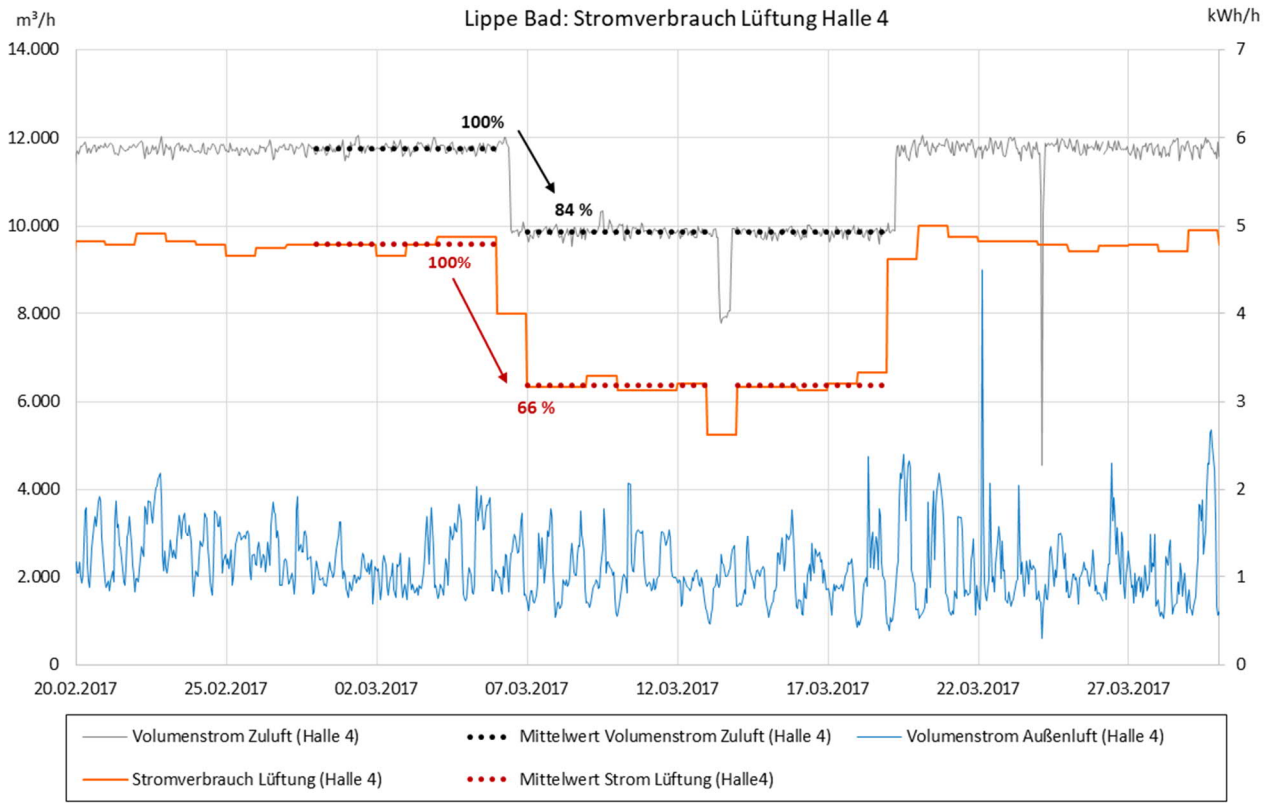

Fig. 53: The supply air volume flow was reduced while the outside air volume flow remained the same. Thereby the power consumption of the ventilation unit drops significantly.

6.3 Lippe bath: try shower area without air reheating

In the Lippe bathroom, the air is sucked out of the changing area at two points, led into the basement in two duct systems, reheated there via heating registers and only then blown into the shower / toilet areas. For this purpose, in addition to the duct construction, two post-heating registers with supply lines and control as well as two fans must be operated.

In order to test whether the operation is also possible without this after-heating, the after-heating in both air circuits was switched off in the Lippe bath on November 2nd, 2016. At the same time, the room temperature should be raised slightly in the changing area. However, the room temperature was not raised as planned. Occasional complaints by some users already on the fourth day (November 6th, 2016) at noon led to the end of the trial and the reheating to be activated again.

This meant that the overflowing air was not reheated on three full days. In the four full operating days before and after the shutdown, between 110 and 113 kWh / day was spent on reheating for each reheater (6.2 to 6.4 kW output per heater, about 17 to 18 h per day). During the shutdown, the heating of the changing areas was operated unchanged (approx. 160 to 260 kWh / day). An evaluation of possible savings, which

After a moderate temperature increase in the changing area, it could not take place as planned. It was not possible to repeat the attempt. In addition to the heating area (post-heating), the power consumption for the fans would also have to be taken into account. The effort of transporting the air to the basement, heating it there and transporting it up again is more complex than operating an overflow fan with little pressure loss or even having it passively overflow (suction through the exhaust air). However, the electricity for the fans is not recorded separately in the Lippe bath.

The Bambados has had good experience with the passive overflow from the changing area into the shower area without reheating. Alternatively, additional heating elements in the showers for reheating would also be conceivable.

6.4 Air routing in the swimming pool (CFD simulations)

The flow of air through the swimming pool is influenced by the positioning of supply and exhaust air valves, and not only the temperature and humidity distribution in the room, but also the concentration of pollutants. Up to now, the focus of optimization in the introduction of air into indoor swimming pools has not been the removal of pollutants, but the adequate blowing of the outer glazing to keep them free of condensate. In passive house indoor swimming pools, this is not necessary due to the higher window qualities. Therefore, an optimized air intake and extraction can be realized taking into account the removal of moisture and pollutants as well as the temperature distribution and air heating. In addition, the good quality of the building envelope in the passive house indoor pool allows the supply air volume flows to be reduced compared to conventional bathrooms (outside air and reduced or no recirculating air - see Chapter 5.1). However, it is therefore all the more important to use the fresh air supplied as efficiently as possible to remove the pollutants from the pool (chlorine degradation products / trihalomethane).

As part of this project, CFD simulations were carried out at the University of Innsbruck [Rojas 2017]. These are based on a model of a hall of the passive house bath Bambados in Bamberg with supply air introduction via swirl outlets (see [Gollwitzer et al. 2015] for documentation and for monitoring evaluation of this project). The investigation of different variants of the supply and exhaust air positioning provides information about an effective removal of pollutants and should serve as an aid for the planning and design of the air duct.

In addition to the air routing implemented in the bathroom ("As-Is", with supply and exhaust air valves on the ceiling), the air routing variants listed in Table 6 were considered using CFD simulation. Based on two operating states defined as representative - with high evaporation and correspondingly high volume flow (A) in summer, as well as low evaporation and correspondingly low volume flow (B) in winter - nine further variants were modeled and simulated. These variants differ essentially with regard to the supply and exhaust air positioning.

Tab. 6: Air routing variants considered for the CFD simulations in [Rojas 2017].
AW = outer wall, IW = inner wall, ZL = supply air, AL = extract air, DA = swirl outlet, ß = mass transfer coefficient for calculating the amount of evaporation.

		Temperatur ZL [°C]	Temperatur Raum [°C]	abs. Feuchte AL [kg/kg]	abs. Feuchte ZL [kg/kg]	Volumen-strom ZL [m³/h]	beta [m/h]	Verdunstung H_2O [kg/h]
As-Is Varianten								
A	Volumenstrom hoch, β=28	30,2	30	0,0146	0,009	45360	28	294
B	Volumenstrom min, β=10	40	30	0,0152	0,004	7560	10	98
Alternativ-Varianten								
B1	DA vertikal ausblasend	40	30	0,0152	0,004	7560	10	98
B2	Abluft unten an AW	40	30	0,0152	0,004	7560	10	98
B3	Abluft unten an AW, DA vertikal	40	30	0,0152	0,004	7560	10	98
B4	Abluft Beckenrand	40	30	0,0152	0,004	7560	10	98
B7	Abluft Beckenrand, DA vertikal	40	30	0,0152	0,004	7560	10	98
B5	ZL Boden AW, AL IW (linear)	40	30	0,0152	0,004	7560	10	98
B6	ZL Boden AW, AL IW (1x)	40	30	0,0152	0,004	7560	10	98
A5	ZL Boden AW, AL IW (linear)	30,3	30	0,0143	0,009	50400	28	306
A6	ZL Boden AW, AL IW (1x)	30,3	30	0,0143	0,009	50400	28	306

The following two key figures were used to assess ventilation efficiency:

- **Air Exchange Efficiency (ACE):** This indicates how well the supply air is used to purge the entire room volume. A value of 1 (best result) corresponds to pure piston ventilation (the air flows through the entire room on the direct path between the supply and exhaust air openings) and 0.5 to complete mixing. ACE values <0.5 indicate a short circuit flow.

- **Contaminant Removal Efficiency (CRE):** This indicates how well a pollutant is removed from the room. The higher the value, the better and in principle values from 0 to "infinite" are possible. A value of 1 results with perfect mixing. "Infinite" would result if the pollutant were extracted directly at the source. The values strongly depend on the position of the pollutant source and the volume of the room under consideration. Various areas were considered in [Rojas 2017]. The overview of results in this report contains the CRE for the entire room volume, as well as for the area relevant for swimmers (10 cm above the water surface). In the latter case, the evaluation range corresponds to that of the pollutant source, ie the best value to be achieved is 1.

The most relevant results of all variants are summarized in Tab. 7. The report [Rojas 2017] contains detailed documentation of the calculation results including graphics of all variants for the spatial distribution of temperature, humidity (this is also considered equivalent to the concentration of pollutants), air speed and air age.

Tab. 7: **Summary of the simulation results from [Rojas 2017]. Color scale: yellow (low / worse) to green (high / better). AW = outer wall, IW = inner wall, ZL = supply air, AL = extract air.**

		ACE Gesamt-volumen	CRE Gesamt-volumen	**CRE Wasser-Oberfläche**	Mittl. Geschwindigkeit Wasser-[m/s]
As-Is Varianten					
A	Volumenstrom hoch, β=28	**0,37**	0,75	**0,58**	0,21
B	Volumenstrom min, β=10	**0,39**	0,79	**0,69**	0,13
Alternativ-Varianten					
B1	DA vertikal ausblasend	**0,45**	0,92	**0,75**	0,09
B2	Abluft unten an AW	**0,5**	1	**0,81**	0,08
B3	Abluft unten an AW, DA vertikal	**0,45**	0,97	**0,77**	0,11
B4	Abluft Beckenrand	**0,49**	0,98	**0,81**	0,11
B7	Abluft Beckenrand, DA vertikal	**0,48**	0,96	**0,78**	0,1
B5	ZL Boden AW, AL IW (linear)	**0,48**	0,98	**0,84**	0,19
B6	ZL Boden AW, AL IW (1x)	**0,47**	0,98	**0,84**	0,2
A5	ZL Boden AW, AL IW (linear)	**0,49**	0,92	**0,71**	0,4
A6	ZL Boden AW, AL IW (1x)	**0,49**	0,92	**0,71**	0,4

It can be seen that the As-Is variants (A & B) show the lowest ACE. Here are both the supply air intake and the exhaust air extraction from the ceiling. With a value of 0.37 or 0.39, this confirms the fear that there is a flow short circuit. A significant portion of the conveyed air volume flow is thus sucked off again unused. For swimmers' health, it is important to remove pollutant outgassing from the water as well as possible. This only works poorly with the As-Is variant. The pollutant removal efficiency (CRE) based on the water surface is 0.69 or 0.58.

A significant improvement already arises when the swirl outlets in the simulations are modeled as "vertically blowing" instead of "horizontally blowing" (variant B1). The results are further improved by moving the exhaust air to the lower hall area. Different possibilities of exhaust air extraction were considered: At isolated points along the outer wall (B2), directly at the pool edge, e.g. at the pool overflow (B4), near the floor along the entire inner wall side (B5) and as two individual exhaust air openings near the floor on the inner wall (B6).

The examined variants with the highest pollutant removal efficiency in relation to the water surface are those with the supply of fresh air along the outer facade and exhaust air extraction near the floor along the inner wall (B5 & B6). For these variants there are ACE's of 0.48 and 0.47 (i.e. values corresponding to almost perfect mixing), and CRE's of 0.84.

Fig. 54 & Fig. 55 show the moisture distribution and the age of the room air for the initial case B and the alternatives B2, B4 and B5 in the cross section of the hall. Among other things, it can also be clearly seen here that high levels of moisture or pollutants (equivalent) are limited to a thin layer just above the water surface with exhaust air extraction near the ground (B5).

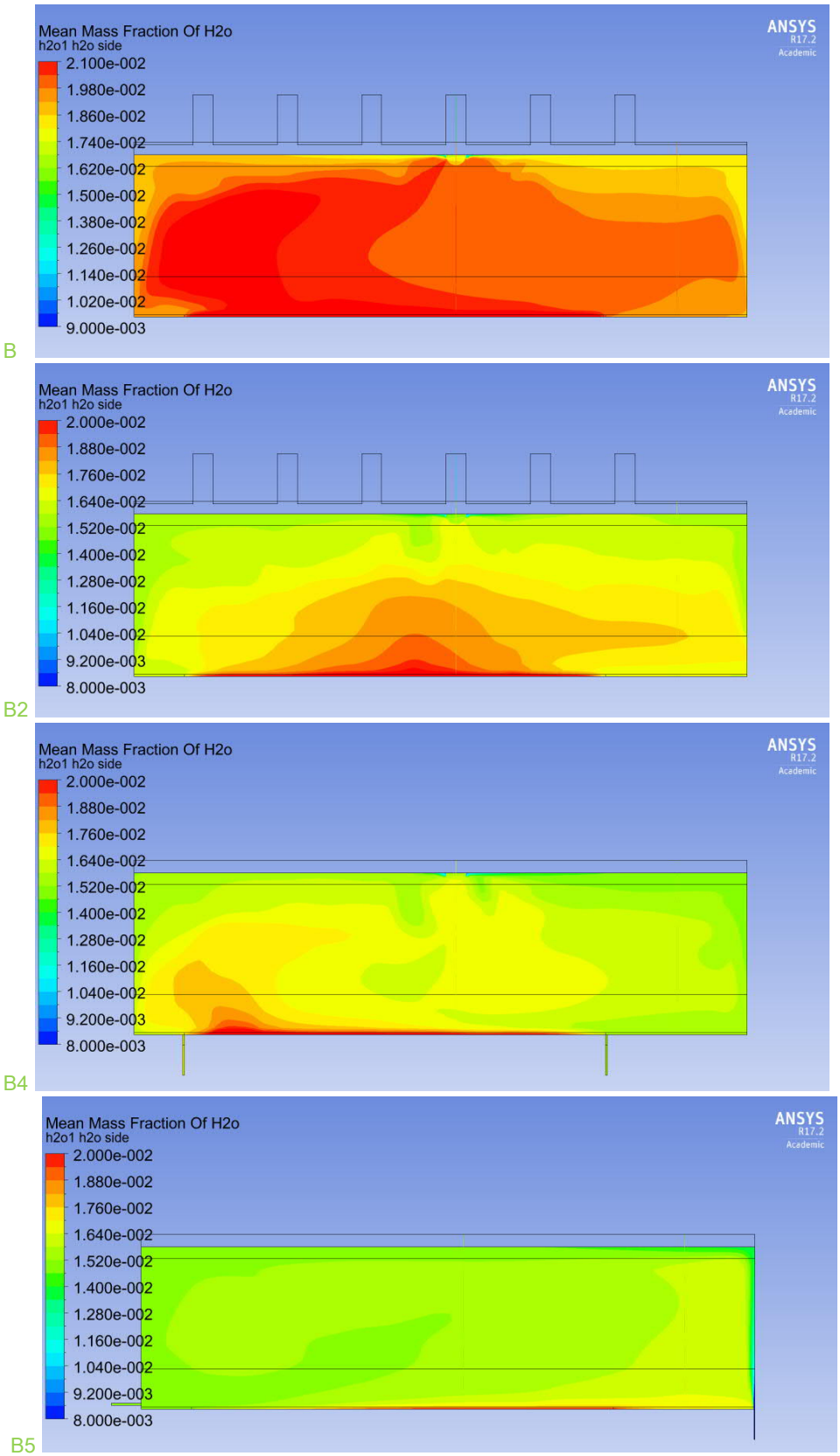

Fig. 54: Moisture distribution in the cross section of the hall for selected variants (from top to bottom): Exit variant (B), exhaust air on the outer wall (B2), exhaust air on the pool edge (B4) and supply air along the outer wall with exhaust air along the inner wall (B5). The inner wall is on the left in this cross-section.

