WATER AND ENERGY MANAGEMENT IN POOL FACILITIES IN DENMARK

1 Contents

Abstract

Under the project VIDENHUB for Vandkultur, a survey is made on swimming facilities in Denmark, and a subtask is investigating water and energy management and technology in the facilities.

Technology, design, and products used in pools are comparable in the Scandinavian countries, and contractors as well as product suppliers are in many cases positioned in each country with the same products and concepts.

The result of the survey is analyzed using recent research from Norway where a benchmarking tool is used for describing the properties of a facility with respect to water and energy management.

The important difference among the countries is the price structure for energy, where Denmark is known for a large difference in price between electrical and thermal energy. Further, there are in Denmark regional submarkets and in a national context this may be considered as a disturbing factor with respect to development of a national code for best practice regarding pool system design.

The most important finding is that the balance between use of electrical and thermal energy in Denmark is quite different, compared with Norwegian numbers. It seems as the rather high costs of electricity and low costs of thermal energy (district heating, gas etc.) results in an adaption to the price structure for energy in the market, rather than a desire to reduce the overall energy use. Lack of guidelines as for instance carbon footprint or equal may also be considered as a barrier.

This may explain the lack of heat pumps for energy recovery from grey water as well as equal concepts for energy recovery from room air and subsequent recycling of energy back to source (air, pool water, tap water). Technology for the purpose is available in the market from multiple manufacturers in Europe, also via distributors in Denmark.

With the growing awareness of energy use in general, and energy from fossil sources in particular, implementation of more advanced system for energy recovery using heat pumps may be a way further.

Water use in pools is in general low in Denmark, compared with other countries. This may be explained by the distinction between DIN19643 which is commonly used as a reference in many European countries, and the Danish guidelines for water management in pools.

1 Introduction

Swimming pool facilities are recognized as a building type that supports public health and well-being and that plays a significant part in community cohesion (1). Denmark has approx. 390 public swimming pool facilities (2, 3), including water parks, training pools, therapeutic pools etc. This building category is recognized as an energy intensive building category that needs to be carefully designed and operated to conserve energy (4). The considerable variation of energy use among the different facilities can be explained by the use, location and by the type of swimming pool facility (5, 6).

Swimming pool facilities are also recognized as a complex building with a challenging indoor environment, in terms of high indoor temperature and relative humidity (RH), complex technical process plant and multiple user groups. Regarding the latter, achieving thermal comfort is always challenging (7). Indoor environment that appears as too hot for staff may still appear to be too cold for the users (8). Too high relative humidity may lead to condensing process in the building skin, followed by mold, corrosion, and discomfort. On the contrary, low relative humidity may led to thermal discomfort and increased evaporation, which is energy intensive both in term of increased water usage, heating demand for pool and in some cases, increase of fresh air flow rate.

Pool water and its impact on air quality are another important topic in swimming facilities. When swimming pool water is disinfected by chlorine, disinfection by-products (DBPs) are formed. This is due to the reaction between chlorine and organic and inorganic contaminants. Several adverse health effects are associated with the presence of DBPs in swimming pools, such as asthma, cancer, and stillbirth among others (9, 10). However, this can be controlled by a proper water treatment system, an effective ventilation system (preferably by source capture) and appropriate water and air exchange rate, which influence the energy usage of the facility.

This study is carried out by “SIAT, Centre for Sport Facilities and Technology, SIAT” at NTNU the Norwegian University of Science and Technology in Trondheim on behalf of “Dansk Svømmeunion”, “Danske Svømmebade”, Denmark and “Lokale- og Anlægsfonden”, Denmark. The work is part of SIAT’s ongoing research on water, energy, and climate in swimming facilities.

The study was divided into three parts:

- Collection of data on energy use, water use, user comfort and operation metrics.
- In-depth analysis of the collected data. Determining the expected energy performance of Danish swimming facilities.
- Case study of a selected pool in Municipality of Aabenraa.

2 Method

2.1 Background

Swimming pool facilities in the Scandinavian countries have some typical properties:

- Design and equipment are relatively similar
- Climatic conditions are comparable
- Ownership and operation in most cases by the municipality

On the contrary, energy systems in the countries are quite different, and pricing of electrical and thermal energy shows substantial differences. While Norway and Sweden in general have a price structure where thermal energy is a little bit cheaper than electrical energy, Denmark is showing a quite different picture. Electrical energy is more expensive than in Norway and Sweden, but thermal energy, provided from sources like district heating, gas boilers or in some cases also cooling water from power plants may be far cheaper expressed as DKK/kWh. The variations in price structure in the different countries gives impact on the technology for heating and energy recovery.

Research from NTNU SIAT the recent years have included investigation of energy and water management in pools, and technologies for energy recovery. A general flowsheet showing air and water flows in a best practice pool facility may be like this:

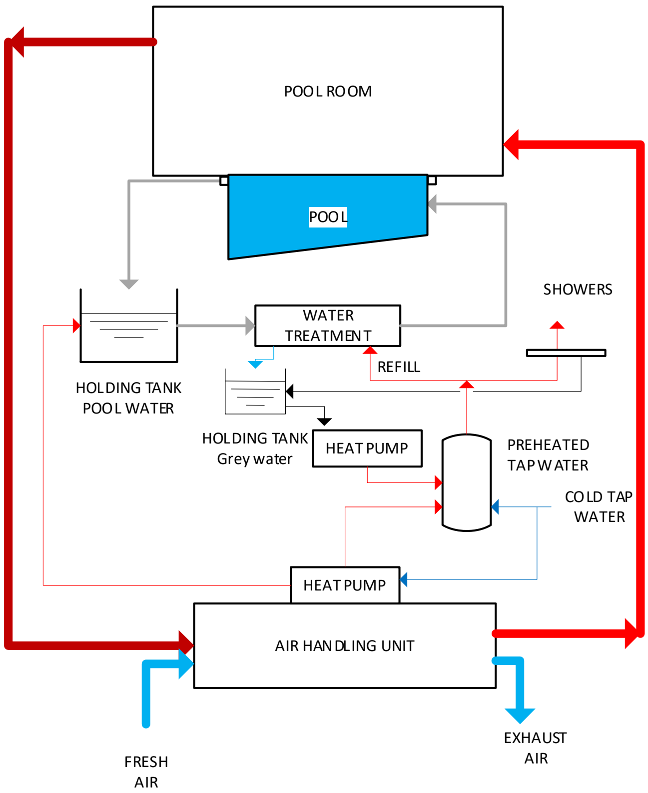

Figure 1 Flow sheet air and water (Kampel 2015)

Considering that the energy in the room air origins mainly from the pool surface as evaporated water, recovery of energy from the air must allow for recycling this energy back to indoor air or pool water on demand.

The use of static heat exchanger for air, combined with heat pump for energy recovery in the air handling unit, where the heat pump circuit is designed for independent operation of condensers for air and water, will allow for energy recovery to air and water. Investigation of several projects in Norway where this concept is implemented is showing that a sports pool normally is operated only with recovered energy, and no extra energy from other thermal source is required. Normally, heat pumps in air handling units are working with COP in range of 6-7.

Accordingly, collection of grey water from showers and filter backwash, and the use of a grey water heat pump for energy recovery, may allow for refilling pools with water at temperature equal to design temperature for the pool. Further, the preheated water may be used for showers, by adding a minor fraction of thermal energy to top up the water temperature. As grey water holds a temperature in range of 29-30^{o}C, and heat pump is working with output temperature in the condenser in range of 32-39^{o}C, the COP of the system is high, normally in range of 10.

In the Norwegian and Swedish market, the use of heat pumps as described above is common, and the investment is showing very good financial profile. This may be explained by the price level for electrical and thermal energy, and the mentioned minor difference in price between them. In Denmark, the price structure is as mentioned above different, including substantial regional variations.

Less investigated is the impact of total air flow, and the ratio fresh air/total air flow in pools. The general guideline from VDI2089, with 4-7 air exchange per hour and 30% fresh air during opening hours is based on empirical findings. Recent research on thermal comfort and air quality in pool rooms allows for more advanced approach. One important finding is that the stripping of gas from water surface to air is a continuous process (9). The disinfection biproducts are in the gas phase in some cases heavier than air and will remain as a layer above the water surface if air velocities are not high enough to disturb the layer and dilute the gases. The second important factor regarding ventilation in swimming hall is the total air flow and air distribution in the room volume. New, well insulated, and airtight building skins with multilayer windows may have surface temperature on the room side close to room temperature, and the risk of condensation on windows and drag of cold air downwards is limited. Further, as the thermal loss through the building skin is reduced, the need of rising temperature on inlet air to compensate for the losses is reduced accordingly.

Finally, new knowledge with respect to thermal comfort and air quality calls for a different approach for ventilation design, in short described with the following criteria:

- Remove pollution (origins from pool water, persons)
- Provide fresh air to persons where they are
- Maintain stable room climate with respect to temperature, humidity, and pressure according to design of building skin
- Design to lowest possible energy (kWh) and effect (kW) demand by demand-controlled flow and advanced energy recovery systems

The covid19 pandemic have emphasized the importance of good ventilation, in particular fresh air rather than recirculation. Newer AHU systems have implemented this feature.

2.2 Data collection

The study was conducted in 3 stages, as Figure 2 illustrate. The initial defined topics and thereby the dependent and independent variables created the base of the questionnaire. See **Error! Reference source not found.** for an overview of the topics. The questionnaire is given in an appendix.

