization. (2017). *Guidelines for Drinking-Water Quality* (4 ed.).
7) ENOVA. (2013). *Bygningsnettverkets Energistatistikk 2002*.

NTNU