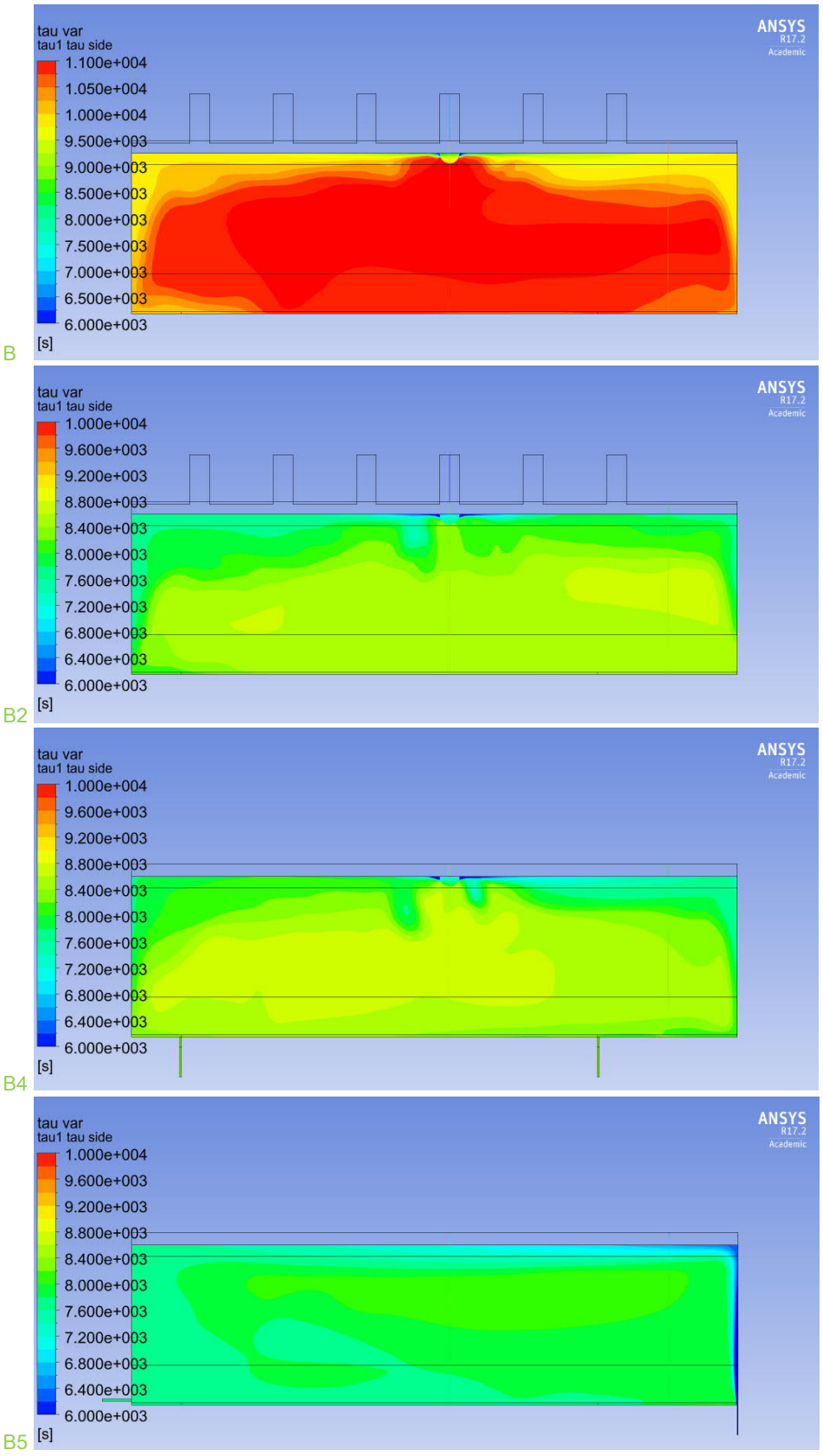

Fig. 55: The calculated age of the air in the cross section of the hall for selected variants (from top to bottom

Bottom): Output variant (B), exhaust air on the outer wall (B2), exhaust air on the pool edge (B4) and supply air along the outer wall with exhaust air along the inner wall (B5). The inner wall is on the left in this cross-section.

Summary

In the overall analysis, the simulation results show that when the exhaust air is positioned near the floor, higher pollutant removal efficiencies are achieved. The exact arrangement (linear distribution vs. selective suction vs. pool edge) does not seem to make a very big difference. These results are in line with the energetic advantages of stratified ventilation (see Chapter 5.1), in which exhaust air extraction creates an advantageous stratification near the ground with high humidity directly above the water surface. In practice, too, positive experiences have been achieved with near-floor extraction (see [Kaluza 2016]). A supply air intake positioned at the bottom and pointing upwards along the outer facade (could also be an inner wall) can be an additional slight improvement compared to an intake from above (e.g. enable via swirl outlets); does not seem to be decisive for ventilation efficiency. These results apply to the hall examined. Trends can be read but the boundary conditions (geometry, use, mode of operation etc.) must be taken into account when planning the air duct in individual cases.

6.5 Pollutant measurements (THM)

A central point for the realization of an indoor swimming pool according to the passive house concept is the energetically motivated reduction of the recirculation and the outside air volume flow (see also the explanations in the basic investigation [Schulz et al. 2009]). The decisive parameters of air quality must be taken into account. In bathrooms, chlorination creates so-called disinfection by-products (DNP) to ensure pool water hygiene. The health assessment focuses in particular on the emerging group of trihalomethanes (THM) and trichloramines (NCl_3). Trihalomethanes (THM) are organic compounds in which the molecular structure of methane (CH_4)

three of the four hydrogen atoms are replaced by different halogens (fluorine, chlorine, bromine, iodine). They arise from the reaction of chlorine with the pollutants in the water and with the organic pollutants introduced by bathers (e.g. urea and amino acids from the sources skin, sweat and urine [Junek et al. 2017]). THM is calculated as a sum parameter from the four compounds trichloromethane (also "chloroform"), bromodichloromethane, dibromochloromethane and tribromomethane. To do this, the THM content is converted to the compound with the lowest molecular weight - in this case, chloroform [1]. THM is poorly water-soluble, volatile and therefore releases gas from the pool water [Junek et al. 2017]. If the hall ventilation is insufficient, THM can accumulate in the hall air. in the

[1] According to [DIN 19643] calculated as chloroform ($CHCl_3$):

THM = A + 0.728 × B + 0.574 × C + 0.472 × D, with A = mg / l $CHCl_3$; B = mg / l $CHBrCl_2$; C = mg / l $CHBr_{2nd}Cl$; D = mg / l $CHBr_{3rd}$

The THM serves as an indicator substance for the assessment of bathing water quality in pool water. Humans probably take up the connections primarily via the air [Sacré et al. 1993].

The studies available in the literature allow only a few conclusions to be drawn about the relationship between the THM concentration in water and in the air with the supply and exhaust air volume flow of the swimming pool. In the preliminary projects, preliminary THM measurements were already carried out in the passive house indoor pools in Bamberg and Lünen ([Peper / Grove-Smith 2013] and [Gollwitzer et al. 2015]). The relationship between the concentration of pollutants and the proportion of outside air as well as the elimination or reduction of the circulating air is to be systematically investigated with the measurement campaigns carried out in three indoor pools. In this way, the effects of the changed boundary conditions of ventilation on the air quality are to be clarified. The selection of the measuring points and room air conditions etc. was developed and determined by the PHI. It is important for the investigation that identical chemical analysis methods are used in the three baths so that they can be compared with one another. Sampling in the baths was carried out under the direction of the PHI together with the chemical laboratory Dr. Graser (CLG) performed from spares. The CLG carried out the chemical analyzes of the air and water samples. The laboratory specifies the measurement uncertainty of the THM values in a range between 10 and 15%.

6.5.1 Measurement procedure

In each of the three investigation campaigns, samples of the indoor air were taken at the same time as samples of the bathing water, since the water is the source of the DNP. After determining the positions of the sampling in the halls of a bath, the measurements were carried out at different rates of air circulation. With constant-flow pumps, samples were drawn from the air at different positions in different halls at the same time. The air samples were taken 20 cm above the water surface to reflect the air pollution that swimmers inhaled. For comparison, a sample was taken at a height of 1.5 m in the pool area to assess the breathing air of staff and bathers.

The sampling with the pumps took 10 minutes each with a suction of 20 liters / minute. In parallel to the air sampling, the air temperature and the relative humidity in the area of the sampling were measured. Activated carbon (tubes) served as the adsorbent. During the sampling, the people in the pool (near the measuring point) were counted and their activity (calm swimming to aqua aerobics) recorded. It can be assumed that the movement of the water surface influences the release of the THM compound. In [Jentsch / Matthiessen 1998] the following statement can be found: "Higher THM loads in the water generally also enable higher THM loads in the air. To what extent this option is implemented,

Water attractions (...) vary. Even normal swimming mode promotes the emission of the THM from the water, short-term peak pollution of the air occurs, for example, during wave operation ".

The activated carbon tubes were analyzed and evaluated in the laboratory shortly after the respective measurement campaign. The data of the supply and outside air volume flow from the GLT data collection of the respective bath were used afterwards.

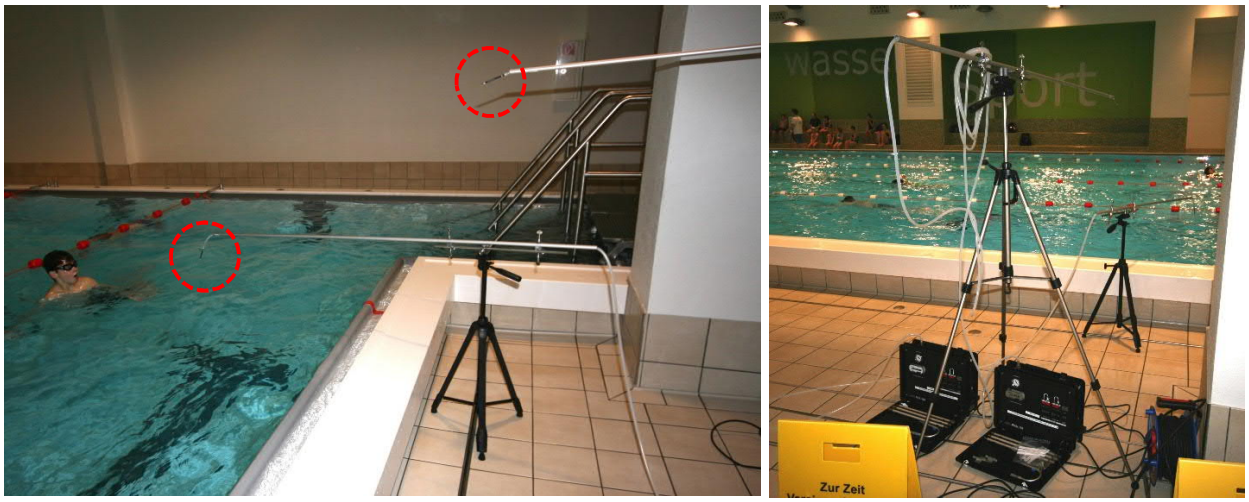

Fig. 56: Air sampling with suction pumps in a swimming pool (Hall 5 in Lippe-Bad Lünen) in 20 cm above the water surface and 1.5 m above the handling.

6.5.2 Bambados THM measurements

In Bambados on January 31st. and 01.02.2017 the sampling was carried out in three halls. These included the leisure area, the sports area with 50 m lane and the small teaching swimming pool 2. In the evening hours of January 31, 2017 between 5:00 p.m. and 7:15 p.m., the first samples were taken in the three halls. At that time the pools were used. The second sample was taken at the same positions in the early morning (4:50 a.m. to 6:00 a.m.) before the bathroom was used for the public. The mode of operation of the ventilation systems is differentiated according to day and post-operation (at night, the setpoints for the air humidity are higher than in day mode; the systems only switch on when dehumidification is required). In the morning hours only the samples above the water surface were taken, none in use.

Fig. 57: Air sampling with suction pumps in the Bambados in the sports hall with 50 m track (left) and in the leisure hall (right)

The results of the THM measurements of the indoor air [CLG 2017-A] are entered as concentrations [µg / m³] in the following diagrams in connection with the volume flows of supply and outside air. The circulating air volume flow can be read from the difference between the supply and outside air volume flow. In order to have an estimate of the volume flow to the hall volume, the air exchange rate (volume flow outside air in relation to the hall air volume) is given for the two periods. In addition, the air temperatures, THM concentrations in the water [µg / l] and the number of people (in the vicinity of the sampling) at the time of sampling are given in text form in the diagrams.

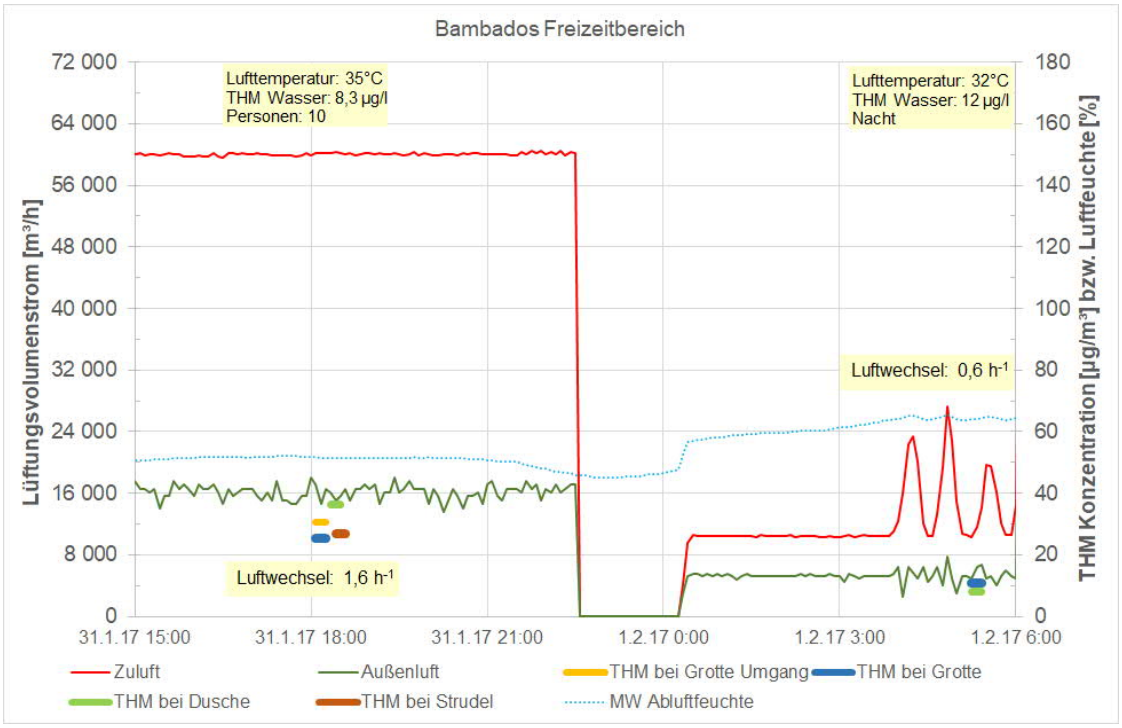

Fig. 58: THM measured values (air and water), rel. Exhaust air humidity and air volume flows during the Measurement period of the LEISURE HALL of the Bambados indoor pool.

The THM values in the leisure hall (Fig. 58) are already low during the first measurement in the evening with values between 25 and 36 µg / m³. The measured value at 1.5 m above the handling (31 µg / m³) lies between the three values measured above the water surface. With a lower outside air change in the morning without using the pool, the THM values above the water surface are even lower (8 and 11 µg / m³). The lower outside air change and the significantly lower recirculation than in daytime operation do not lead to an increase in concentrations here.

In the sports hall (Fig. 59), the daily air exchange rate is significantly lower than in the leisure hall. The airflow also differs from that in the leisure hall. Due to the introduction and extraction of air in the ceiling area, not optimal air currents were identified in previous investigations (short-circuit currents) (cf. [Gollwitzer et al. 2015]). Overall, it should be assessed that in the sports sector - analogous to the passive house concept - only a minimal amount of recirculated air is used. The measured THM concentrations in the evening hours with values between 51 to 83 µg / m³ with a greater use of the pool are somewhat higher than in the leisure hall. The measured value from handling is again between the values above the water surface.