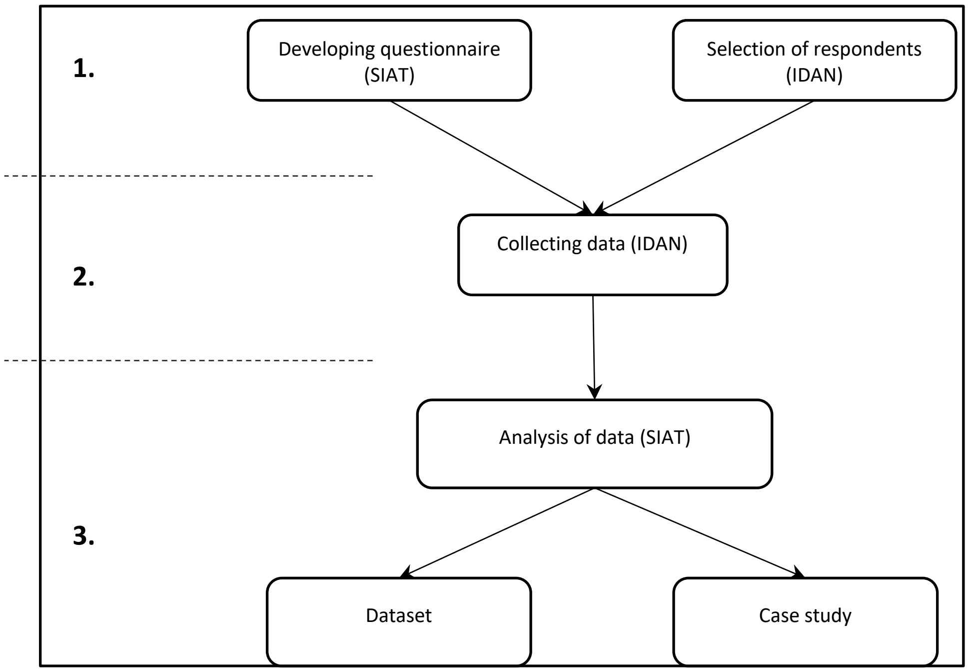

Figure 2 Workflow-chart for the study where each stage is defined by task and executive organization.

The selection of respondents was picked among the members of the association "Danske Svømmebade". The survey was distributed by IDAN to the respondents by e-mail, and the respondents who needed guidance were given advice by telephone. The response can be summarized as follows:

- *149 facilities responded to the survey.*
- *106 reported water surface area*
- *104 reported annual operation hours*
- *88 reported number of visitors*
- *70 reported water usage*
- *46 reported ventilation air flow rates*
- *23 reported energy distribution between electricity and thermal energy*
- *23 reported only electricity*
- *16 reported only total energy usage*

The structure of the questionnaire included the following information tags:

Physical properties

Facility info 1

- ID
- Name
- Adress
- Constr.year
- Last refurbishment
- Last refurbishment walls, roof, floor, windows

Pool info

- Number of pools in facility
- Type of attractions
- Pool info
    - Dedicated room
    - Water surf area
    - Water volume
    - Water Temperature
    - Swimmer Capacity
    - Added salt (g/l)

Technical description

Room

- Room volume

Ventilation

- Air supply placement
- Air extract placement
- Nominal air flow rate
- Indoor temperature
- Indoor relative humidity

Water circuit

- Filter type
- Disinfection type
- Reuse of water?

Energy plant

- Heat source room
- Heat source water
- Heat recovery pool water?
- Heat recovery shower?

Key variables

Consumption data 2017-2019

- Water usage
- Electricity
- Thermal
- Total

Operational info

- Opening hours 2017-2019
- Number of visitors

User and employee satisfaction

- Thermal comfort
- Humidity comfort
- Health issues

Figure 3 Collected information in survey

2.3 Normalizing energy use

The reported energy data was climate corrected with the purpose of making the energy performance of the facilities climate independent and comparable. The energy data was normalized to the climate of Oslo, Norway 2010 with the international recognized degree-day method (11, 12). By normalizing the data to Oslo 2010 the outcome of the study can be on compared with several other studies.

The degree-day method is taking in to account the number of degree days for the geographical location, for one specific year, and is normalizing the climate dependent share of the energy use (13). The degree days were collected for each facility’s respective region, see

The degree-day variable was extracted from the annual weather reports in the Danish Meteorological Institute database (14). The method is given in equation 1. Beside the number of degree-days, the climate dependent share of the energy use is an important parameter. For swimming facilities, 40 % may be considered as an appropriate key number (15).

$$DE_{Oslo} = DE_{actual\ facility}\left((1-0.4) + 0.4 * \left(\frac{HDD_{17,Oslo}}{HDD_{17,actual\ facility}}\right)\right)$$

2.4 Linear regression analysis

In this study, regression analysis was used in the analysis of the usage data. It was used to identify the relationship among the variables. The dataset and the residuals were tested for the fundamental assumptions using linear regression, such as normality, independence and heteroskedasticity (16). The variables were tested for multicollinearity.

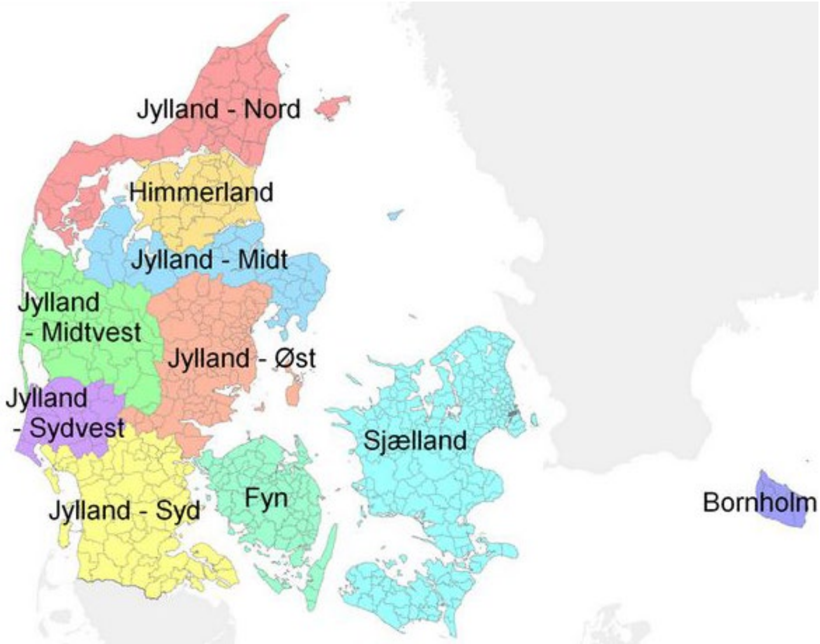

Figure 4 Regions in Demark applied in the climate correction model.

Region	2017	2018	2019
Jylland North	3140	3047	3028
Jylland Middle and West	2999	2957	2904
East Jylland	3011	2921	2902
South Jylland	2893	2838	2764
Fyn	2836	2787	2726
West and Southwest Sjælland, and Lolland and Falster	2881	2805	2724
København and North Sjælland	2944	2852	2766
Bornholm	2945	2823	2744

Table 1 The degree-days applied in the climate correction model (14).

2.5 Benchmark

Analysis of energy and water management is executed using a set of benchmarks as described in (5). While buildings normally are benchmarked using usable area, sports facilities are more equal to process facilities where the operation (people visiting and using the pool) and process (water surface, water treatment, air, and water heating) are the most significant indicators. In this report the following benchmarks are used:

Energy use per visitor	kWh/p
Energy use per water surface per year	kWh/ws*y
Water use per visitor	l/p

3 Results and Discussion

3.1 Descriptive

The dataset is represented by a group of swimming facilities which approx. 8.5 million visitors in 2019. 87 swimming facilities reported the annual attendance where the key metrics are:

- Average - 97 133 visitors
- Median - 55 000 visitors
- Min/max – 240/442 5231 visitors

The distribution of the annual attendance and the variation among the respondents are shown in Figure 5 and Figure 6. The plots show a significant variation regarding the usage of the facilities where 15 % reports an annual attendance above 200 000 visitors.

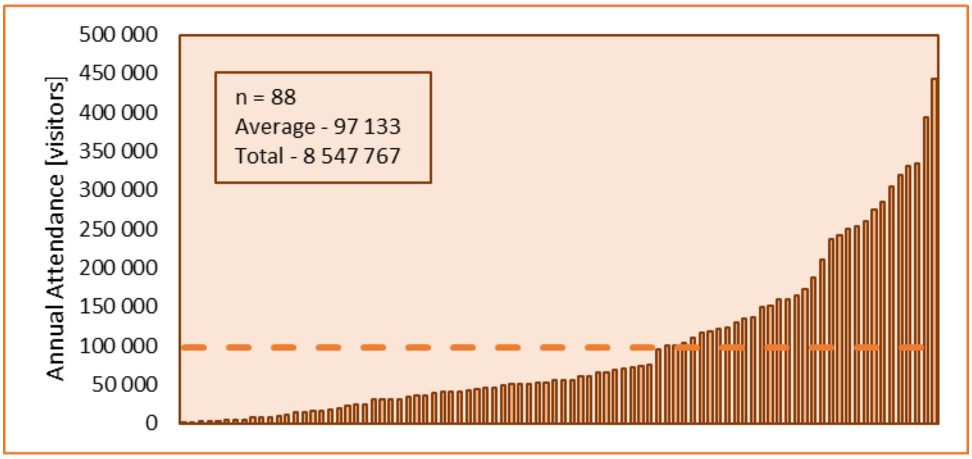

Figure 5 Annual attendance 2019

Regarding the physical properties of the facilities, the average (and median) pool surface area is 387,5 m^2. Approx. 15 % of the swimming facilities is represented by a pool surface area above 1000 m^2.

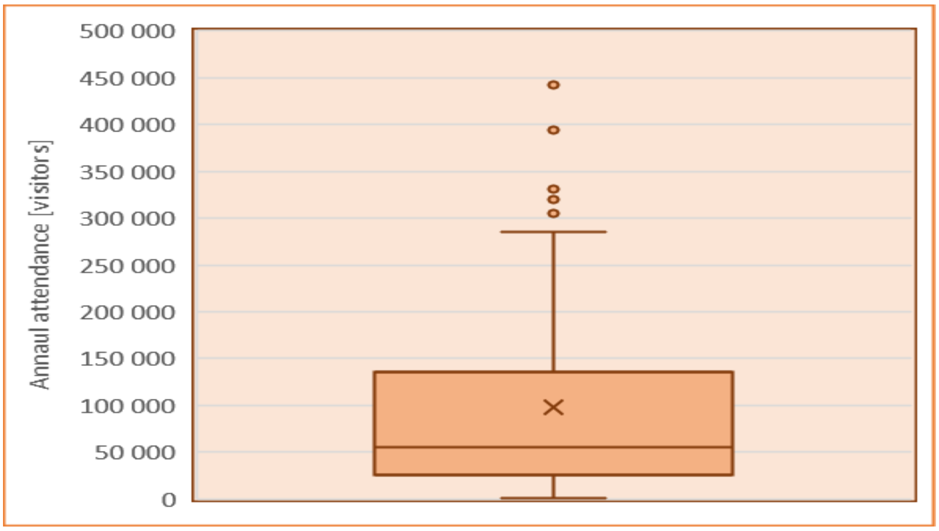

Figure 6 Box plot - the reported annual attendance

The spread of visitors indicates that the variation in size of the facilities is equally widespread, and from that follows that the design concept, technology and operation are diverse. With a larger number of cases, the survey could have been split in categories to unify the results and getting better correlation between the tested properties.