At the end of the night, the indoor air readings are significantly lower (26 and 29 µg / m³) than during the day. Here, too, the lower air exchange with practically no recirculating air during the night does not have a negative effect on the concentration. The measured value in the pool water, at 14 µg / l, is slightly higher than in the evening hours.

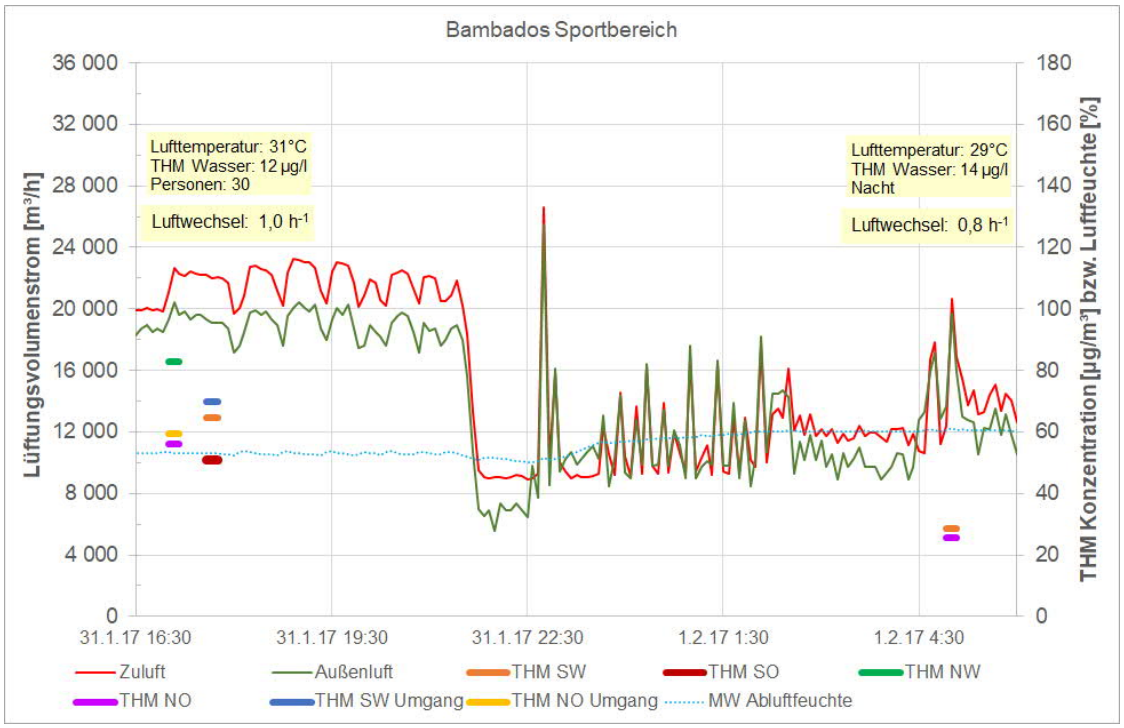

Fig. 59: THM measured values (air and water), rel. Exhaust air humidity and air volume flows during the Measurement period of the SPORTS HALL of the "Bambados" indoor pool.

The third area examined in Bamberg's Bambados is the training pool 2. There, only one air sample was taken over the water and one in use. The pool water was also sampled (day and night 18 µg / l). Both air samples are very low at only 14 µg / m³ when the pool is used intensively. The air change in the small hall during the evening hours averages 4.3 h^{-1} significantly higher than in the other two halls. There is no recirculated air in the hall at the time of the measurements (supply air corresponds to the outside air volume flow). In the early morning hours the air change is 2.6 h^{-1} again significantly lower. The THM concentration above the water surface is still halved (7 µg / m³). All in all, the values in the hall of teaching pool 2 are all particularly low. Neither the lack of air circulation, nor the reduction in the air exchange rate had a negative impact on the concentration. However, the air exchange rate in the small hall (low room height) is relatively high in comparison.

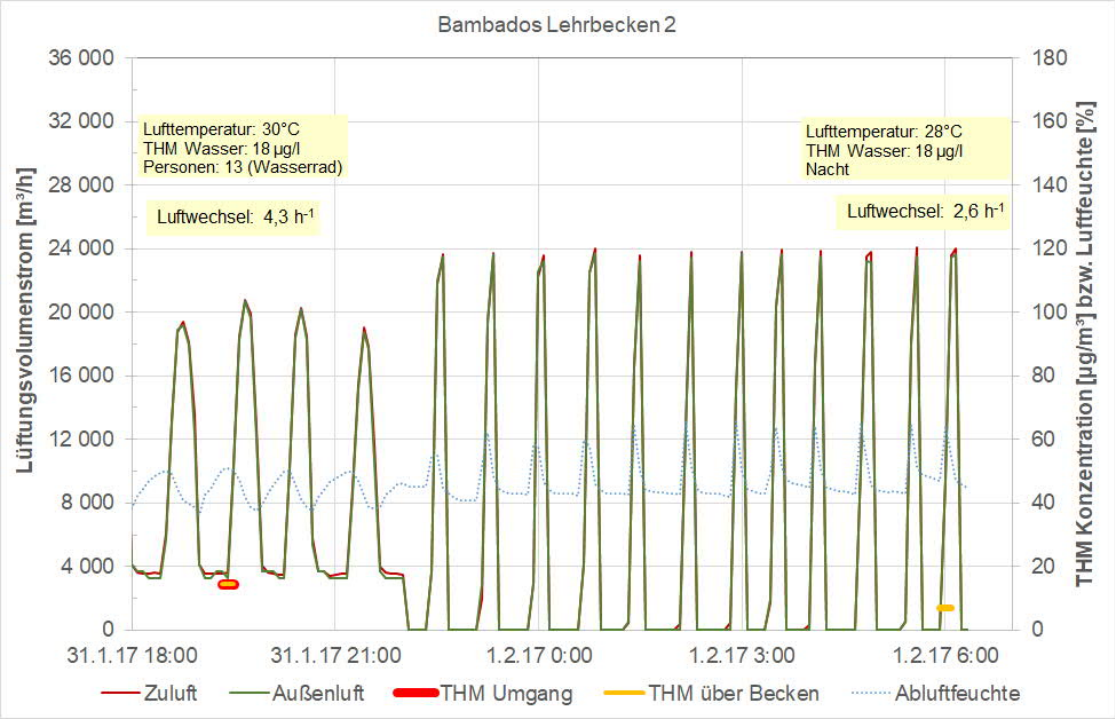

Fig. 60: THM measured values (air and water), rel. Exhaust air humidity and air volume flows during the Measurement period of LEHRBECKEN 2 of the indoor pool "Bambados".

The comparison with the orientation measurements in the context of the previous monitoring [Gollwitzer et al. 2015] shows that the THM concentrations in the indoor air improved during the 2017 measurement campaign. For comparison, the measured values are shown in a table.

Tab. 8: Measurement results of the orienting THM measurements as part of the Bamberg monitoring

Bambados (from [Gollwitzer et al. 2015]) supplemented with the measured values from 2017. The measured values were rounded to values without decimal places. Legend: "without air circulation" = without air circulation

THM-Concentration [µg / m³]	6.2.2014 11:00 a.m. - 4:30 p.m.	31.3.2017 10:00 - 14:00 Eve	1.2.2017 early morning
Educational pool			
Pool water	*14 µg / l*	*-*	*18 µg / l*	*18 µg / l*
Air exchange rate h-1	*4.7 - 6.1*	*2.1 - 11.2*	*4.3*	*2.6*
Educational pool 1	22 or air circulation	28 or air circulation	-	-
Training pool 2	20 or air circulation	26 without air 14 or air		7 or air circulation
Handling LB 2	-	-	14 oU	-
Leisure pool				
Pool water	*11 µg / l*	*-*	*8 µg / l*	*12 µg / l*
Air exchange rate h-1	*0.9 - 1.1*	*1.0*	*1.6*	*0.6*
At the grotto	46	75 or air circulation 25th		11
Dealing grotto	-	-	30.6	-
Near shower	53	64 or air circulation 36		8th
With the whirlpool	50	28 or air circulation 27		-
Sports pool				
Pool water	*12 µg / l*	*-*	*12 µg / l*	*14 µg / l*
Air exchange rate h-1	*0.6 - 0.7*	*0.6 - 1.4*	*1.0*	*0.8*
South-east	149	145 without air circulation	51	-
Northwest	146	86 or air circulation 83		-
Northeast	146	71 or air circulation 56		26 or air circulation
North-East dealing -		-	59	-
Southwest	170	123 or air circulation	65	29 or air circulation
South-West dealing	-	-	70	-

To classify and compare the measured values, the information that is known from the literature is compiled: According to publications by the Federal Environment Agency (1994) and Eichelsdörfer (1996), the mean for 70 measurements of the THM concentration in the indoor pool air is 20 cm above the water surface at 36 µg / m³ (minimum

7.3 µg / m³ and maximum 219 µg / m³) [GSF 1997]. Studies by the Baden-Württemberg State Health Office showed an average THM pollution of the air (20 cm above the water surface) in indoor swimming pools of approx. 51 µg / m³ (minimum 15 µg / m³, maximum 192 µg / m³) [GesAmtBW 2015] and [Jovanovic et al. 1993].

An extensive investigation including THM concentrations in water, air and blood can be found in [Jentsch / Matthiessen 1998]. In summary, THM pollution of the air in 10 pools in the range from 74 to 453 µg / m³ is reported; the mean values of the individual baths examined there were between 76 and 196 µg / m³. The THM loads in the pool water were in some cases significantly higher than the current limit of 20 µg / l.

In [Tardif et al. 2016] describes an investigation of 41 indoor swimming pools in Canada. Deviating from this, the total value of the THM concentration is calculated by simply adding the four individual compounds and not, as is usual in **Germany [DIN 19643], added to the weighting formula (see footnote 1, page 57). This is a direct comparison Not possible.** For an example from the study, instead of the simple total of 191.3 µg / m³, only 164.0 µg / m³ (weighted addition) would result. Therefore, the mean values from the study were converted: The THM loads in the pool water were converted on average

54.4 µg / l very high in comparison. The air had mean values of the equivalent of 164.0 µg / m³, with very high maximum values.

In four investigation periods of a modern bath in Frankfurt, THM loads of only 8 to 28 µg / m³ (mean values) were measured in the indoor air with a very low THM load in the pool water (1.6 to 4 µg / l) [Junek et al. 2017]. These are classified as "... very low indoor air pollution ...".

In comparison to the literature values, the measured values of the measurements from 2017 in the Bambados can be rated as good. It becomes clear once again that the air flow in the sports area is not optimally solved; a proposal to change the air flow was made to the operator. Due to the air flow there are slightly higher exposure values, which are still in the low range with an average of 64 µg / m³ (evening hours with moving water). The other two halls show low mean values of 30 µg / m³ (leisure hall) and 14 µg / m³ (teaching swimming pool). It can be determined for the Bambados that good ventilation with low THM values can be achieved with ventilation without recirculation according to the passive house concept. The reduction or elimination of the circulating air can be carried out and recommended without hesitation.

6.5.3 Lippe-Bad THM measurements

An even more extensive measurement campaign was carried out in Lippe-Bad in early February 2017. Sampling took place in all four halls of the bath (Hall 1 + 2, Hall 3, Hall 4 and Hall 5) at three times: In the afternoon of February 9, 2017 between 4:20 p.m. and 5:50 p.m., the first samples were taken in the taken four halls. At that time the pools were used. The second sample was taken in the early morning of the following day (4:50 a.m. to 5:40 a.m.) before the public use of the bath (smooth water surface). Then the operation of the ventilation systems in the four halls was manually adjusted to a reduced proportion of recirculated air. In the afternoon, samples were taken at the identical positions at around the same time as the lecture (02/10/2017 from 3:40 p.m. to 5:00 p.m.).

The results of the THM measurements of the indoor air and pool water from the chemical laboratory CLG Dr. Graser KG has been analyzed [CLG 2017-B]. The THM values of the air are again entered as concentrations [µg / m³] in the following diagrams in connection with the volume flows of supply and outside air. The diagrams including the other information are identical to those of the Bambados.

Concentrations between 60 and 74 µg / m³ were determined as starting values (afternoon) in Hall 1 + 2 (Fig. 61); slightly lower in handling (55 µg / m³). In the after hours, 73 and 88 µg / m³ were found to be slightly higher, although there was no use. However, the concentration in the pool water was also somewhat higher at 20 instead of 16 µg / l. As a result of the reduction in the proportion of recirculating air, the outside air volume flow automatically but also unintentionally decreased (outside air change from 1.4 to 0.9 h $^{-1}$). The following afternoon - after lowering the air volume - three times higher THM concentrations were measured and a lower one (mean water surface 89 µg / m³; handling 110 µg / m³). It can be assumed that the reduction in the circulating air volume flow has resulted in less optimal mixing of the hall air. This explains why, under otherwise comparable boundary conditions (number of people, water temperature and THM level in the pool water), two measured values rise noticeably above the water surface and one decreases. In addition, the lower outside air exchange leads to less removal of pollutants. The air flow in this hall is therefore not optimally designed to reduce the proportion of recirculated air.

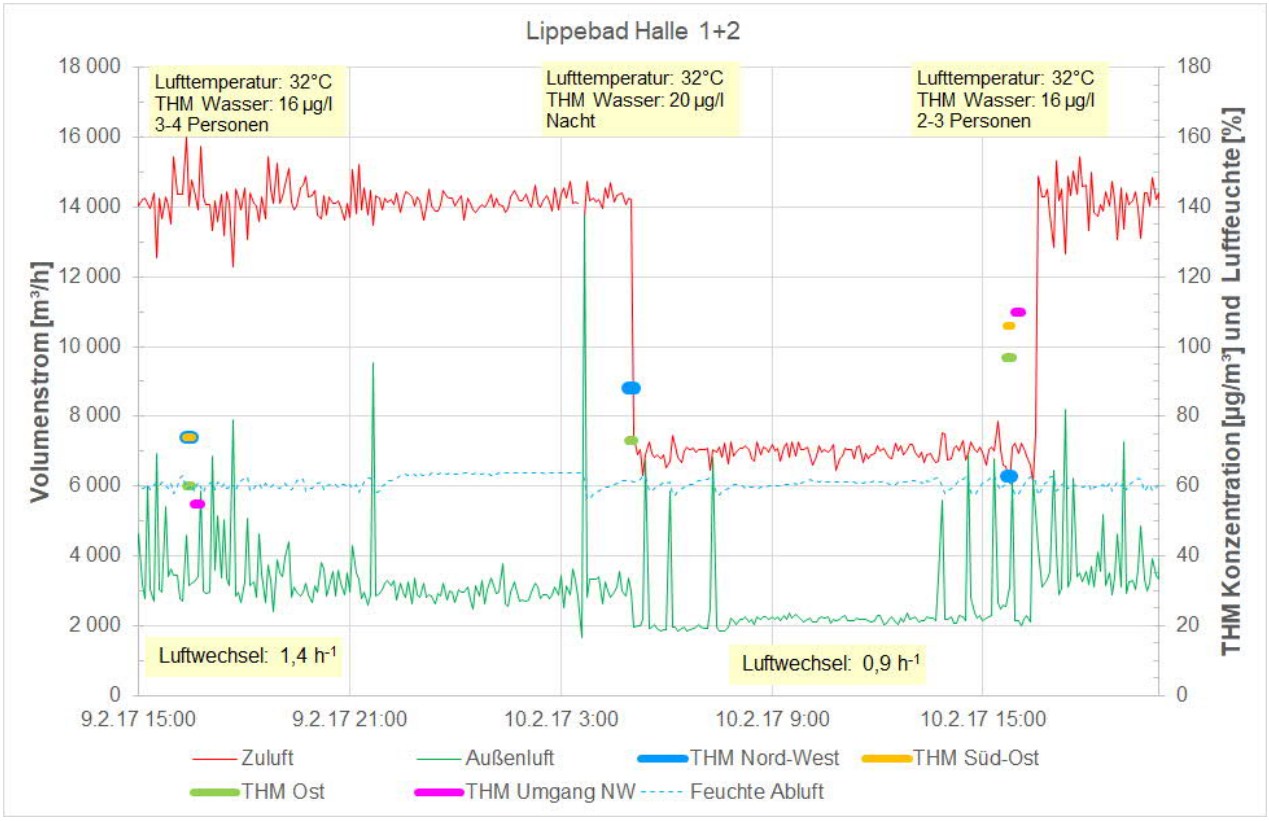

Fig. 61: THM measured values (air and water), rel. Exhaust air humidity and air volume flows during the Measurement period of hall 1 + 2 of the Lippe bath.