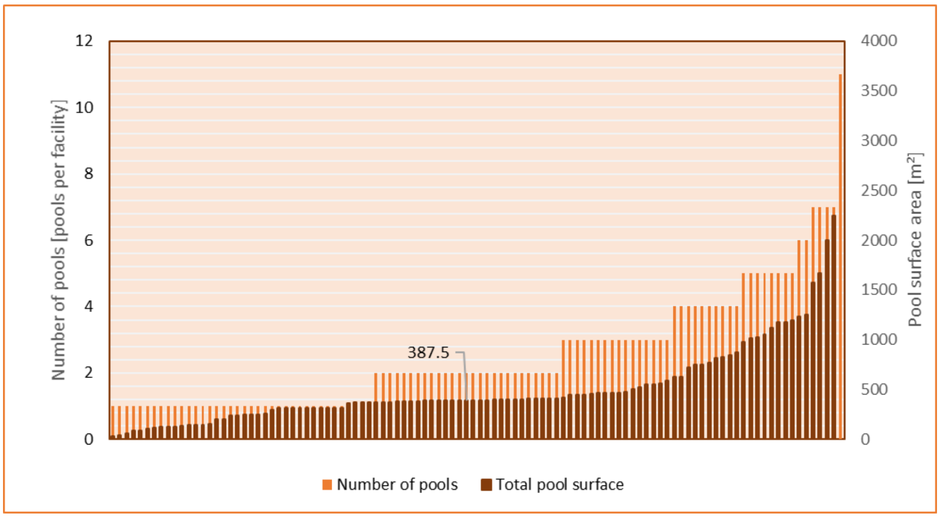

Figure 7 Distribution of the pools total surface area in each facility.

The reported energy data is lacking confidence, and a great portion of the reported data could not be included in the analysis. In total 26 facilities, out of the 149 facilities, reported energy usage which could be included in the analysis. The final dataset showed that it represented the whole range of facilities, with respect to size, expressed as pool surface area. However, larger facilities are overrepresented in the selection compared to the original dataset, where the median pool surface area is approx. 500 m^2 compared to the whole selection represented by a median 387.5 m^2.

The pool surface area for the facilities who reported reliable energy data are shown in Figure 8. This reveals the challenge smaller facilities are facing regarding energy system design and lack of energy management during operation.

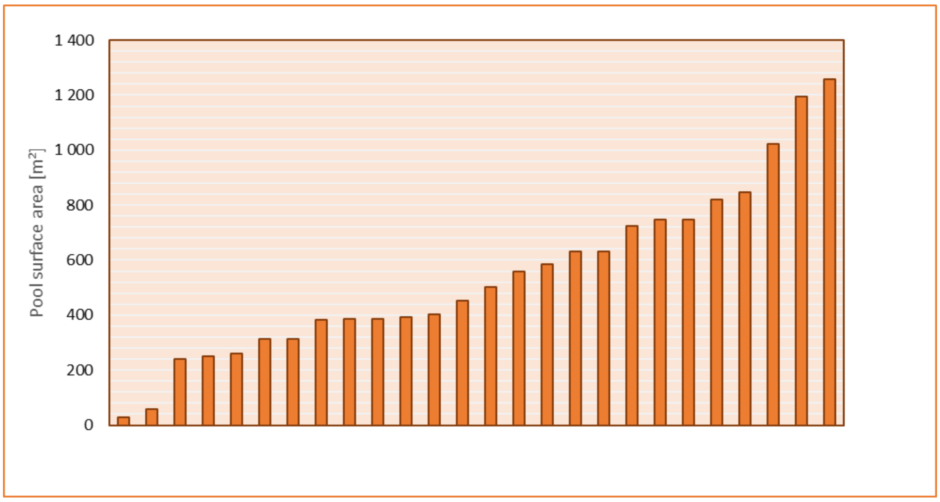

Figure 8 Pool surface area for the swimming pool facilities included

The climate corrected annual specific energy use with respect to water surface and visitors is shown in Figure 9 and Figure 10. The selection of facilities ranges from 997 to 4,193 kWh/m^2ws*y. and from 5 – 47 kWh/visitor. The energy data is averaged at 2,716 kWh/ m^2ws*y, and 19 kWh/visitor, respectively.

Findings from Norway indicates that the energy use per visitor is reported from 7 – 35 kWh/visitor (9). The energy use with respect to the water surface area is found to range between 3,288 to 4,285 kWh/m^2ws*y. for swimming facilities built after 1960 (11).

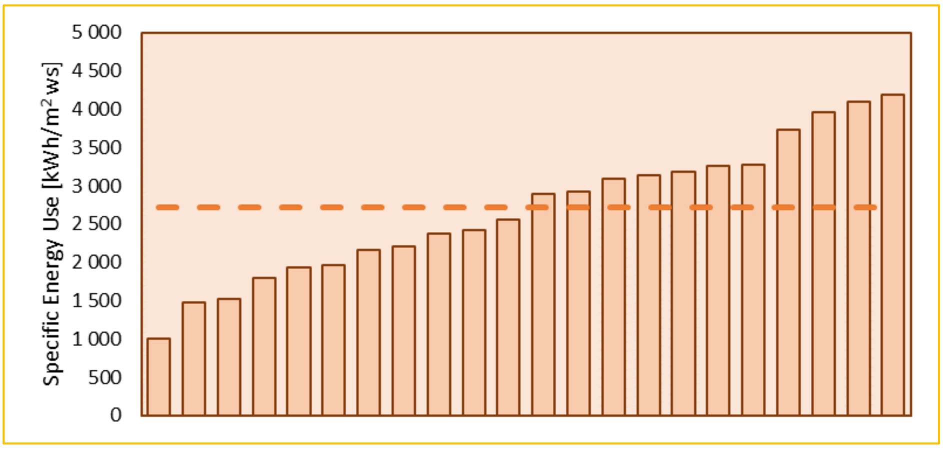

Figure 9 Specific energy use 2018 – Annual energy use per square meter water surface. Total energy use climate corrected to Oslo 2010.

From the Norwegian research, energy use expressed as above is showing a decrease against increasing pool surface. The small pools, typically 110-300 m^2 of water surface will have higher energy use than larger pools.

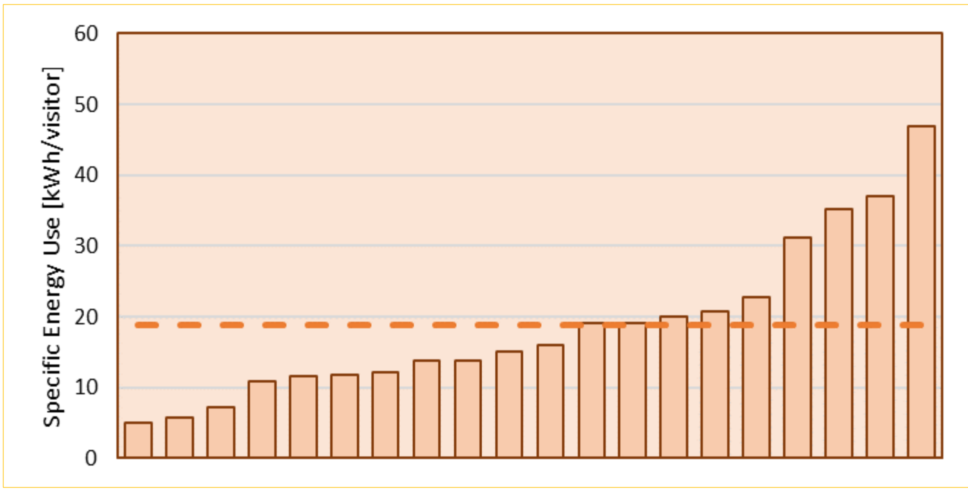

Figure 10 Specific energy use 2018 - Energy use per visitor- Total energy use climate corrected to Oslo climate 2010. Average is 19 kWh/p.

The specific energy use is showing a substantial spread, also known from the Norwegian market.

Water usage is averaged at 80 liters per visitor, ranging from 20 liters per visitor to 160 liters per visitor. In comparison, Norwegian swimming facilities has been reported to range between 40 – 350 liter per visitor.

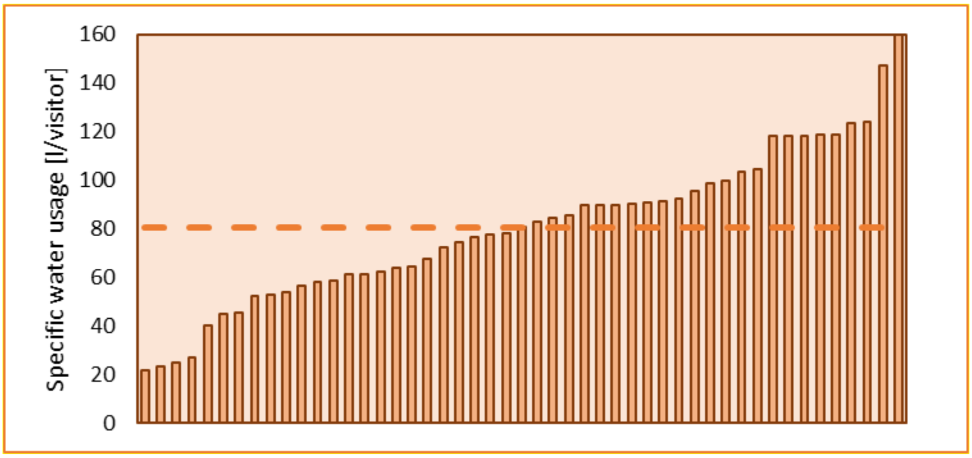

Figure 11 Specific water usage, liter per visitor, for 2017. Average is 80 l/p

Water usage is seen to correlate well with both the size of the facility, with respect to the pool surface area, but also with the number of visitors.

Bearing in mind the main water sinks in swimming facilities are filter backwash (with subsequent replacement of the same amount of water) and showering, this connection is obvious. The strong correlation implies a strong culture on water economics among Danish swimming facilities.

The low specific water usage, compared to Norway, can also be explained with different practices in design. Norwegian swimming facilities normally are designed and operated after the specified bleed water requirements in the DIN 19643 (17, 18). According to DIN 19643, bleed water shall be 30 l/p for pool with temperature <34^{o}C, and 60 l/p for pools with higher temperatures.

The Danish guidelines do not have an equal requirement. Understanding the bleed water concept may give different outcomes. If water for backwash is included in the bleed water balance, it may be shown that using standard pressurized sand filters, the back wash water volume will equal to the mentioned numbers in DIN19643 for pools with regular operation and weekly backwash of filters. Other filtration concepts may give other water balance numbers. If back wash water is recycled using membrane systems, it would be expected to find reduced water consumption in facilities with such equipment in operation.

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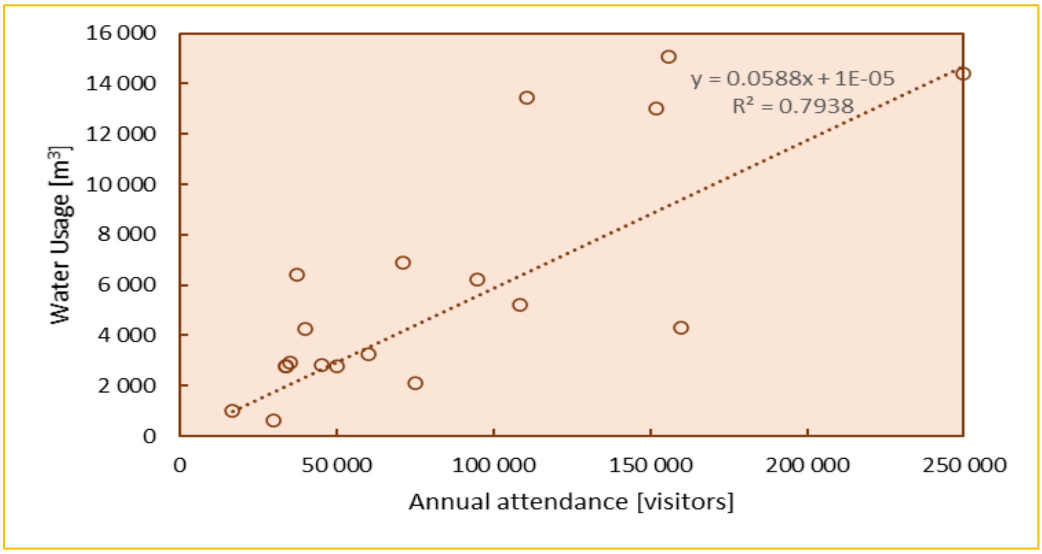

Figure 12 Annual water usage for 2018 plotted against annual attendance

If water usage and pool surface are plotted against each other, an equal relation is determined. There is an obvious relation between pool area and visitors.

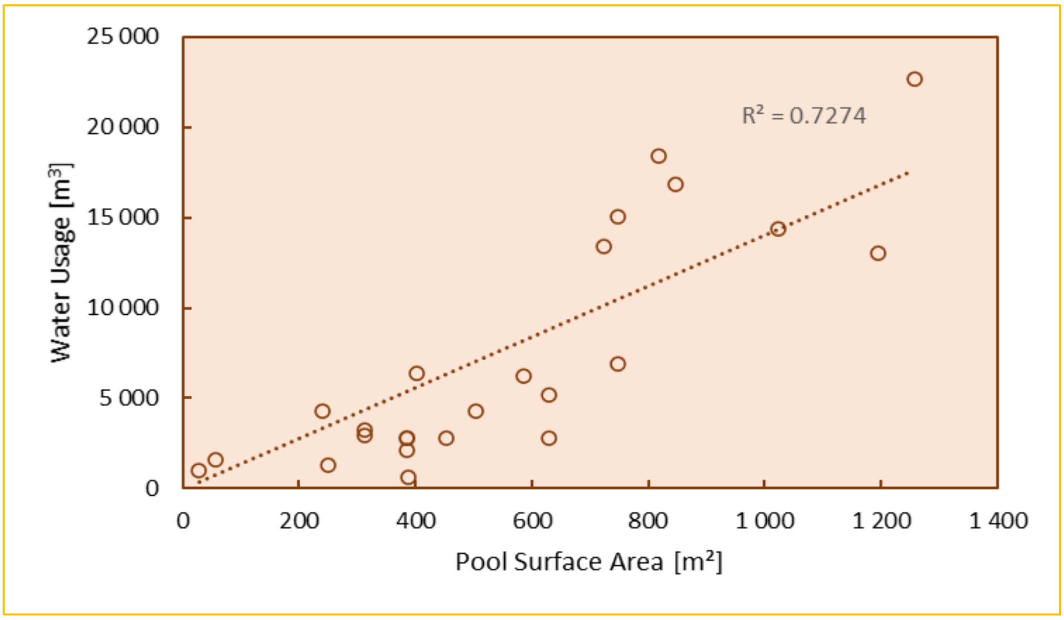

Figure 13 Annual water usage for 2018 plotted against the facility's pool surface area

3.2 Water treatment systems

From the survey, some typical plant designs may be investigated.

1.1.1 Water treatment concept

The key process for water treatment in pools is the filtration unit. The following products are identified, including no of plants:

Filter concept	N
Sand filter	45
Diatomit	8
Membrane	2
Glassfilter	5

The low number of plants in each category do not allow for a more detailed investigation on how the different systems impact the water or energy use in the plants.

1.1.2 Water for filter backwash

It is anticipated that the different filtration systems may show different back wash water demand, and this spread may be detected from the water use numbers. From the survey, the following information is collected:

Back wash water source	N
Cold water	15
Holding tank	15
Pre-heated water	12
Re-used water	4

Combining the source of backwash water with total water use or use of thermal energy, it is not possible to indicate any preferences due to the limited data set.

3.3 Analysis of energy use

3.3.1 Electrical energy

From the survey, it may be anticipated that electrical energy is mainly used for the technical equipment like light, blowers, pumps etc. This energy fraction is depending more on the use of the facility, and less on the climate impact. With a larger data set, the results could have been split to categories of pools, expressed by pool surface or other properties.

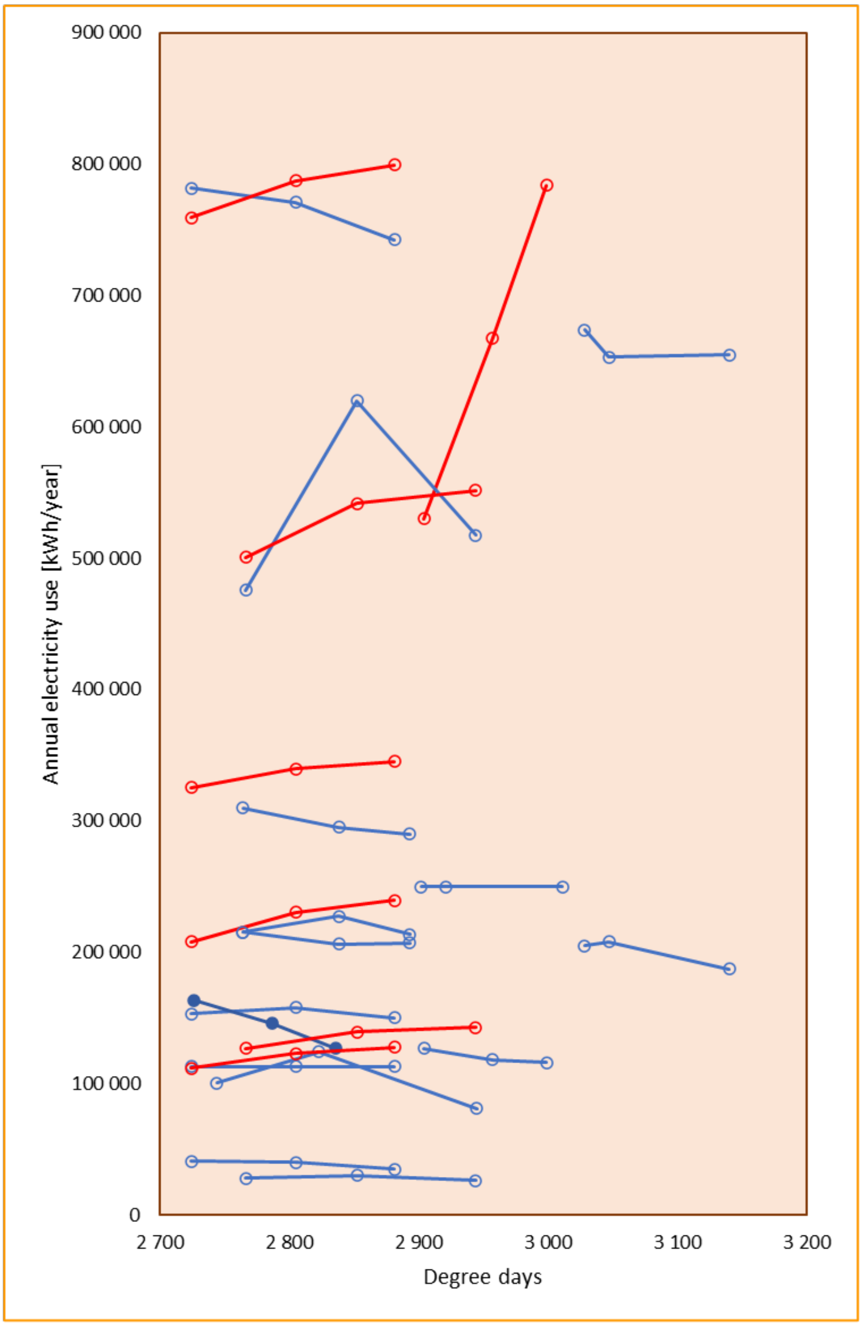

Figure 14 Annual electricity use and the corresponding degree days. Each line represents a facility. Red lines represent a positive correlation while blue lines represent negative or no correlation.