The measured values from Hall 3 in Fig. 62 show a similar behavior of the THM concentrations. However, the outside air change here was already reduced by the control of the system at night before the manual lowering of the circulating air volume flow was stopped in the early morning. Shortly afterwards, the outside air exchange rose again to the initial value. The THM concentration of the pool water with values around 30 µg / l is significantly higher than in pools 1 + 2. Since the pool water is the source of the THM concentration in the air, higher values are to be expected here: The two measurements above the water surface increase from the initial values 62 and 69 µg / m³ to 91 and 140 µg / m³ in the following afternoon. Here, too, there is a clear spread between the last two values,

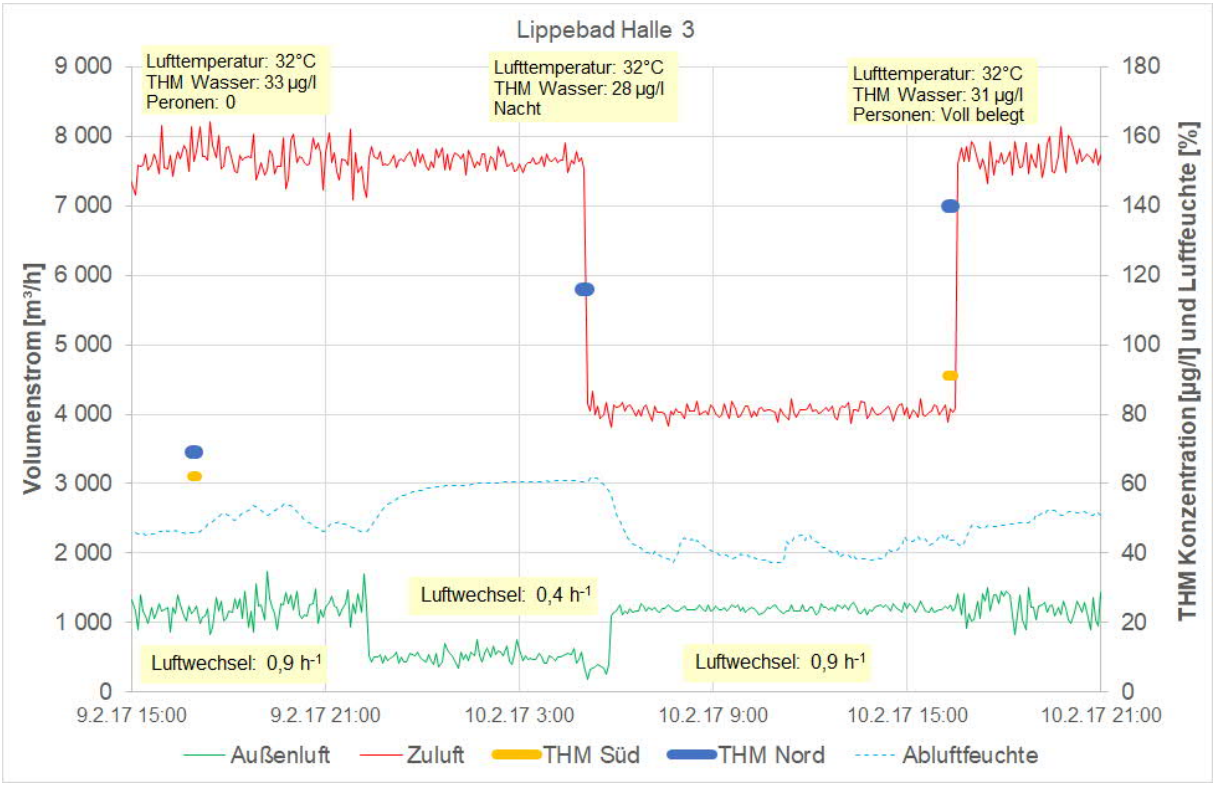

Fig. 62: THM measured values (air and water), rel. Exhaust air humidity and air volume flows during the Measurement period of hall 3 of the Lippe bath.

Hall 4 is in the air network with Hall 5, whereby both halls have their own ventilation units. The THM measured values in Hall 4 (Fig. 63) also show a significant increase after the reduction in the proportion of recirculated air. In this hall too, the change in outside air at night was automatically reduced (halved). The measured values above the water surface increase from 61 or 56 µg / m³ to 105 or 99 µg / m³. The increase in handling is more moderate (50 to 84 µg / m³).

Hall 5 (Fig. 64) shows a very similar result with an increase in concentrations above the water surface by 55 µg / m³ to values 79 and 124 µg / m³ on the second afternoon. Here, too, the increase in handling is lower (56 to 85 µg / m³).

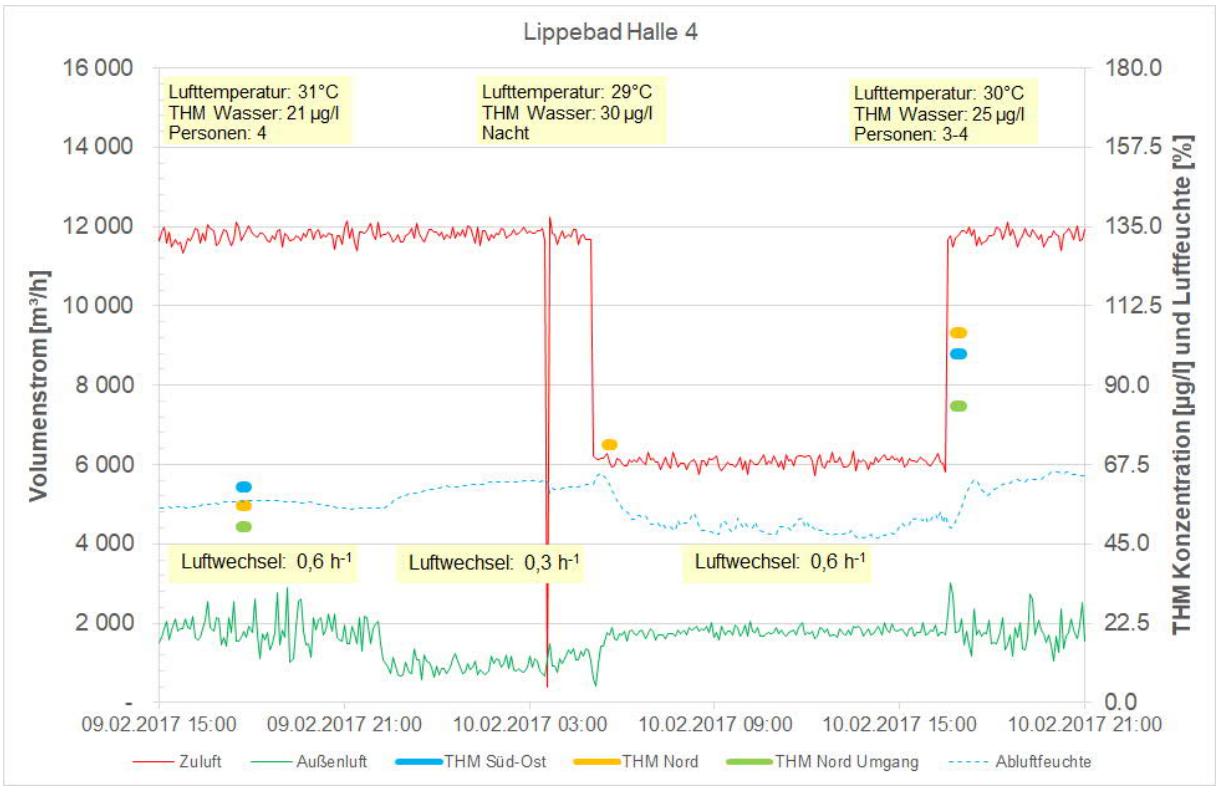

Fig. 63: THM measured values (air and water), rel. Exhaust air humidity and air volume flows during the Measurement period of hall 4 of the Lippe bath.

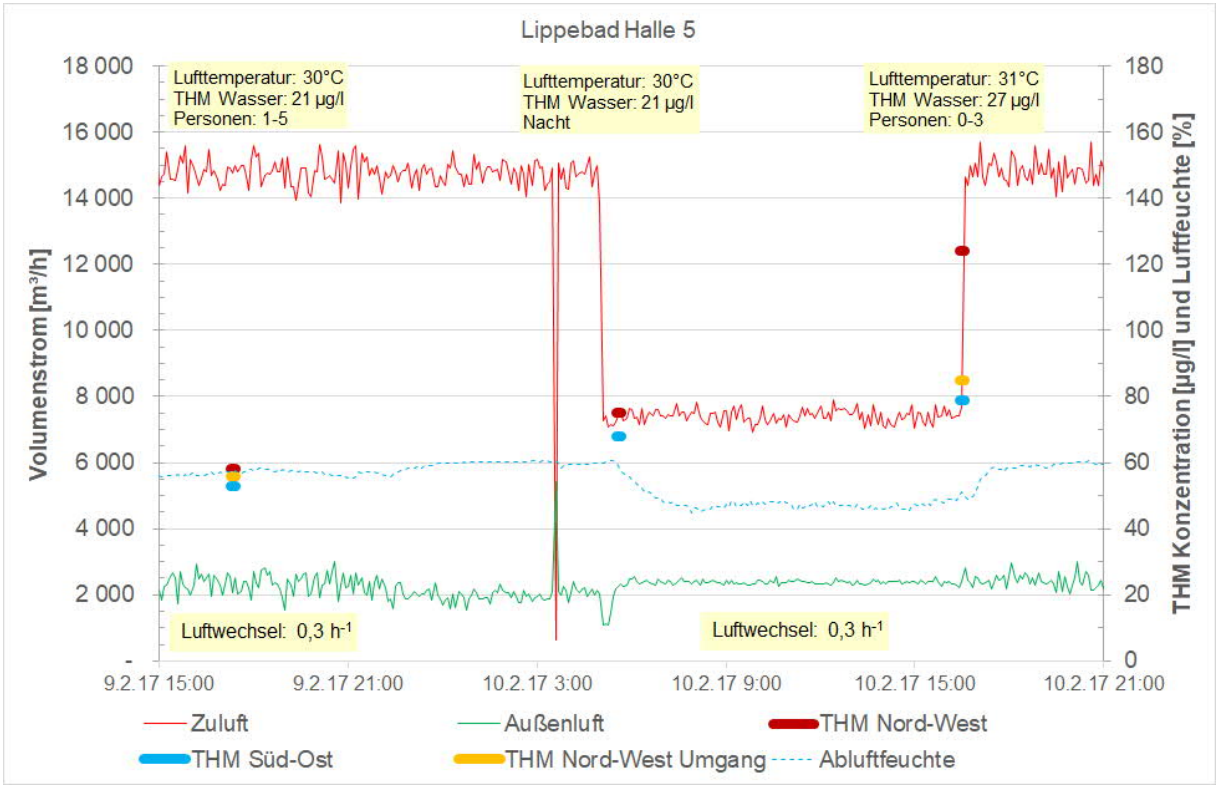

Fig. 64: THM measured values (air and water), rel. Exhaust air humidity and air volume flows during the Measurement period of hall 5 of the Lippe bath.

Tab. 9: Measurement results of the THM measurements from 09 and 10 February 2017 in the Lippe-Bad. The measurements were taken rounded to values without decimal places. Legend: "without air circulation" = without air circulation

THM-Concentration [µg / m³]	02/09/2017 afternoon	02/10/2017 Early morning	02/10/2017 afternoon
Hall 1 + 2			
Pool water	*16 µg / l*	*20 µg / l*	*16 µg / l*
Air exchange rate h-1	*1.4*	*0.9*	*0.9*
Northwest	74	88	63
South-east	74	116	106
east	60	73	97
Dealing north-west	55	-	110
Hall 3			
Pool water	*33 µg / l*	*28 µg / l*	*31 µg / l*
Air exchange rate h-1	*0.9*	*0.4*	*0.9*
south	62	-	91
North	69	116	140
Hall 4			
Pool water	*21 µg / l*	*30th*	*25 µg / l*
Air exchange rate h-1	*0.6*	*0.3*	*0.6*
South-east	61	-	99
North	56	73	105
Dealing north	50	-	84
Hall 5			
Pool water	*21 µg / l*	*21 µg / l*	*27 µg / l*
Air exchange rate h-1	*0.3*	*0.3*	*0.3*
Northwest	58	75	124
South-east	53	68	79
Dealing north-west.	56	-	85

As the analysis of the previous THM examination of the indoor air in the Lippe-Bad differs from that chosen for this measurement campaign, a direct comparison with the earlier values from [Peper / Grove-Smith 2013] is not possible. Overall, the Lippe bath shows that the THM concentrations are higher than those in the Bambados. The concentrations in the pool water as the source of the air pollution are already higher than in the Bambados (mean values of all water measurements 14 versus 24 µg / l). Another reason for the higher concentrations in the hall air is assumed to be the type of hall flow (arrangement of supply and exhaust air) (see above). The lowering of the circulating air volume flows leads to an increase in THM concentrations in the halls. In total, the 9 measured values in the Lippe bath are without the circulating air reduction (total average over water surface: 63 µg / m³) compared to the values cited in the literature (see above in the section THM measurements of Bambados) as comparable. The peak values determined after the circulating air reduction (maximum 140 µg / m³) are significantly below the peak value concentrations described in the literature (453 and 219 µg / m³) [Jentsch / Matthiessen 1998] [GSF 1997]. The mean value of the 9 values measured above the water surface after the circulating air reduction is exactly 100 µg / m³ and can be described as not optimal in comparison with the literature. Since the air flow in the Lippe bathroom cannot be changed without great effort, a reduction in the air circulation is only moderate and is recommended at night. The peak values determined after the circulating air reduction (maximum 140 µg / m³) are significantly below the peak value concentrations described in the literature (453 and 219 µg / m³) [Jentsch / Matthiessen 1998] [GSF 1997]. The mean value of the 9 values measured above the water surface after the circulating air reduction is exactly 100 µg / m³ and can be described as not optimal in comparison with the literature. Since the air flow in the Lippe bathroom cannot be changed without great effort, a reduction in the air circulation is only moderate and is recommended at night. The peak values determined after the circulating air reduction (maximum 140 µg / m³) are significantly below the peak value concentrations described in the literature (453 and 219 µg / m³) [Jentsch / Matthiessen 1998] [GSF 1997]. The mean value of the 9 values measured above the water surface after the circulating air reduction is exactly 100 µg / m³ and can be described as not optimal in comparison with the literature. Since the air flow in the Lippe bathroom cannot be changed without great effort, a reduction in the air circulation is only moderate

6.5.4 THM measurements at family pool Niederheid

In another bath (state capital Düsseldorf; family bath Niederheid; operator: Bädergesellschaft Düsseldorf mbH), THM measurements were carried out in the course of the comparable investigation. The bathroom is a renovated indoor pool. Although there is no passive house building envelope, it was selected for its optimized air flow. The engineering office Inco from Aachen implemented stratified ventilation there (for explanation, see 5.1 Ventilation guidelines in the swimming pool).

The indoor pool has a central, elongated swimming pool, which with a 25 m - pool, an educational pool and a paddling pool. The showers and adjoining rooms are on one long side. The other long side is glazed. The supply air can optionally be introduced 80% from below on the facade (old ducting) and 20% on the ceiling or in reverse proportion. The supply air outlet on the ceiling is located on the front of the hall above the suspended ceiling. The air is introduced with little impulse. It simply flows out of a large channel into the hall and is distributed above the suspended ceiling. From there it moves down through larger gaps. A third of the exhaust air flows into the showers. Two thirds of the exhaust air is extracted in the hall on the same face as the supply air inlet. The central exhaust air grille of the hall is at floor level and measures 2 mx 2 m. Moisture stratification occurs due to the extraction of the exhaust air near the floor. The relative humidity is very high directly above the water surface, but is already much lower at a height of 50 cm (difference of approx. 10 percentage points or more). During stratification, this stratification could be clearly confirmed with moisture sensors. At one point, this stratification was caused by a cold draft from a warehouse During stratification, this stratification could be clearly confirmed with moisture sensors. At one point, this stratification was caused by a cold draft from a warehouse During stratification, this stratification could be clearly confirmed with moisture sensors. At one point, this stratification was caused by a cold draft from a warehouse

(open door) disturbed. No moisture difference could be measured there. The stratification is demonstrably sensitive to colder incoming air.