In Figure 14, electricity use is plotted against climate, expressed as degree days. Results are a bit divided, but with one exception, the correlation between electricity and climate seems to be limited – as described above.

A clearer picture becomes visible when studying energy use per visitors. Ranging from 4 to 2.5 kWh/p, where smaller pools have a higher usage than larger pools, the numbers may be considered as low.

Smaller pools may have lower opening hours, and subsequently the share of energy used outside opening hours are higher, given the fact that the main equipment like pumps and ventilation systems are running 24/7.

As a general conclusion, electrical energy in pool facilities is closely related to rotating equipment and light, and the nature of the facility (open water surfaces, constantly circulation of air and pool water) requires an equally constant operation of the mentioned equipment.

3.3.2 Thermal Energy

Thermal energy is partly related to climate impact (the building envelope's energy loss and heating of ventilation air), but the main share is related to the operation, i.e., visitors using water in the showers and by using the pools, causing increase in evaporation, and need of filter backwashing as the pool water becomes polluted by the users.

The share of energy use related to climate is for a new facility expected to be very limited, compared with energy use related to energy use for ventilation and water (pool water and tap water) heating.

With the limited number of reported data, it is not possible to draw straight conclusions, but some general comments may be given:

1. Ventilation is demand-controlled, and with just fair level of energy recovery. The energy needed for ventilation is a 24/7-demand, reduced during closing time and increased during opening time. This concept will maintain an annual demand of energy from thermal sources.

2. Heating of pool water as well as tap water is provided directly from thermal energy, and energy recovery from grey water is in most cases not implemented. Energy demand follows the opening hours and visitor's attendance directly. The use of storage tanks for hot tap water is not examined in the survey.

The following diagrams are example of benchmarks used to describe energy use in relation to a selected set of variables:

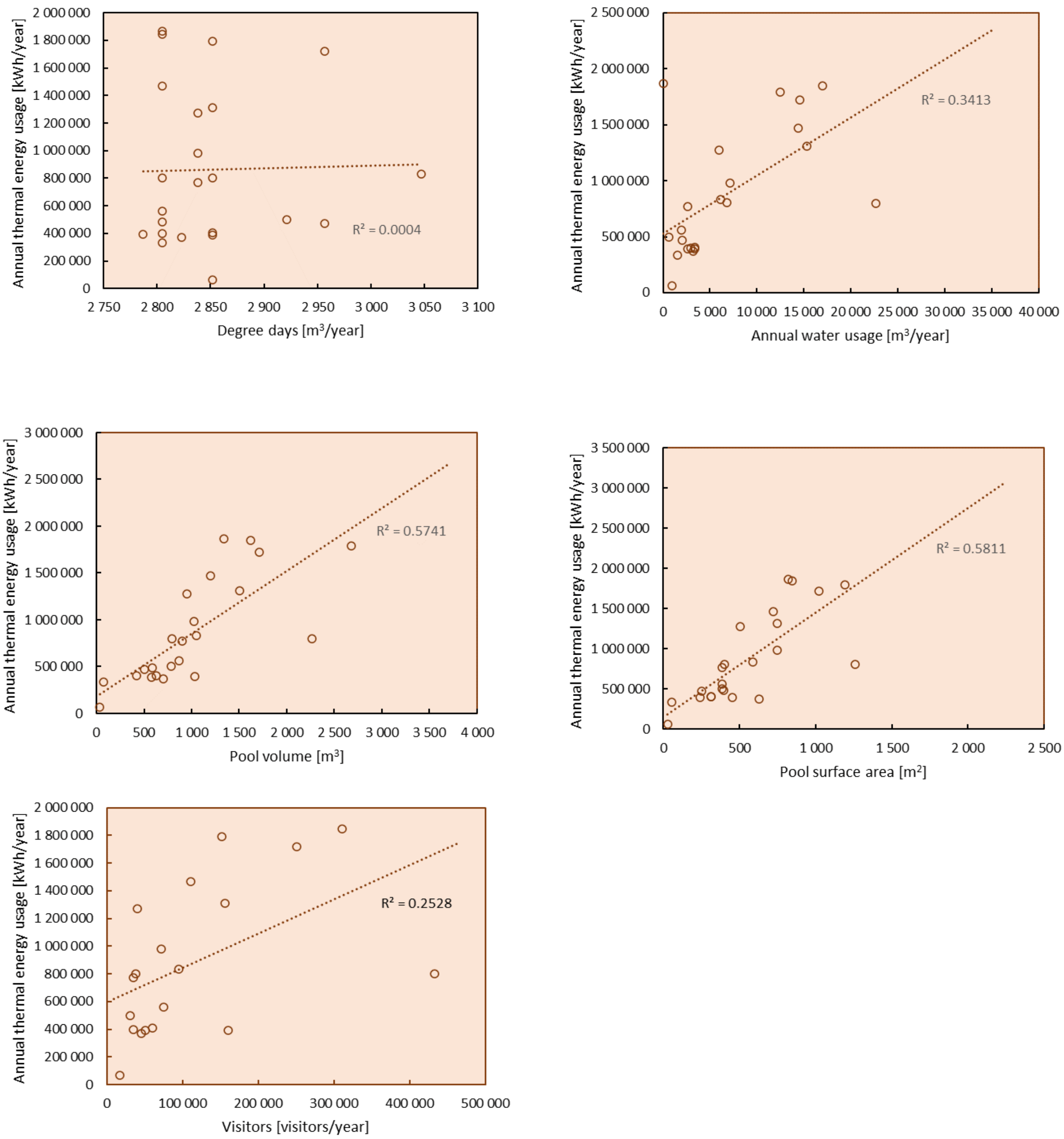

Figure 15 Thermal energy use - various benchmarks

The different diagrams indicate that the latter explanation may be the stronger one. In general, thermal energy use in pools included in the survey is high, and the relation between water usage, pool surface and users are close.

Plotting the relative share of the total energy for the facilities reporting both thermal and electrical use gives the following diagram:

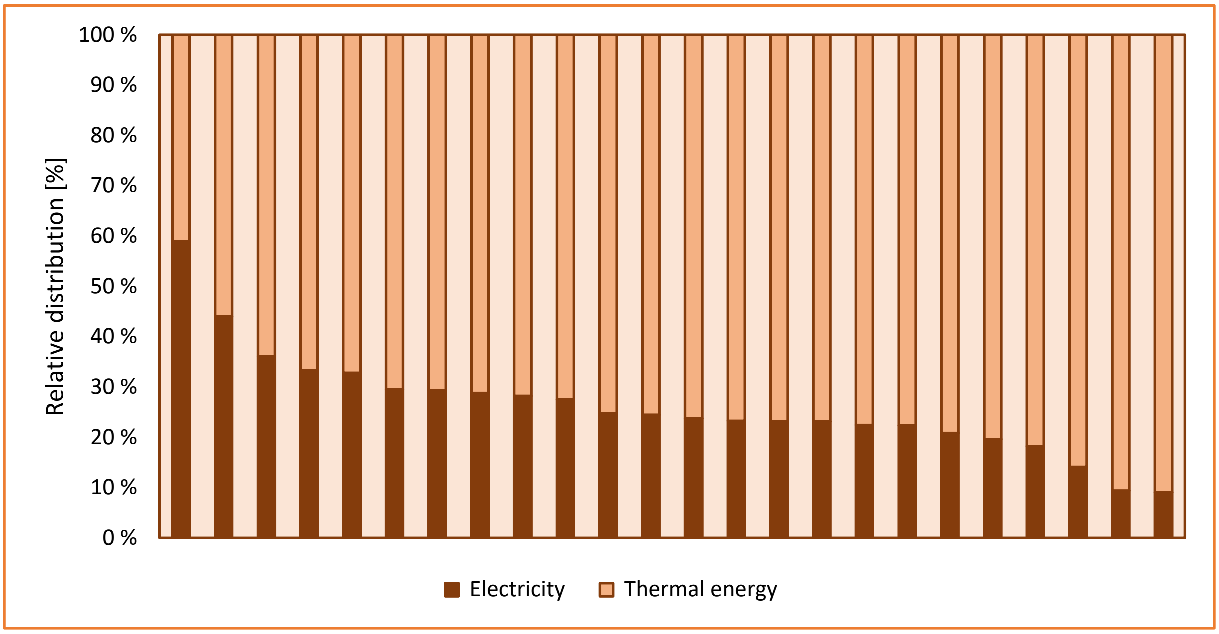

Figure 16 Relative energy distribution thermal vs electrical

Compared with Norwegian numbers, thermal energy both as share of the total and in absolute numbers are surprisingly high. For a medium size facility designed in accordance with passive house code for the building skin, it may be anticipated a ratio 70/30 in electrical vs thermal energy use in the Norwegian market. This example is based on the use of heat pumps for energy recovery from air as well as grey water.

3.4 Energy recovery

The pool facility contains a high energy base, in terms of pool water with a temperature in range of 28-37^{o}C and room air with temperature in range of 30-32^{o}C and relative humidity in range of 55-65%. As the ambience most of the time represents a lower energy level, the successful design and operation aims for minimum of energy transfer through building envelope and mechanical systems like water treatment, sanitation, and ventilation.

There are several findings that may explain the limited attention to energy recovery concepts known from other countries in Scandinavia and Germany among others.

3.4.1 Backwash water source

Filters for pool water treatment need backwashing, and the backwash water must be drained off due to level of pollutants. As an estimate, backwash water may equal to 50 l/p in average per year.