The design volume flow for this hall, calculated according to [VDI 2089], is 39,000 m³ / h. However, the bath is operated with a reduced proportion of recirculated air. During the sampling (21 and 22 February 2017), an average of only 19,000 m³ / h was extracted. This corresponds to a volume flow reduction of approx. 50% compared to [VDI 2089]. Unfortunately, the outside air volume flow is not recorded on the building management system. So the Umbzw. Do not determine the proportion of outside air. The THM measurements were carried out at three different times:

- 80% of the facade (20% from the ceiling) during bath operation with fresh air
- early in the morning before bathing with 80% supply air on the ceiling (20% facade) and an indoor temperature increased by 0.5 to 1K
- during bath operation with supply air at 80% on the ceiling (20% facade) and hall temperature increased by 0.5 to 1 K.

Fig. 65: Air sampling with suction pumps in Bad Niederheid in Düsseldorf in front of the central one Suction grille (left) and above the water surface and in use (right).

A total of 18 air samples and six water samples were taken on February 21 and 22, 2017 for the THM measurement. The laboratory evaluation of the samples [CLG 2017-C], which were taken 20 cm above the water surface, shows THM values between 8 and 31 µg / m³ and an average of 21 µg / m³ (12 measured values). In order to be able to assess the strain on the staff, an additional four samples were taken at a height of 1.5 m. There the results were significantly lower (5 - 10 µg / m³; 4 measured values). Samples of the mixed air from the entire halls were taken from the exhaust air grille at a height of 1.5 m: 16 µg / m³ and 20 µg / m³. The THM load in the water was measured in parallel for all three operating states. These values are between 6 and 9 µg / m³ (6 measured values).

The three different modes of operation of the air supply show no influence on the THM measurement values. Earlier tests by engineering company Inco in this bathroom have shown that the supply air under the ceiling is not recommended for non-passive houses (high heating load), as this leads to high radiation asymmetry.

Tab. 10: Measurement results of the THM measurements from February 21 and 22, 2017 in the Niederheid sports pool (Düsseldorf).

The measured values were rounded to values without decimal places.

THM-Concentration [µg / m³]	02/21/2017 afternoon	02/22/2017 Early morning	22.02.2017 noon
Sports pool			
Pool water	*7 µg / l*	*9 µg / l*	*7 µg / l*
inside	27	31	21
Facade side	11	24th	8th
Dealing inside.	9	--	10th
Handling facade 9		--	5
Exhaust grille	16	--	20th
Children's pool			
Pool water	*7 µg / l*	*8 µg / l*	*6 µg / l*
inside	24th	28	27
Facade side	28	24th	24th

The low THM concentrations in the air (8 - 31 µg / m³) are primarily the result of the low THM concentrations in the pool water. The measured values in the air clearly show that the principle of "stratified ventilation" ensures a good flow through the hall, even with a reduced volume flow. The THM load in handling and thus the load for the bathroom staff are clearly reduced again. The measurement shows that "stratified ventilation" is also recommended in terms of pollutant removal for indoor swimming pools. These results are also confirmed by the flow simulations carried out (see section 6.4 above). In comparison with the best listed literature values (8 - 28 µg / m³) from [Junek et al. 2017] can keep up with the measurements from the Sportbad Niederheid very well.

6.6 Programming ventilation unit swimming pool

In Germany, the regulation of ventilation devices for swimming pools is often offered by ventilation companies as standard. Alternatively, the regulation is carried out via the BMS. Normally the regulation follows [VDI 2089], ie the total volume flow is kept constant and only the proportion of outside air varies depending on the dehumidification requirement. The passive house concept provides for regulation without recirculation to reduce electricity costs, ie the total volume flow varies (see also section 5.1). In order to implement this, precise information on the regulation had to be worked out for each project. The aim of this research project was to provide assistance for future projects. For this purpose, the Passive House Institute has developed an exemplary ventilation control. Thanks to the cooperation with the ventilation manufacturer FlaktGroup Deutschland GmbH, this regulation could be implemented directly in a program code in 2017. With the swimming pool ventilation devices (CAIRpool) from the manufacturer, you can now choose between ventilation according to VDI and passive house ventilation. It should be noted that passive house ventilation should only be selected with a suitable passive house building envelope. This collaboration enabled preparatory work to be carried out, which otherwise at

every project between TGA planner and Programmers of ventilation control must be done.

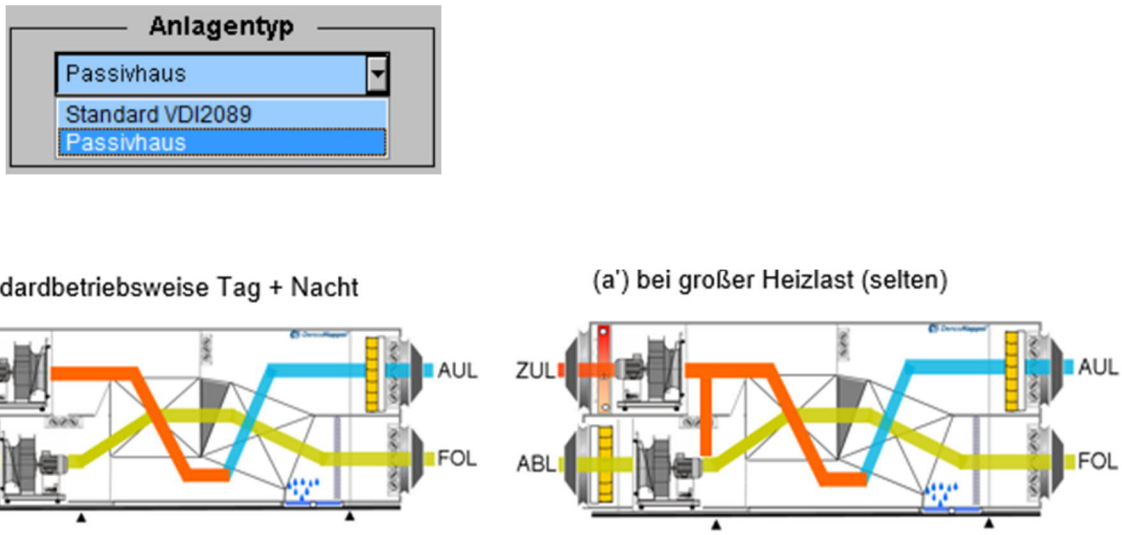

Fig. 66: Above: VDI control selection menu or passive house ventilation; bottom left: functional diagram at pure outdoor air operation (standard operation with PH ventilation); bottom right: Outdoor air operation with additional function "circulating air heating" (not necessary or rarely required in PH); Graphics © FlaktGroup Deutschland GmbH

The exact description of the control can be found in the following tables. It is an example of passive house ventilation (without circulating air), but also contains points such as fresh air flushing and cooling, which are not part of the passive house concept. As an alternative to the intermittent idle mode, in which the device switches on at regular time intervals to monitor the humidity and temperature using the exhaust air sensors, the monitoring can also be carried out continuously by installing additional humidity sensors in the hall. This prevents regular switching on for measuring purposes.

Therefore, the description of the example regulation is also available as an Excel file for further project and device-specific adaptation on request from the Passive House Institute.

Tab. 11 lists all setpoints and differentiates where they can be set. The various ventilation regulations are described in Table 12. So-called controllers are used (a controller is an internal variable; example: if the formulas in the program calculate from the measured values that there is a need for dehumidification, the dehumidifier controller becomes active, which in turn leads to further actions in the control system, e.g. controlling the fan) . If you want to understand why which actions were carried out in the ventilation unit, it is very helpful to be able to see the respective status of the controller. Tab. 13 lists the data exchange between the ventilation unit and the BMS. The data points are sorted by input or output on the BMS.

For future passive house indoor pools, planners and builders can either use the FlaktGroup program directly or commission ventilation manufacturers or GLT companies, which in turn can use the descriptions listed here for programming. If the ventilation control is programmed in the BMS, the interfaces of the trades will consequently shift.

Tab. 11: Example of a regulation description for swimming pool ventilation (Excel file on request from Passive House Institute available); Part 1: Definitions of target values

(Explanations: the "fresh air purge" is intended for bathrooms that want to open windows permanently in summer; the "shift to RH should be day" means that a higher indoor humidity is permitted at night in warmer outside temperatures.)

Lüftungsregelung Schwimmhalle		
Die Passivhaus Lüftung ist nur in Gebäuden mit geeigneter Passivhausgebäudehülle möglich.		
Sollwerte auf GLT einstellbar:		*Hinweise zu den Sollwerten*
Tsoll Tag	32°C	*auf diese Temperatur wird die Hallenluft geheizt*
Tsoll Nacht	31°C	
Tmax	4 K über Tsoll Tag	*auf diese Temperatur wird die Hallenluft gekühlt (soweit möglich); Eingabe begrenzt auf >=2K*
rFsoll Tag	58%	*auf diese Feuchte der Hallenluft wird entfeuchtet*
rFsoll Nacht max	61%	
Volumenstrom min.	5.000 m³/h	*Außenluftvolumenstrom nach VDI 2089 entweder 15% oder 30% des Auslegungsvolumenstroms einstellen*
Zeitprogramm	Mo 6-22 Uhr Badebetrieb, 22-6 Uhr Ruhebetrieb...	*Vorspülbetrieb einplanen*
Intermittierender Ruhebetrieb	0 (nicht aktiv) oder Stundenzahl z.B. 2h	*in diesem Abstand schaltet sich das Gerät nachts zur Überwachung der Feuchte und Temperatur ein*
optional:		
Vol.strom Soll Frischluft	10.000 m³/h	*Volumenstrom sollte passend zum möglichen Volumenstrom durch RWAs/Fenster, die für die Frischluftspülung geöffnet werden, gewählt werden.*
Betrieb Fortluft-WP	automatisch	*automatisch oder aus*
Sollwert im Programm des Lüftungsgerätes:		
rF soll Nacht	Schiebung zu rF soll Tag: 30%Punkte (beginnend bei 0°C bis 15°C Taußen), aber maximal rFsoll Nacht max	
Frischluftspülung Modus (ZU/AB)	ZU	*je nach Position der ZU-/AB-Luftventile und der Fenster den reinen Zu- oder Abluftbetrieb des Lüftungsgerätes wählen*
Legende Messwerte:		
Temp	Temperatur in Halle	*Abluftsensor wird verwendet, evtl. Nachrüstmöglichkeit: Sensoren im Raum für die Regelung nachts verwenden*
rF	Feuchte in der Halle	*Abluftsensor wird verwendet, evtl. Nachrüstmöglichkeit: Sensoren im Raum für die Regelung nachts verwenden*
Taußen	Lufttemperatur außen	

Tab. 12: Example of a regulation description for swimming pool ventilation (Excel file on request from Passive House Institute available); Part 2: Description of the scheme

Lüftungsregelung Schwimmhalle Die Passivhaus Lüftung ist nur in Gebäuden mit geeigneter Passivhausgebäudehülle möglich.			
von GLT	*Regelung Lüftungsgerät*	*an GLT*	*Regelung GLT*
	Betrieb Lüftungsgerät		
Zeitprogramm	**Badebetrieb:** Lüftungsgerät immer an, nur bei Störungen aus (z.B. Motorstörung)		
Zeitprogramm, rF soll Nacht, Tsoll Nacht, Intervallschaltung Nacht	**Ruhebetrieb:** Lüftungsgerät ausgeschaltet, aber Feuchteüberwachung: - einschalten nach Intervallschaltung Nacht - abschalten, wenn rF > rFsoll Nacht - 2 % und Temp > Tsoll Nacht + 1K - Mindestlaufzeit 20 Min		
rF soll Tag, rF soll Nacht	Regler Entfeuchten wenn rF > rFsoll		
Volumenstrom min.	**Außenluft-Volumenstrom:** - variabler Volumenstrom nach Entfeuchtungsbedarf, keine Umluft - Minimalvolumenstrom laut GLT (Volumenstrom min.) - Volumenstrom Fo/ Volumenstrom AU: Balance oder leichter Unterdruck im Gebäude	*Volumenstrom-höhe*	*ggf. Regelung Klappen Zuluft für konst. Druck*
	Klappe Umluft Entfeuchten/Heizen geschlossen		
	Klappe Au, Fo: offen, so daß kein unnötiger Widerstand		
	Filtertrocknung: In der Regel nicht notwendig, da nur kurze Stillstandszeiten		
Tsoll Tag, Tsoll Nacht	Regler Heizen wenn Temp < Tsoll		
	Heizregister: Heizleistung in Abhängigkeit von Tsoll		
	Klappe Umluft Heizen: wenn Heizlast mit momentanem Außenluft-Volumenstrom nicht gedeckt werden kann, Umluftanteil stetig hochfahren		
	Regler Frostschutz		
	Frostschutz für Heizregister: wenn T Zuluft <10°C wird geheizt		
	Frostschutz für Rekuperator: T Fortluft < -5°C, stetig AU-Luft über Bypass		
Tmax	Regler Kühlen wenn Temp > Tmax		
	Meldung an GLT: Empfehlung Sonnenschutz aktivieren	*Empfehlung Sonnenschutz*	
	Bypass auf, wenn Temp > T außen, Bypass zu, wenn Temp < Taußen		
	Volumenstrom: Wenn Bypassklappe 60 Min. vollständig geöffnet, Temp > T außen + 4 K und Temp > T max, dann Volumenstrom auf Nennvolumenstrom hochfahren		
GLT gibt Freigabe zu Frischluftspülung, wenn Fenster/RWAs geöffnet	Regler Frischluftspülung wenn GLT Freigabe zur Frischluftspülung		
Vol.strom Soll Frischluft, Frischluftspülung Modus	Wenn Temp > T soll + 2K und T außen > 25° entweder nur Zuluft- oder nur Abluftventilator an, auf Vol.strom Soll Frischluft		
Betrieb WP	Wärmepumpe (in der Fortluft)		
	- Grundvorraussetzung: Volumenstrom > 20% (abhängig von WP Größe) - wenn Heizanforderung Luft - wenn Kühlanforderung (falls vollumschaltbare WP)		
	Autokalibrierung Druckdosen		
	- einmal wöchentlich oder einmal täglich, wenn nötig		
	Prioritäten der Regler:		
	- Regler Kühlen sperrt Regler Heizen - Frostschutz hat immer Vorrang - Frischluftspülung sperrt Regler Entfeuchten und Regler Heizen		

Tab. 13: Example of a regulation description for swimming pool ventilation (Excel file on request from Passive House Institute available); Part 3: Data exchange between BMS and ventilation unit

Bezeichnung	Einheit	Lüftungs-gerät Ausgang	Lüftungs-gerät Eingang
T Abluft	°C	X	
rel. Feuchte Abluft	%	X	
T Zuluft	°C	X	
T Fortluft	°C	X	
T Außenluft	°C	X	
Betrieb Lüftungsgerät	Ruhebetrieb, Badebetrieb, Automatik, aus	X	
Betrieb Wärmepumpe		x	
Regler Entfeuchten		X	
Regler Heizen		X	
Regler Kühlen		X	
Regler Frostschutz		X	
Regler Frischluftspülung		X	
Empfehlung Sonnenschutz	0/1	X	
Volumenstrom Zuluft	m³/h	X	
Volumenstrom Abluft	m³/h	X	
Volumenstrom Außenluft	m³/h	X	
rF soll Tag	% r.h.		X
rF soll Nacht	% r.h.		X
Tsoll Tag	°C		X
Tsoll Nacht	°C		X
Tmax	°C		X
Zeitprogramm			X
Volumenstrom min.	m³/h		X
Vol.strom Soll Frischluft	m³/h		X