Backwash water may be collected from different sources, and the survey points out three different concepts:

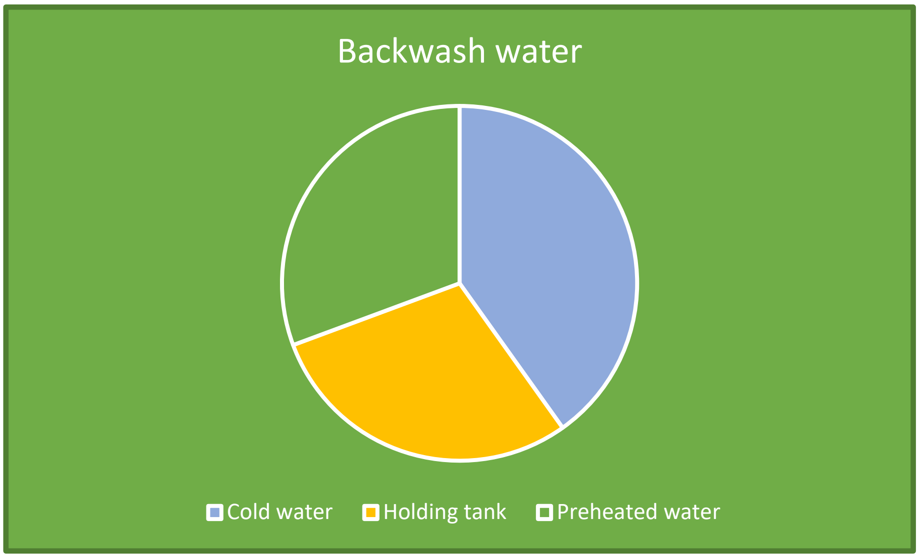

Figure 17 Water source for backwashing. n=90

1. Backwash water may be collected from the pool's holding tank. In this case, an equal amount of water must be provided from the grid.
2. Pre-heated water may be used for backwashing. Preheating may be achieved by use of thermal energy or heat energy from sources like heat pumps or bleed water from the pool.
3. Backwash water may be collected directly from grid, or via an intermediate storage tank. This water is cold, and even if some minor temperature increase may occur during storage time, the concept will chill down the filter during the process.

3.4.2 Energy recovery from backwash water

As an estimate, 50% of the water usage in a pool may origin from backwashing filters, and thereby the discharge of backwash water to drain represents a substantial energy loss.

If backwash is made by use of water from holding tank, the discharge temperature is close to pool temperature. Accordingly, this will require a refill of water to pool, and the concept will give a certain replacement of water in the pool.

If backwashing of filters is performed by use of cold water, the discharge temperature will be close to cold water temperature, but during first stage of backwashing, the warm water in the filter is replaced with cold water. Accordingly, when backwashing is completed, the filter is filled up with cold water, and this will be forwarded to pool and required further heating to reach pool temperature.

If backwash water is made by use of pre-heated water, the discharge temperature will equal to source, with the modifications mentioned above.

Best practice for energy saving may be backwashing by use of water from holding tank, and energy recovery from water by use of a heat pump before discharge.

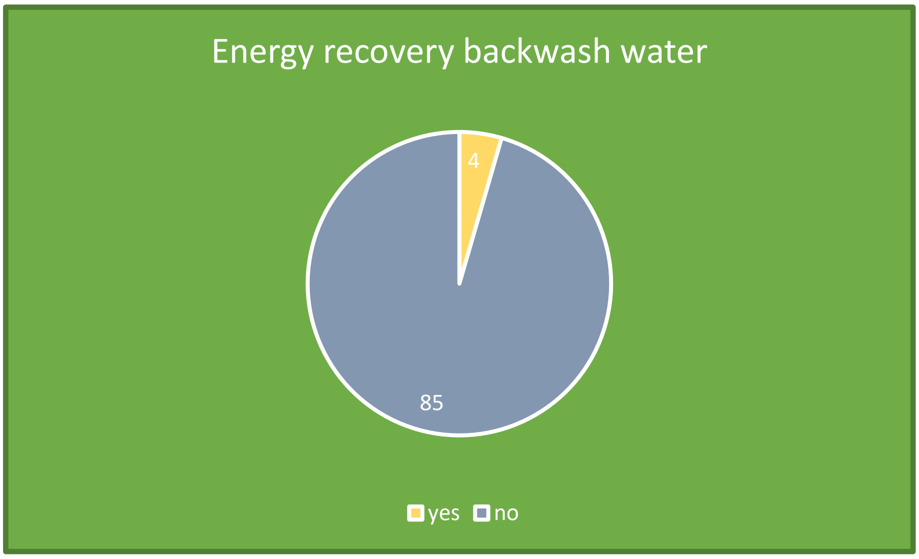

Figure 18 Energy recovery pool water. n=89

3.4.3 Energy recovery from shower water

Energy recovery from shower water (grey water) is a complicated process which must be implemented from design stage. Sewer pipes must be divided in grey water and black water, and grey water must be collected in a holding tank. The most used concept is using heat pumps with evaporators designed to purpose, i.e., chilling of polluted water without clogging or scaling. To reach an economical target, systems are normally combined, where backwash water and shower water both are collected in the same holding tank.

The heat pump is provided with internal pump which feeds the grey water through the heat pump and further to sewer system. On the warm side of the heat pump, fresh water from city grid is heated to around 30-40°C and may be used for refilling pool as well as preheating shower water.

4 Discussion

The survey is giving a valuable insight in a selection of pool facilities in Denmark and may be used to describe some key performance indicators for each pool as well as the grand total.

4.1 Ventilation

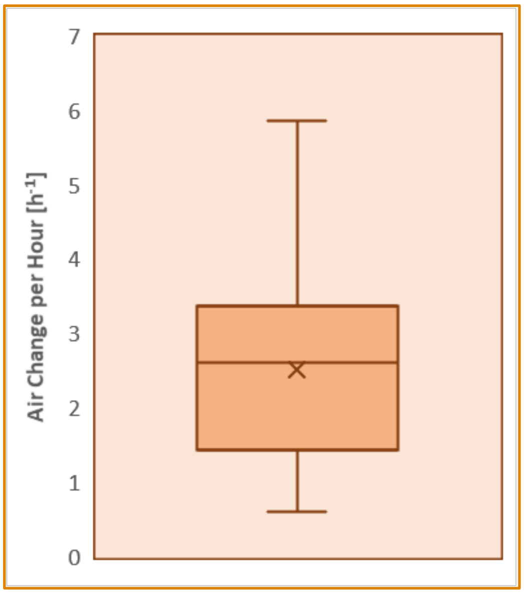

Figure 19 Air changes pr hour (ACH)

The air exchange numbers are showing a substantial variation, and the average is low compared with traditional design guidelines such as VDI2089 (18), which advises an air exchange in range of 4-7 during opening hours. While air change show variations, the fresh air rate as share of the total is not clearly described in the survey. With further reference to VDI2089, a typical design is 30% fresh air and 70% recycled air during opening hours, and up to 100% recycled air during closing hours.

To clearly understand the impact of air flow, the findings should be combined with the feedback on indoor climate.

4.2 Water usage

The water usage is equally showing variations, and some explanations may be given:

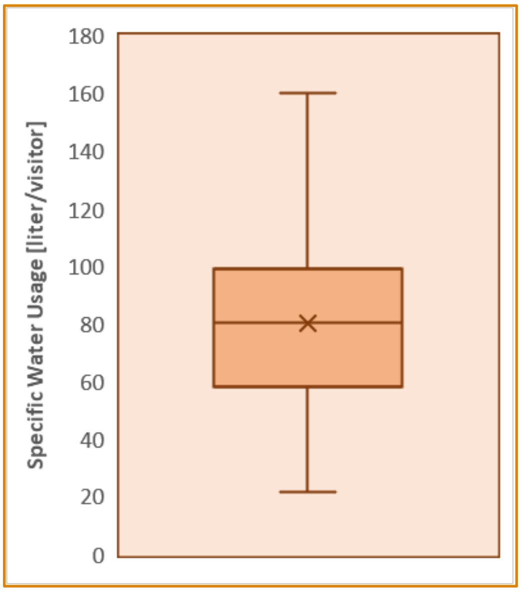

Figure 20 Water usage

Use of sea water, rainwater or lake water as an additive may reduce the use of water from the water works. If water usage is declared as purchased water from grid, it may be a deviation between purchased tap water volumes and discharged wastewater volumes.

Use of water treatment systems for cleansing of backwash water is considered to reduce water demand for backwash with up to 70%. These systems are rather rare in the Scandinavian market, but the number of installations is rising. Different technologies are available in the market, with different level of treatment (UF, RO etc) and different recovery rate (rate of flow recycled vs flow used for filter backwashing and subsequent discharged). The performance of the systems is questioned with respect to pollutant that may pass through the filters and be retained in the pool water system.

As there is no general guideline for bleed water use in Denmark, the fraction of high numbers may only be explained by

- Unexpected water use (overflow in balancing tanks, leakages)
- More frequent filter backwash due to high bather load, weak filter performance or capacity constraints

4.3 Indoor climate

Figure 21 illustrate the calculated difference in water vapor pressure for the facilities where the dotted line gives the recommended level for the respective facility. This is the driving force for the evaporation rate and is especially important for facilities with dehumidification based on fresh air supply and without air side heat recovery system. Above 50 % of the facilities has reported indoor environment that exceed the recommended level, which contribute to excessive thermal energy use in the pool circuit. This diagram proofs that several facilities should consider redesign of the ventilation system to ensure good indoor climate and better energy management.