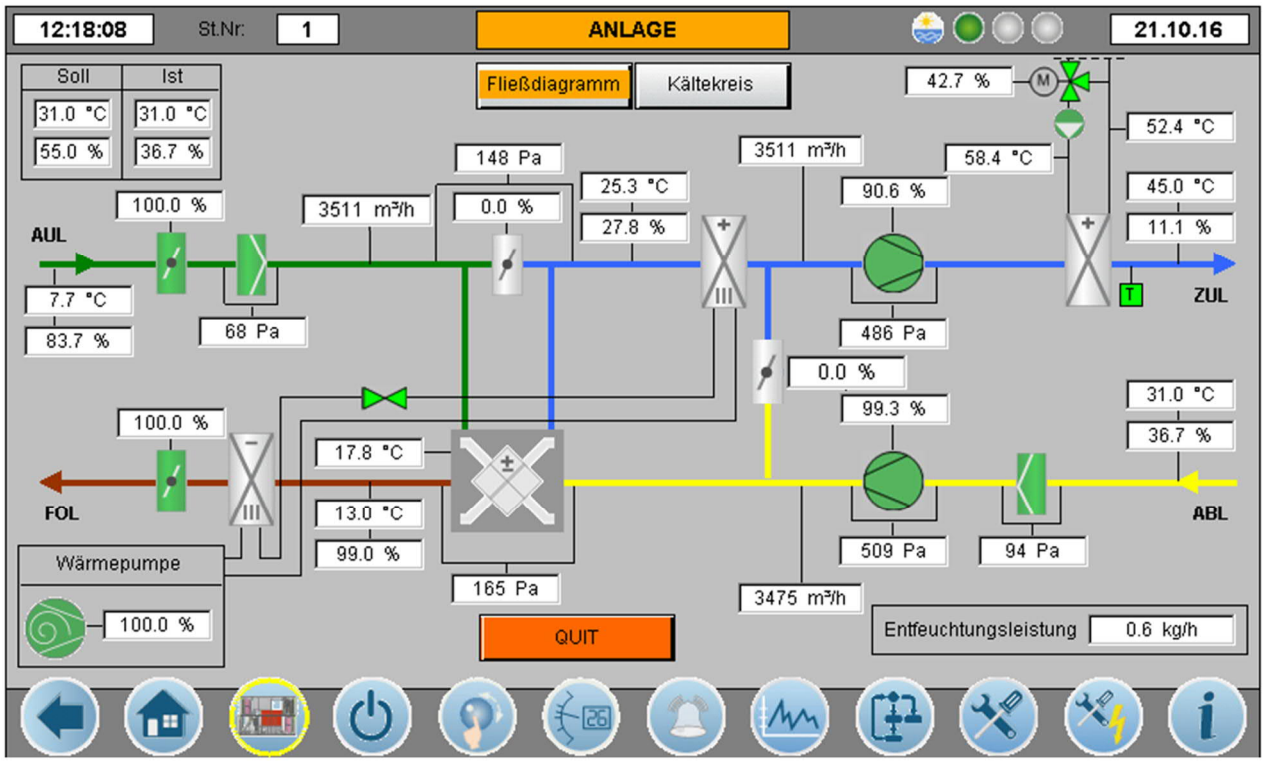

Fig. 67: System diagram on the display of the CAIRpool ventilation unit (pure outside air operation), graphic © FlaktGroup Deutschland GmbH

7 Swimming pool technology: guide

A large part of the energy consumption in swimming pools is required to provide the warm, hygienic pool water. On the one hand, heating is required to heat the cold water to the pool temperature (see Section 8.5) and, on the other hand, a not inconsiderable amount of electricity is required to clean and transport the pool water (circulation and operation of the attractions) (see Section 8.1). Careful planning of the swimming pool technology including component selection and mode of operation can significantly reduce energy requirements. Due to the generally higher temperatures and loads (30-32 ° C & 2.7 m² / P) for non-swimmers and leisure pools compared to swimmers' pools (28 ° C & 4.5 m² / P), the savings potential is higher there and to one to ensure efficient operation.

There are numerous different approaches to pool water treatment with different filter systems. The advantages and disadvantages of the different systems are not part of this report and the selection should be made for each bathroom according to the boundary conditions and with regard to energy efficiency.

When it comes to the electricity requirements of the water treatment plant, the pumps for pool water circulation are in the foreground. Electricity consumption can be reduced in the long term, in particular through the selection of pumps, a demand-controlled mode of operation and a design of the pipeline network with reduced pressure losses. This not only saves operating costs but also reduces the risk of overheating in technical rooms due to lower waste heat. The energy requirement for heating the pool water can be effectively reduced, for example, with systems for heat recovery and / or wastewater treatment. Measures to reduce evaporation are also beneficial, such as increased indoor air humidity or demand-controlled operation of the water attractions.

7.1 Pool water circulation

The circulation pumps are in operation all year round and have comparatively high outputs. These long runtimes make even a small improvement noticeable in terms of energy and costs. With a very efficient system, a power consumption of 25-40 W per m³ / h circulation volume flow can be achieved (based on the processing volume flow at nominal load according to DIN 19643, depending on the type of pool and load factor k = 0.5 m-³). The derivation is described in chapter 8.1. In relation to the pool area, this corresponds to approx. 10-17 W / m² for sports pools and approx. 17-29 W / m² for non-swimmer and vario pools. Some specific aspects that contribute to increasing energy efficiency in this area are listed below.

Pipeline network:

The composition of the pipeline network determines the head to be handled by the pump. The lower the pressure drop, the less energy is required. This planning task is a basic prerequisite for efficient operation. As a guideline, 5-10 mWS (with medium filter contamination) should be aimed for an efficient solution (see chapter 8.1)

- the lower the better. Technically, a lot is possible here and there are projects (indoor pool Brilon, outdoor pool Hangeweiher) in which the pressure losses at the operating point have been reduced up to 3.5 mWS [Kaluza 2018].

The following measures help to reduce pressure losses:

- Compact pipe network with as short and direct lines as possible
- Generous dimensioning of the pipe diameter. As a guideline for the design, 1-1.3 m / s is recommended as the speed for the pumped medium
- Low-pressure fittings (e.g. two 45 ° downpipes instead of 90 ° T-pieces, FW flaps (spring-closing) instead of conventional non-return flaps etc.)
- Increase of the surge water tank compared to the ground level (reduces the geodetic height difference)

- Choice of pool water inflow
- The use of diffusers after the pumps (see eg [Kaluza 2014a])

Pump selection:

Ultimately, the decisive factor for the efficiency of the pump is the efficiency of the overall system at the actual operating point, ie the combined efficiency of the electric motor plus the pump hydraulics and the electronic control. For an efficient solution, total efficiencies (pump, motor and frequency converter) of over 70% should be aimed for. Below are some concrete recommendations for action and tips for pump selection:

- The priority is to ensure high efficiency of the electric motor. The internationally introduced IEC efficiency classes serve as an aid here. Efficient systems are usually permanent magnet motors or synchronous motors compared to conventional asynchronous motors.
- It is important to correctly tune the system for the actual operating points, not just the maximum power required. Precondition for this is an exact calculation and a good understanding of the pressure losses during operation. Here, for example, the selection of the pump is optimized based on the average pressure drop across the filter, instead of the pressure drop at maximum design. A high level of efficiency can only be achieved in practice by selecting the right pump. In addition, this increases the longevity of the pumps and enables quieter operation.

- The use of frequency converters (FU) has become the state of the art for efficient operation. The higher investment costs usually pay off through the saved energy and maintenance costs over the life cycle of the pump. By controlling the speed of the pump by means of an FC, high efficiency can also be achieved at different operating points (e.g. night reduction or with different degrees of pollution of the

Filter). In addition, the use of an FI guarantees a buffer for efficient pump operation if the pressure drops in the system should in practice deviate from the planning values.

- The choice of material for the pump has an impact on its efficiency and especially on wear. The risk of corrosion can be reduced by using coated pumps.

Operating mode:

It is not absolutely necessary to continuously circulate the pool water with a full design volume flow. Outside of the operating hours or with a small number of bathers, the electricity consumption can be reduced by partial load operation. A mandatory prerequisite for this is a guarantee of water quality. The regulation can, for example, be done very simply using a time switch for different reduction levels, for example the lowest partial load always outside of operating hours and an average partial load at known times with little operation (eg no clubs or school classes). The savings potential is particularly high for non-swimmer pools, in which the nominal circulating volume flow according to DIN is designed with a higher pool occupancy density.

- **Temporary volume flow reduction.** The power consumption drops in proportion to the third power of the reduction factor, which means that even small reductions are very effective. In any case, it must be ensured that the flow through the pool is guaranteed. Smaller reductions in the volume flow over longer periods are more advantageous than temporary, strong reductions in terms of ensuring the water quality, since the flow and water change rate are less impaired here.

- In a so-called **Internal circulation** the volume flow below the water surface of the basin is taken, i.e. it circulates without an overflow channel and the splash water tank. Correspondingly lower pressure losses also reduce the electricity requirement. Here too, care must be taken to ensure adequate flow through the pool. The internal circulation can be implemented for the entire volume flow or only for a partial volume.

7.2 Water attractions

Water attractions such as slides, massage jets, water mushrooms or similar require additional electricity to operate the pumps. In addition, increased evaporation arises from the operation, with associated evaporation heat losses and increased ventilation requirements. As an essential energy saving measure for attractions, it is important to pay attention to a good regulation, that is, an operation only if necessary. There are various options for this, e.g. via manual buttons with a timer (automatic switch-off after a preset operating time), via automatic triggers (e.g. light barrier in the event of slides) or via timers (fixed times or intelligent control taking into account the number of visitors).

7.3 Pool water heating demand

It can be expected that the heating requirement for pool water with efficient solutions in the range of approx. 400-700 kWh / (m^2_{WF} a) lie (for derivation see chapter 8.5). However, there are many influencing factors here that can cause large deviations and make a comparison without further information difficult (e.g. interaction with the efficiency of swimming pool technology).

In general, the lower the water temperature, the lower the heating requirement. The temperature should therefore be kept as low as possible in accordance with the intended use and visitor comfort. In addition, the required amount of fresh pool water every day is crucial for the heating requirement. As a guideline for the minimum hygienic volume, at least 30 liters per guest apply. In practice, the quantities of water required for filter rinsing are often decisive for water consumption. This amount depends on the filter technology selected and the boundary conditions in the individual case. As a guideline, in the case of conventional multi-layer filters, a filter rinsing water requirement of approx. 0.6 m³ / (m² month) for swimmer pools or 1 m³ / (m² month) for non-swimmer pools can be used (see 8.2).

There are two possible approaches to reduce heat loss at this point. The greater the amount of fresh water required, the more important these measures are.

- Heat recovery from the warm filter rinsing wastewater, either with a passive approach using a heat exchanger or as an active system with a heat pump (significantly more expensive). See Chapter 9 for an exemplary cost-benefit analysis.
- Treatment of the filter rinsing waste water for reuse in the bathroom, for example as process water (toilets) and / or as filling water for the pools. See also chapter 8.3 for the operational experience in the Lippe bath and chapter 9 for a cost-benefit analysis of different treatment plants.

Another effective measure to reduce the heating requirement of the pool water is the reduction of the heat of evaporation. Effective measures are, for example

- Increase in indoor air humidity, continuously or at least outside opening hours (see also chapter 5.1). As a guideline for planning, a humidity of around 55-60% is suggested during the operating hours. A prerequisite for this is a well-insulated building envelope and thus the avoidance of condensation. For reasons of building protection, the relative humidity should not exceed 64%.

- Lowering the water level at night (no evaporation via the channel system and an overall reduced evaporation area)

- Design of the water overflow (channel system)
- Few water attractions or reduced running times only when actually used.

7.4 Further savings potential for swimming pool technology

In the field of swimming pool technology there are other starting points for saving energy. It is important that the overall system (components and control) is matched to the use and the selected filter technology. It is important to reduce the number of electricity consumers, to use the most efficient technology possible and to keep the heating and electricity requirements low by the mode of operation. Other examples of further savings measures are:

- Reduced heat loss by avoiding roof vents (e.g. splash water tanks)
- Integrate the guidance of the measuring water to check the water quality in the circulation circuit, ie without additional pumps. In addition, the measurement water is returned to the pool circuit instead of being discharged as waste water. This reduces both electricity and water consumption.
- Regular cleaning of the pump filter for efficient pump operation.

8th Swimming pool technology and sanitary: selected questions

8.1 Power consumption of circulation pumps

The electricity consumption of the circulating pumps of the pool circuits is usually very important for indoor swimming pools. According to the evaluation of the measurements in the Lippe bath, the power consumption of these pumps alone accounts for 23% of the total power consumption (see chapter 3.2 "Long-term power consumption"). By optimizing the system and the selection of pumps, this power consumption can be significantly reduced; specific recommendations are listed in Chapter 7.

Fig. 68 to Fig. 70 show the measured power consumption and circulating volume flows over two years (2016 & 2017) in the Lippe-Bad, each broken down for the three basin circuits. In addition to the absolute power consumption (Fig. 68), the specific values per m² pool area (Fig. 70) or per m³ / h circulation volume flow (Fig. 70) are interesting and informative for evaluating energy efficiency. Tab. 14 contains an overview of the relevant results from the Lippe bath.

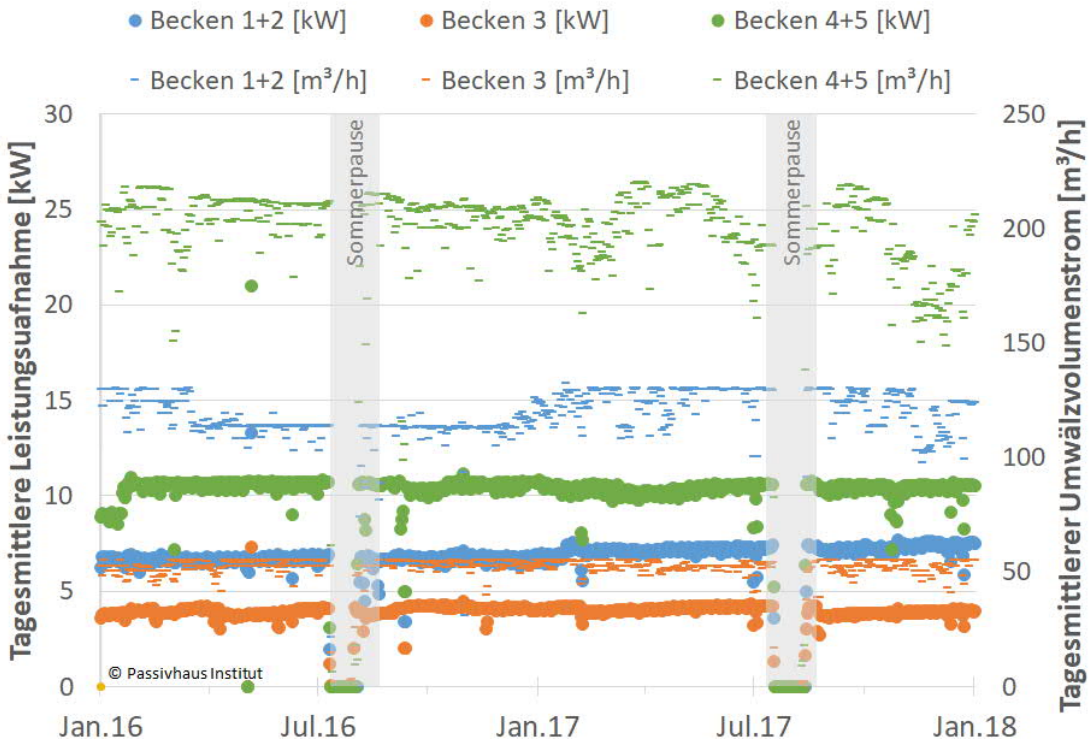

Fig. 68: Measured power consumption and circulation volume flow of the three basin circuits in the Lippe bath over two years 2016 & 2017.