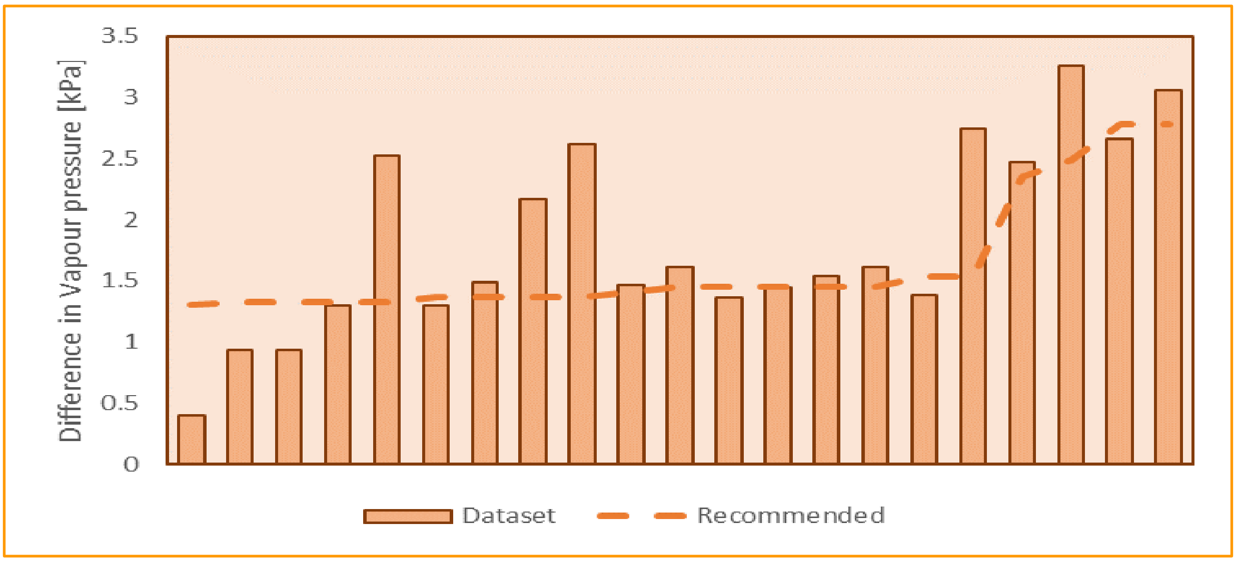

Figure 21 Difference in vapor pressure. Calculation based on recommended vs reported values.

In the survey, a qualitative comment on different climate aspects like hot/cold, humid/dry, and possible eye/skin/health issues is given. The findings are accumulated and plot against air exchange rate, to demonstrate if air flow may impact user's perception of the room climate.

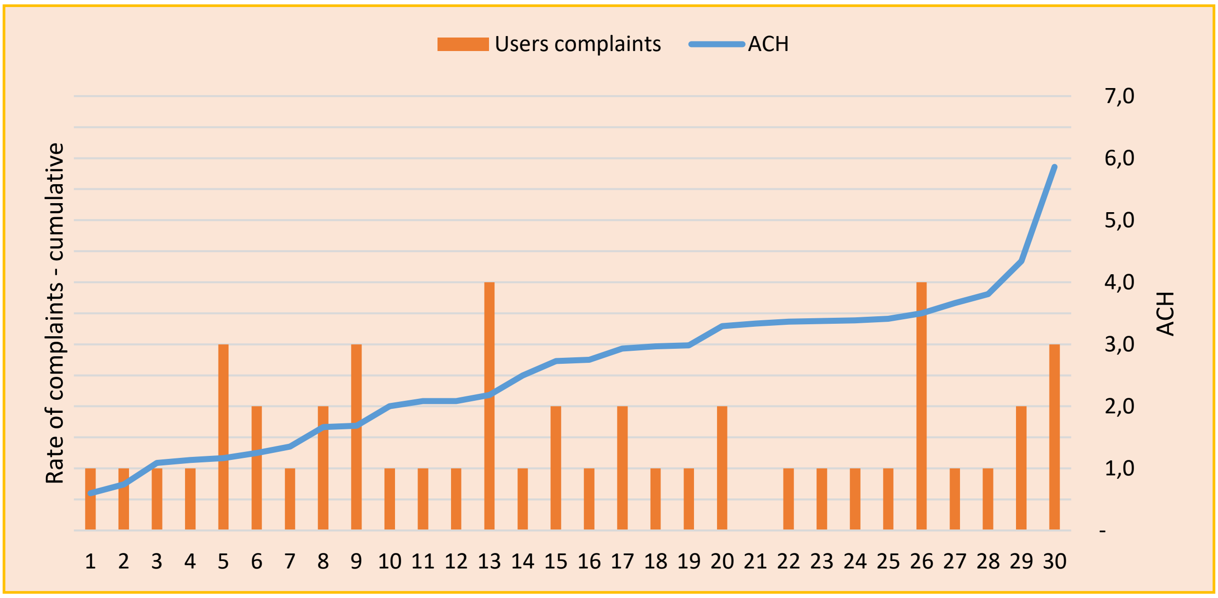

Figure 22 Users complaints vs ACH, (air exchanges pr hour)

The first impression of this graph is that there is limited or no relation between user's complaints and the air flow in the room. As the survey does not describe fresh air/recirculated air it is not possible to give a clear conclusion based on this diagram, how air flow may impact user's satisfaction. It seems as there are some more complaints from facilities with low ACH (Air Changes pr Hour), which could be expected.

Further, the substantial spread in air flow is a bit surprising. With a median ACH in range of 3, the survey indicates a different approach to ventilation design in most of the facilities. With reference to the German VDI2089, a proposed ACH design is in the range 4-7 (18). It should be mentioned that Air Change does not explain climate by it own, as rate of air distribution in the room, and in particular in the residence zone for the visitors, will have a substantial impact on the rate of satisfaction.

4.4 Energy use

The overall assumptions on the energy management in the facilities included in the survey may be:

- Electricity consumption is optimized by use of demand control of rotating equipment.
- Thermal energy consumption is high, as there are few or no heat pumps for energy recovery, neither on the grey water side nor on the ventilation side.

A diagram showing the energy mix for each facility is shown in Figure 23. This diagram concludes the findings described above, where the electrical and thermal share of the energy use is discussed by use of different parameters.

From the studies performed in Norway, the typical range of thermal vs electrical energy is 60/40 to 40/60.

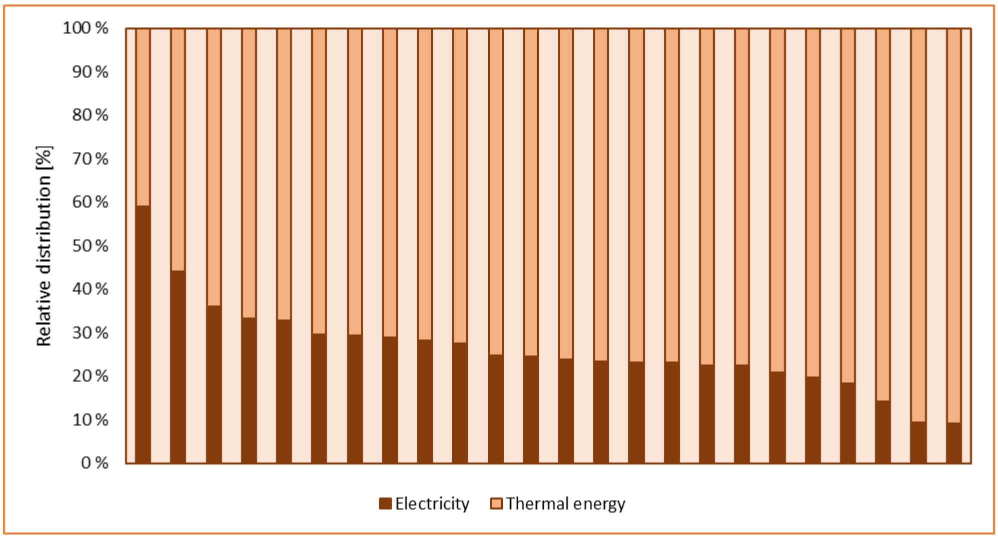

Figure 23 The energy distribution between thermal energy and electricity.

It may be anticipated that there is a substantial potential for reduction of the thermal energy use in the facilities if appropriate technology is implemented. Taking the recent development in energy prices into account, the potential of cost savings may be worth the effort of an assessment.

5 Case study, Bov svømmehal

Bov svømmehal is a medium size swimming facility with two swimming pools with a total water surface area of 387,5 m². Both the number of pools and water surface area is represented as the median in the dataset. The facility is in Padborg, in southern Jylland, and had on average 34 000 visitors per year for 2017-2019.

Figure 24 Bov Svømmehal, Aabenraa kommune

Bov svømmehal is an old swimming facility built in the 70's. Through the last six years, extensive refurbishment has been carried out, where the windows were replaced in 2015, the roof was renewed in 2020 and the pools and the HVAC system was refurbished in 2016.

The ventilation system is serving the swimming hall by supplying fresh air along the outer facades, below the windows, and the extract air grill is placed at the inner wall. This is a traditional air distribution system found in Scandinavian countries.

The pools are heated to 28°C and 34°C and the set-points for the room air is 29°C and 54 % relative humidity.

The water treatment train consists of diatomite filter, granular activated carbon filter and the disinfection stage is by liquid chlorine, electrolysis, and UV treatment. The facility has not experienced any complaints from the user group regarding the indoor environment, but the staff is dissatisfied by both the thermal environment, indoor temperature, and humidity, and the air quality due to eye issues.

Energy performance

Bov svømmehal is seen to have a poor energy performance compared to other swimming facilities in the dataset. The energy usage per visitor is 37 kWh/visitor, which is approx. twice the average at 19 kWh/visitor. See Figure 25. Also, when the energy use is normalized with respect to the water surface area the facility is seen to have a poor energy performance. See Figure 26. The facility has potential for improvements.

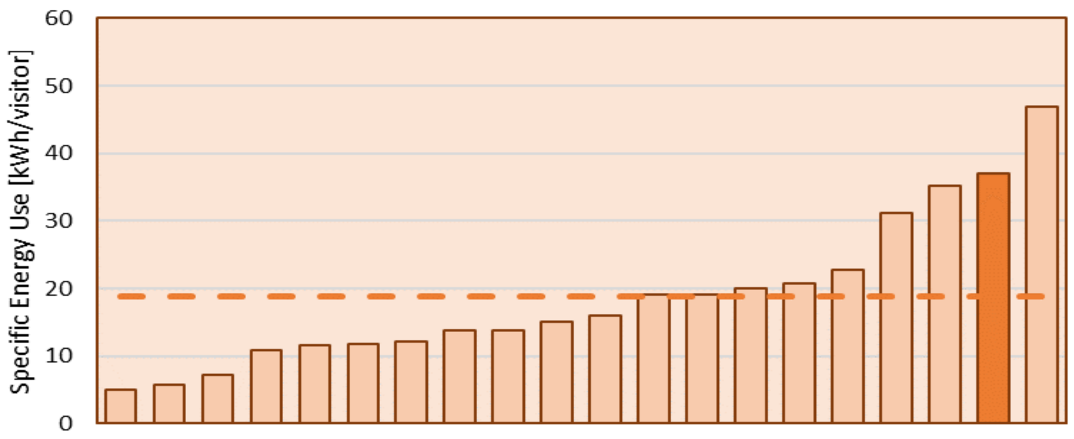

Figure 25 The distribution of the recognized specific energy use per visitor for the dataset for 2018. Bov svømmehal is identified as the dark orange column.

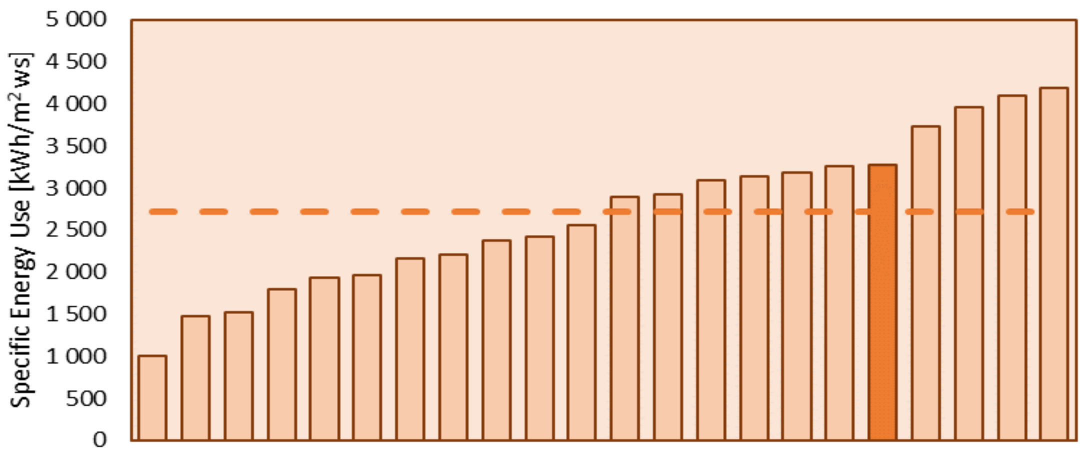

Figure 26 The distribution of the recognized specific energy use, per water surface, climate corrected for the year 2018. Bov svømmehal is identified as the dark orange column.

The energy system is based on thermal energy supply by district heating and electricity. There is not installed any system for heat recovery and the thermal/electricity distribution is 22 % electricity, which is slight below the median and average, see Figure 23.

Analysis of energy performance – systematic approach

Thermal energy demands for swimming facilities can be divided into the following categories:

- Room heat demand (due to heat transmission through the building envelope.)
- Air change rate room
- Pool heating demand (due to heat loss and evaporation)
- Water replacement rate pool
- Heating tap water for showers, domestic hot water

The swimming facility has carried out considerable refurbishment for both the technical system and regarding improving the building envelope. Even though it is reported that the roof and the windows are renewed, the outer walls still lack good insulation. This is reported to still have the standard of 1978, which contributes to high room heating demand. However, the net area is not considerable, so this measure alone does not explain the low energy performance alone.

The energy performance of facilities without heat recovery systems, like Bov svømmehal, are especially vulnerable for the operation of thermal indoor environment. Improper indoor conditions will increase evaporation, which will both increase the swimming pool heating demand and the required fresh air flow rate. Bov svømmehal has organized the swimming hall with two swimming pools; a training pool and a therapeutic pool represented by water temperatures at 28°C and 34°C respectively. The facility has reported dissatisfaction among the staff regarding too high indoor temperature and humidity, which is the reason for the deviation to the recommended level. This deviation has an impact on energy use, due to the abovementioned effects. Due to the evaporation rate dependency to the difference in water vapor pressure between the ambient air and the air close to the water surface, this decision contributes to increased energy use for both pools.

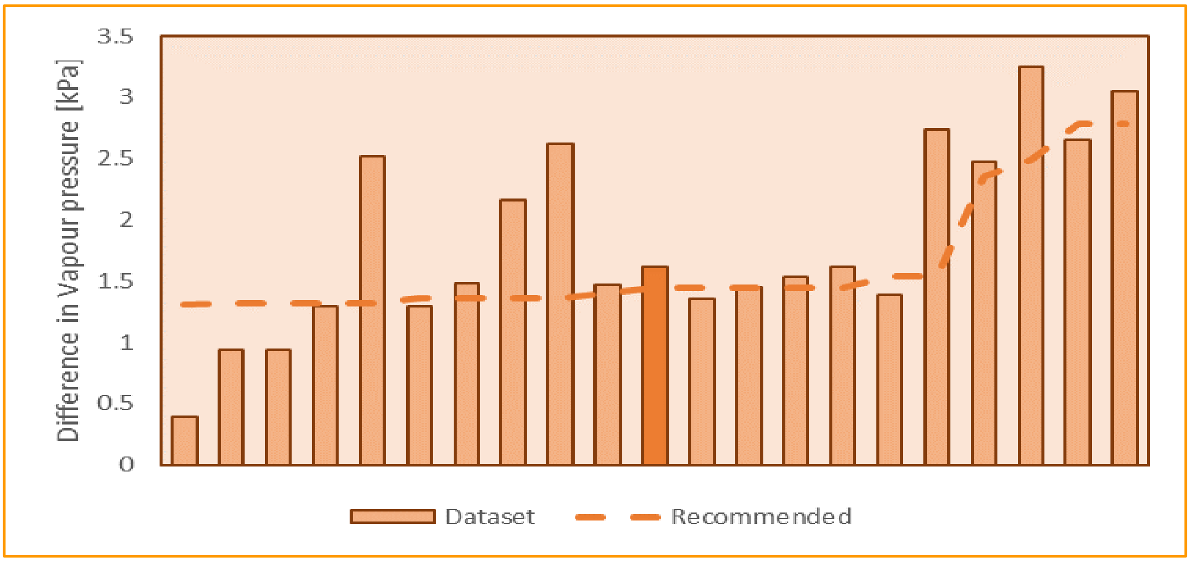

Figure 27 Vapour pressure

Figure 27 illustrate how this difference is compared to the recommended level. Bov svømmehal is identified as the dark orange column, which only represent a slightly increase. However, the therapeutic pool differs from recommended level, by approx. 30 %. This contributes to an 30 %

increased evaporation rate. This may also partly explain the staff's dissatisfaction and complaints due to eye issues. The facility would obviously profit from tuning the indoor climate.

A general consideration is that there is an almost linear relation between water use and energy use. Bov pool facility is following this trend and using specific numbers it comes clear that the water use is a bit above the average, maybe 10-15%.

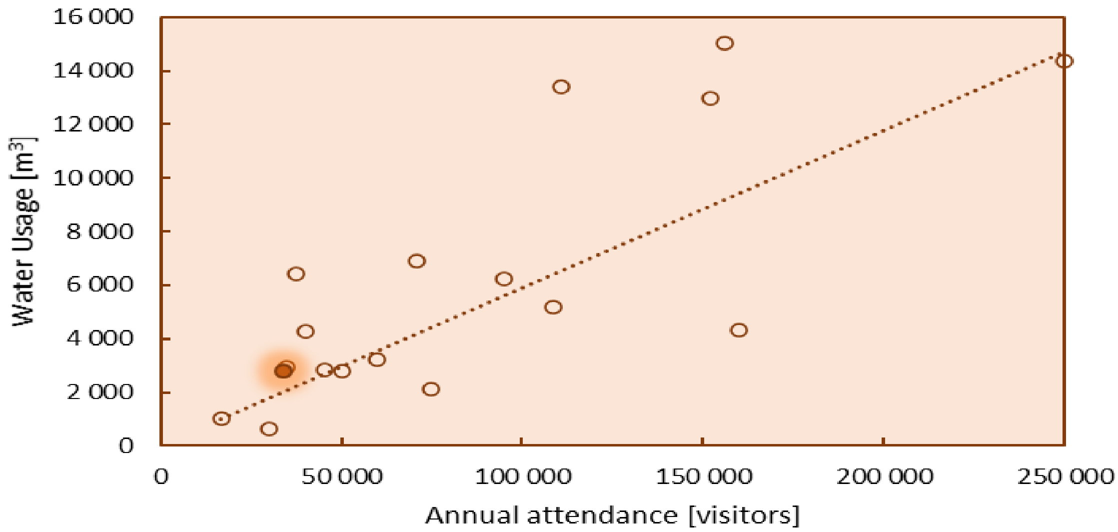

Figure 28 Water and energy use, including Bov highlighted

6 Conclusion

A survey is made on swimming facilities in Denmark, and a part of the survey is investigating water and energy management in the facilities.

Technology, design, and products used in pools are comparable in the Scandinavian countries, and contractors as well as product suppliers are in many cases positioned in each country with the same products and concepts.

The important difference among the countries is the price structure for energy, where Denmark is known for a large difference in price between electrical and thermal energy. Further, there are regional submarkets and in a national context this may be considered as a disturbing factor with respect to development of a national reference for best practice regarding pool energy system design.

In a context of sustainability, energy management may be described with the following priority:

1. Reduce the demand
2. Recycle as much as possible within an economical framework
3. Identify more sustainable energy sources

This general code may be refined by implementing the following priorities:

1. Maintain good indoor climate for the users and the building
2. Optimize investment costs against performance to comply with best practice

The general findings from this survey are, that the total energy use is in the higher end for thermal energy, while electrical energy use is on a low/fair level. If reduced energy is a goal – and with reference to the UN17 statements it should be – measures to reduce the total energy use must be investigated. Sources for energy saving are building skin, ventilation, and grey water. Introduction of heat pumps in air handling units as well as grey water system may be a good start, and the cost/benefit analysis will for each facility give a rather clear answer. The driving force in such an analysis is the quantities of energy and water used, and most important, the price of electrical and thermal energy at site now, and in future.

When the technological and financial potential for energy saving and reuse is reached, next step would be to identify other energy sources, like for instance PV, thermal solar panels, small wind turbines or heat pump utilizing outdoor air as source of energy.

Acknowledgements

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