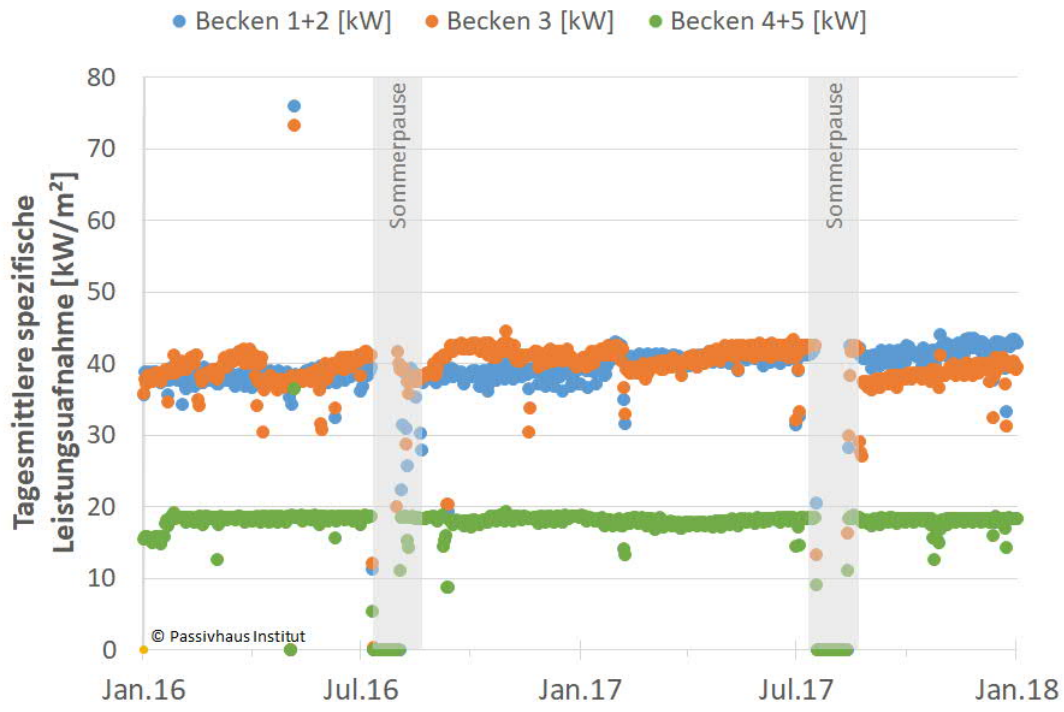

Fig. 69: Specific power consumption of the circulation pumps per m² pool area (as daily average) of all three pool circuits in the Lippe bath.

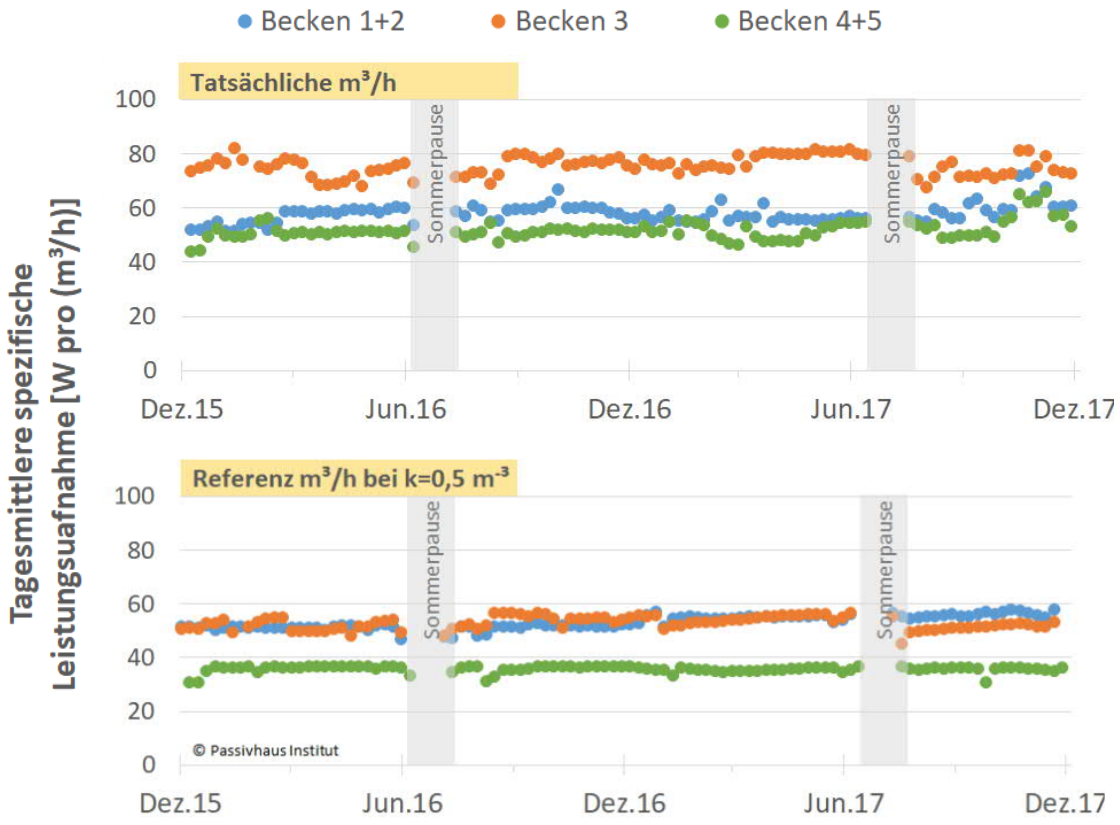

Fig. 70: Specific power consumption of the circulation pumps per m³ / h circulation volume flow (as Weekly average) of all three pelvic circuits in the Lippe bath. With reference to the volume flow actually conveyed (top) and to the volume flow calculated according to [KOK 2013] with load factor k = 0.5 m⁻³ (bottom).

Tab. 14: Absolute and specific power consumption of the circulation pumps in the Lippe bath.

Average power consumption of the circulation pumps in the Lippe bath 20 16/2017			
	Basin 1 + 2 basin 3 basin 4 + 5		
kW	6.9	4.0	10.4
W / m² pool area	40	40	18th
W / (m³ / h) measured volume flow	58	76	52
W / (m³ / h) k = 0.5 m-³ resilience factor (reference value)	53	53	36
Reference values			
Pool area [m²]	175	100	575
Average volume flow m³ / h with k = 1 m-³ (ultrafiltration)	65	40	145
Average volume flow m³ / h measured in 2016/2017 & Increase compared to UF design	120 185%	52 130%	200 138%
Circulation volume flow m³ / h with k = 0.5 m-³ (typical for most filter types)	130	75	290

It can be expected that different pool types have different specific electrical power consumption per m² pool area. Depending on the usage assumption for the pool types and accordingly different nominal loads according to [KOK 2013], the hygienically necessary circulation volume flow per m² pool area varies. With a higher nominal load of 2.7 m² / P for pools 1 + 2 and 3, the required nominal circulation volume flow per m² pool area is higher than for the swimmer pools 4 + 5 with 4.5 m² / P. It is therefore to be expected that the specific electricity consumption for swimmer pools will generally be lower than for vario or non-swimmer pools. The measured power consumption in the Lippe bath (Tab. 14) based on the pool area is on average 40 W / m² for pools 1 + 2 and 3, and 18 W / m² for pools 4 + 5.

The swimming pool technology in the Lippe bath is based on ultrafiltration. One advantage of ultrafiltration is that it can be operated with lower circulating volume flows: The design is carried out with a resilience factor of k = 1 m³, instead of 0.5 m³ for fixed bed and precoat filters. In principle, systems with ultrafiltration can be operated with a 50% lower volume flow, as is the case, for example, in the Bambados in Bamberg. In the case of the Lippe bath, the circulating volume flows had to be increased somewhat in order to achieve the desired water quality. In long-term operation, the increase in the circulation volume flow in the LippeBad corresponds to 185% for pools 1 + 2, 130% for pools 3 and 138% for pools 4 + 5 compared to a design with a k-factor of 1 (common for ultrafiltration).

It is a coincidence that the specific consumption values per m² of pool area for pools 1 + 2 and 3 are the same: The actual operating point for pool 3 is less efficient per actually realized circulation volume flow (76 Wh / m³ compared to 58 Wh / m³), but this is the specific volume flow promoted lower than for pools 1 + 2. Basin 4 + 5 with 52 Wh / m³ has the best system efficiency in the Lippe bath and an increase in the circulation volume flow to approx. 138% compared to design with k = 1 m-³.

For comparability between different baths - regardless of the filter technology and the volume flow actually realized - the design circulation volume flow according to the guidelines for bath construction [KOK 2013] with a uniform load capacity factor k = 0.5 m-³ is suggested (see [Peper / Grove-Smith 2013], p.89). This is the usual resilience factor for most filter technologies, except for ultrafiltration. In the Lippe bath, this value is 53 W / (m³ / h)$_{k = 0.5}$ for pools 1 + 2 and pool 3 as well as at 36 W / (m³ / h)$_{k = 0.5}$ for pools 4 + 5 (see Fig. 70 and Tab. 14).

As already described in the first monitoring report [Peper / Grove-Smith 2013] (p. 87ff.), The actually implemented circulation volume flow (m³ / h) gives way in the Lippe bath from the Planning values from (ensuring water quality). In addition, components were retrofitted that led to an increase in pressure losses in the pool circuit. The electricity consumption in Lünen therefore does not correspond to that which can be achieved with optimized new planning. Additional reductions in the circulation volume flow or a planned partial internal circulation could not be implemented during operation.

Reference values

Low pressure drops and a high overall efficiency are the basis for electricity-efficient water circulation. If the pressure loss is halved, the power consumption also drops linearly by 50%. Tab. 15 contains the corresponding overview of results for swimmer pools for non-swimmer pools with continuous operation with nominal volume flow. Accordingly, approx. 2540 Wh / m³ can be regarded as an efficient solution with continuous full-load operation. This corresponds to 10-17 W / m² for sports pools and 17-29 W / m² for non-swimmer pools.

Further savings can be achieved by lowering the circulation volume flow. Assuming an overall efficiency of 70% (pump, motor & frequency converter), the expected specific current consumption can be calculated with different pressure losses and operating modes. In a first approximation, the current consumption with a reduced volume flow is calculated as. =

, with P = power consumption, Q = volume flow at operating point 1 and operating point 2. Fig. 71 shows the corresponding savings potential by lowering the volume flow.

Tab. 15: Estimation of the specific electricity requirements of the circulation pumps for different Pressure losses (boundary conditions: resilience factor k = 0.5 m-³, total efficiency = 70%).

Sports pool:

Nenn-Volumenstrom	Druckverluste	mittlere spezifische Stromaufnahme	
m³/h pro m²	mWs	Wh/m³	W/m²
0,44	4	16	7
0,44	6	23	10
0,44	8	31	14
0,44	10	39	17
0,44	12	47	21
0,44	15	58	26
0,44	25	97	43

Non swimmer pool:

Nenn-Volumenstrom	Druckverluste	mittlere spezifische Stromaufnahme	
m³/h pro m²	mWs	Wh/m³	W/m²
0,74	4	16	12
0,74	6	23	17
0,74	8	31	23
0,74	10	39	29
0,74	12	47	35
0,74	15	58	43
0,74	25	97	72

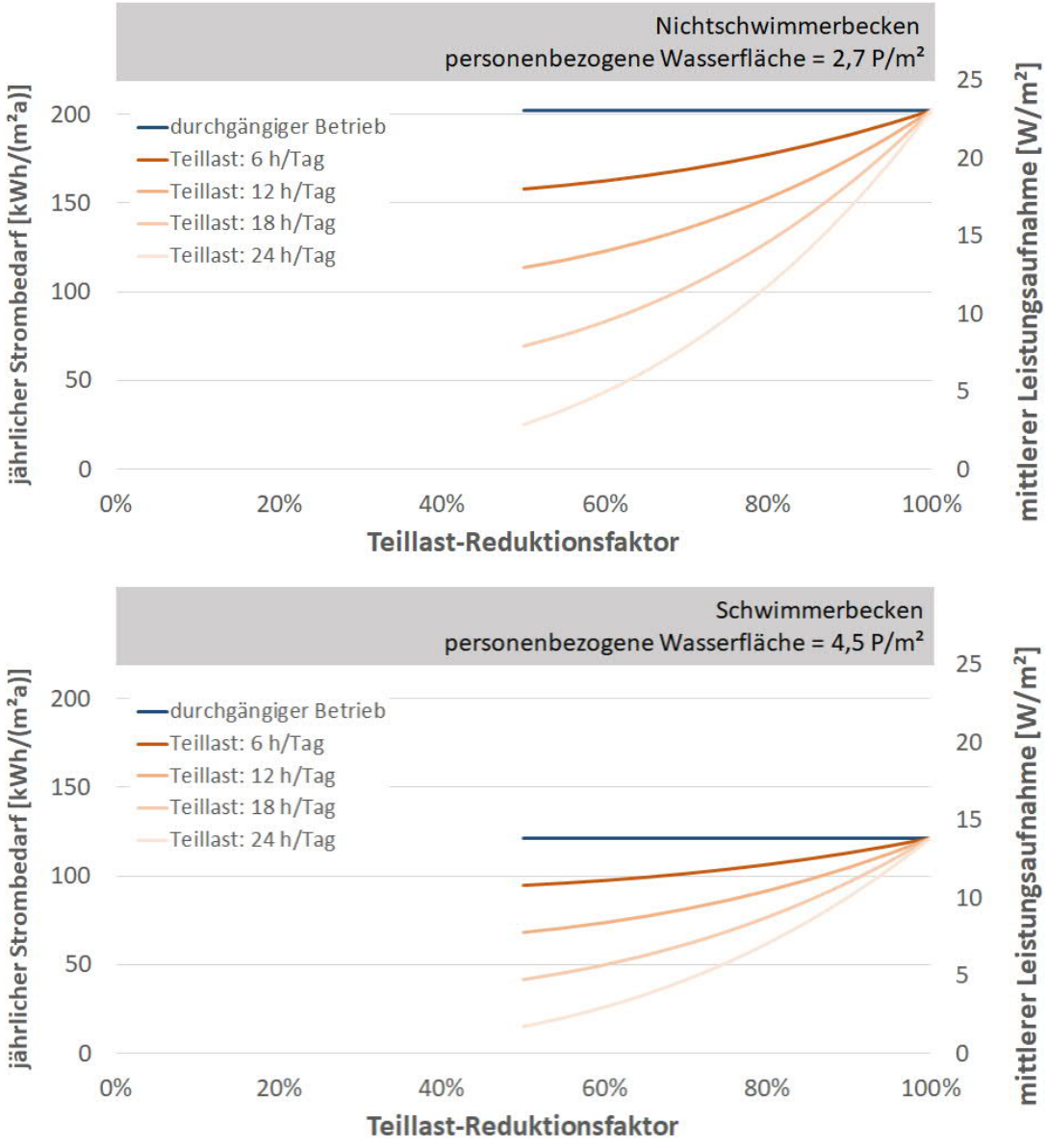

Fig. 71: Examples of the electricity demand of the circulation pumps at different part-load companies for one Non-shimmer pool (above) and a swimmer pool (below). Boundary conditions for the calculation: 8mWS pressure loss and 70% overall efficiency of the pump.

In practice, the pressure losses are often significantly higher than the technical potential and the savings potential is not exploited by common planning approaches. At this point, it would be very important to disseminate concrete planning approaches in order to be able to implement sewer networks with greatly reduced pressure losses in the future. Fig. 72 and Fig. 73 show pressure losses (at the operating point) of individual components in the pool circuit as concrete examples and as an aid for orientation values. The total pressure losses in these examples are 5.8 mWS (Fig. 72) and 9 mWS (Fig. 73) in the optimized case. Each individual bathroom has a slightly different structure and it is important to optimize the overall system in individual cases.

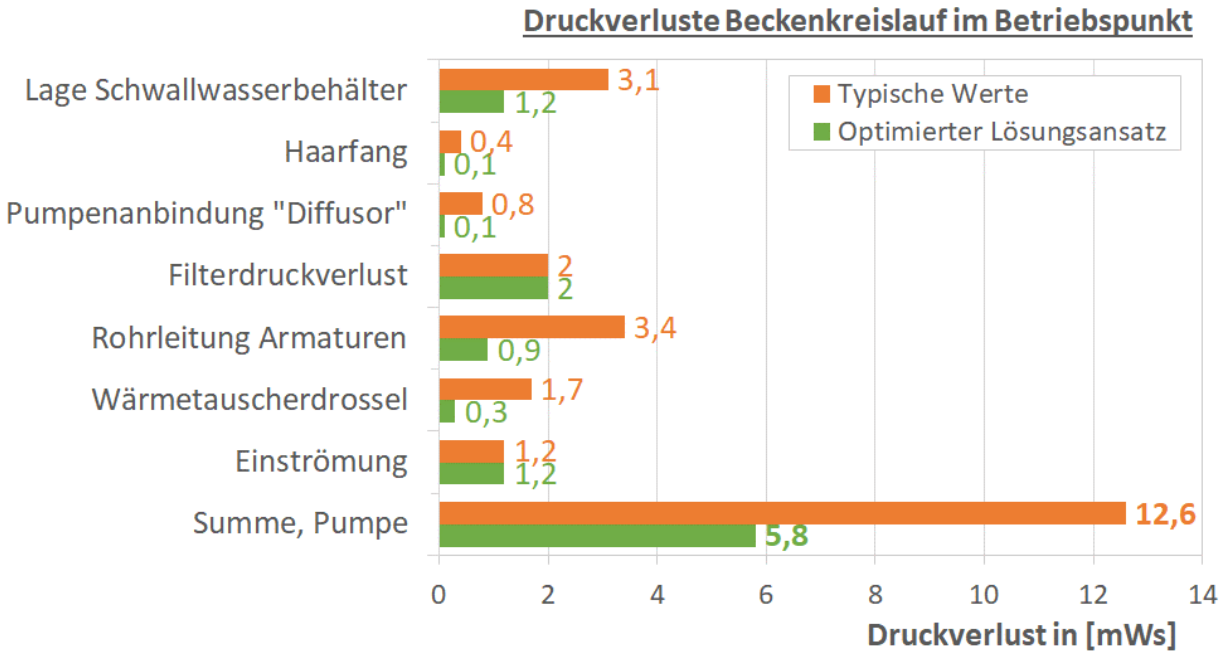

Fig. 72: Exemplary pressure losses of individual components of a pool circuit for common solutions (red) and an optimized approach (blue). The data were processed by the engineering company Inco and represent average values from measurements and analyzes of numerous baths. In total, the pressure losses are reduced by more than 50% from 12.6 mWS to 5.8 mWS. Source: Inco.

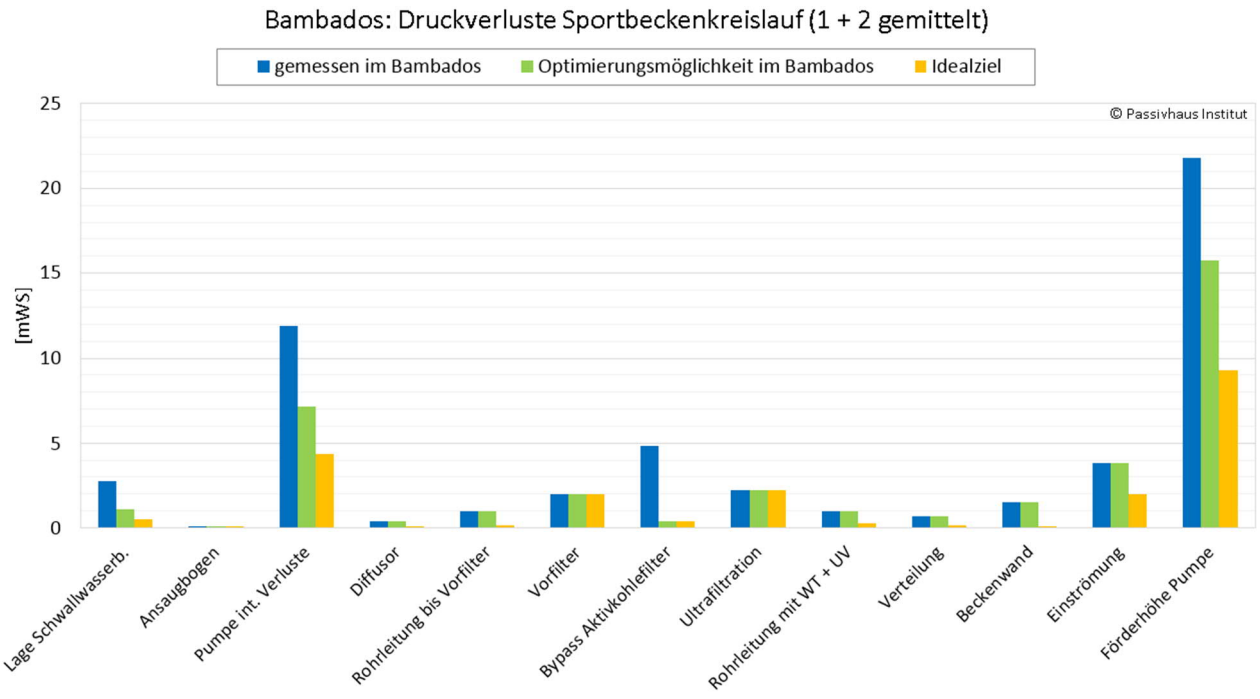

Fig. 73: Example of the pressure loss of individual components of the sports pool circuit in the Bambados Indoor swimming pool: Average measured pressure losses (blue), as well as their optimization potential through retrofitting (green) and, in comparison, the ideally realizable pressure losses with new planning (yellow). Source: [Gollwitzer et al. 2015], [Kaluza 2014].

8.2 Fresh water consumption pool water

As a hygienic guideline, 30 liters of fresh water per bathing guest apply to maintaining good bathing water quality. In practice, the amount of water actually used in the pool circuits is often determined by filter rinsing. In the Lippe bath, ultrafiltration is used as filter technology, which usually has a higher water consumption than conventional sand / multilayer filters.

The evaluation of the data confirms that the fresh water consumption in this bath is actually significantly higher than required by hygienic guidelines. In 2016, 241,274 visitors were registered via the cash register system (see course of the year in Fig. 74). That corresponds to 24 visitors per m² of pool area per month. Fig. 75 shows the monthly water consumption for the three pool circuits as an example for 2016 compared to the standard value of 30 liters per guest. On an annual average (excluding August, when the water is completely replaced), 76 liters of fresh water are replenished per visitor, i.e. approximately 250% of the hygienic requirements. Taking into account the additional 13 l / P filling water from the rinsing wastewater treatment plant, the proportion is approx. 300% of the hygienic requirements.

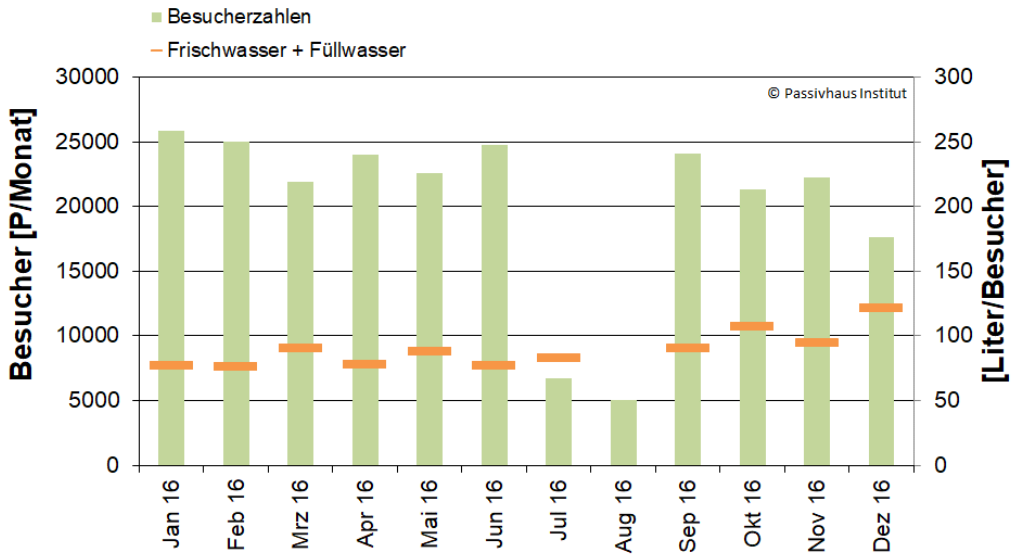

Fig. 74: Monthly visitors (number of people based on the cash register system count) in 2016 and the equivalent fresh water quantities per guest in the Lippe bath.

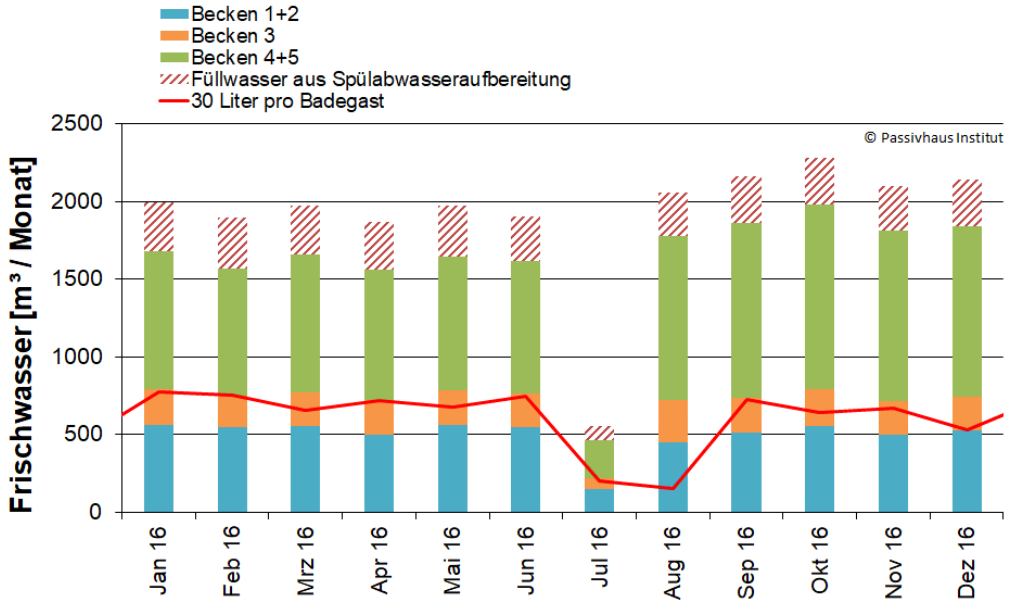

Fig. 75: Monthly fresh water consumption in the Lippe bath for the three pool circuits compared to the minimum hygienic requirement of 30 liters / guest (number of people based on counting by the cash register system).

A look at the specific consumption values (including fill water) in the Lippe bath per m² pool area (Fig. 76) shows a difference between the pool circuits: With

The average specific fresh water consumption for pools 4 + 5 (swimmer pools) in 2016 was 1.8 m³ / (m² month) lower than the 2.8 m³ / (m² month) used for pools 3 and 3.3 m³ / (m² month) for pools 1 + 2. This is only to be expected, because the filters are designed according to the nominal load, which is set lower for swimmer pools.

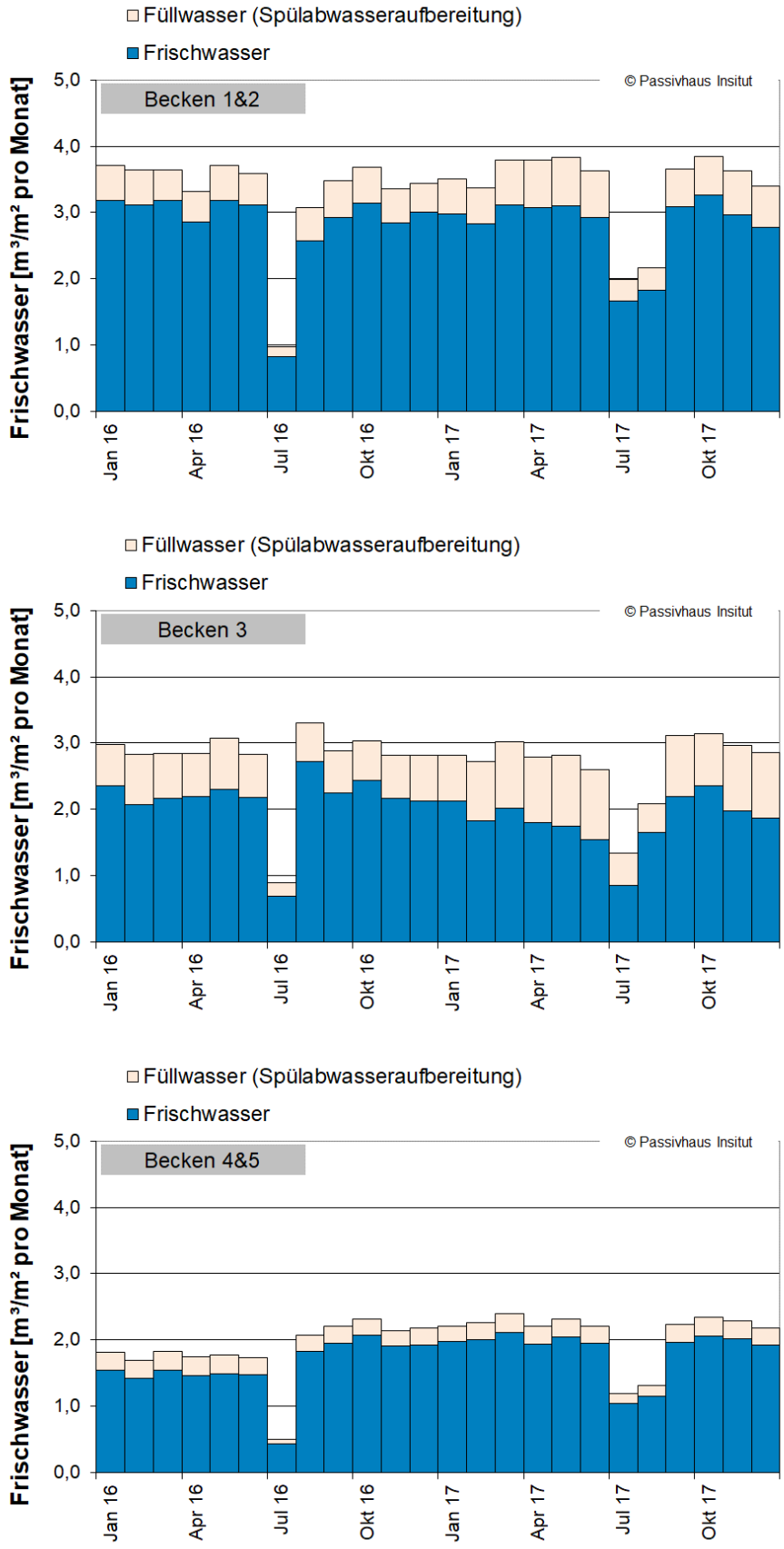

Fig. 76: Specific monthly water consumption per m² pool area of the three pool circuits in the Lippe Bad over time 2016-2017.

Reference values

Based on a similar number of visitors per m² of pool area as in the Lippe-Bad (approx. 24% on average around 11% of the [KOK 2013] nominal load), of 18 visitors per m² per month for a swimmer pool (SB) and 30 visitors / (m²month) for a non-swimmer pool (NSB) can be expected. This results in a hygienic fresh water requirement of

0.5 m³ / (m² month) (SB) or 0.9 m³ / (m² month) (NSB). This value can of course vary greatly from project to project depending on the number of visitors.

In comparison, the typical water requirement for filter rinsing with conventional multi-layer filters can also be calculated. The filter size per m² pool area can be calculated from the requirement of a flushing speed of 30 m / h and the nominal loads according to [KOK 2013] (0.015 m^2_{Filter}/ m^2_{pool} for self-service and 0.025 m^2_{Filter}/ m^2_{pool} for NSB). Assuming a flushing water volume of approx. 4.5 m^3 / m^2_{filter} and two rinses per week, the water requirement is 0.6 m³ / (m²month) (SB) or 1 m³ / (m²month) (NSB). These values are of a similar order of magnitude as the previously calculated hygienic fresh water requirement. With other filter systems, the water requirement can be significantly higher, such as in the case of ultrafiltration in the Lippe bath. It is to be expected that the actual fresh water requirement will be somewhat higher than the pure amount of filter rinsing water, since additional water losses due to bathers' discharged water, evaporation and water taps for samples etc. must be compensated for.

From an energetic and economic point of view, it is desirable to achieve the desired water quality with the lowest possible fresh water quantities (saving on fresh water, waste water and heating energy). This should be taken into account when considering the advantages and disadvantages of different filtering methods.

8.3 Lippe bath: rinse water treatment

In swimming pools, the water filters in the pool water circuits must be backwashed regularly. The resulting rinse water can continue to be used. To reduce costs for heating energy, water and wastewater, a rinse water treatment system was installed in the Lippe bath. This means that heat, water or both can be recovered from wastewater. The rinse water treatment was gradually put into operation from early 2014 to mid-2015. Since then it has been operated continuously. The following evaluation was carried out for 2016.

Scheme

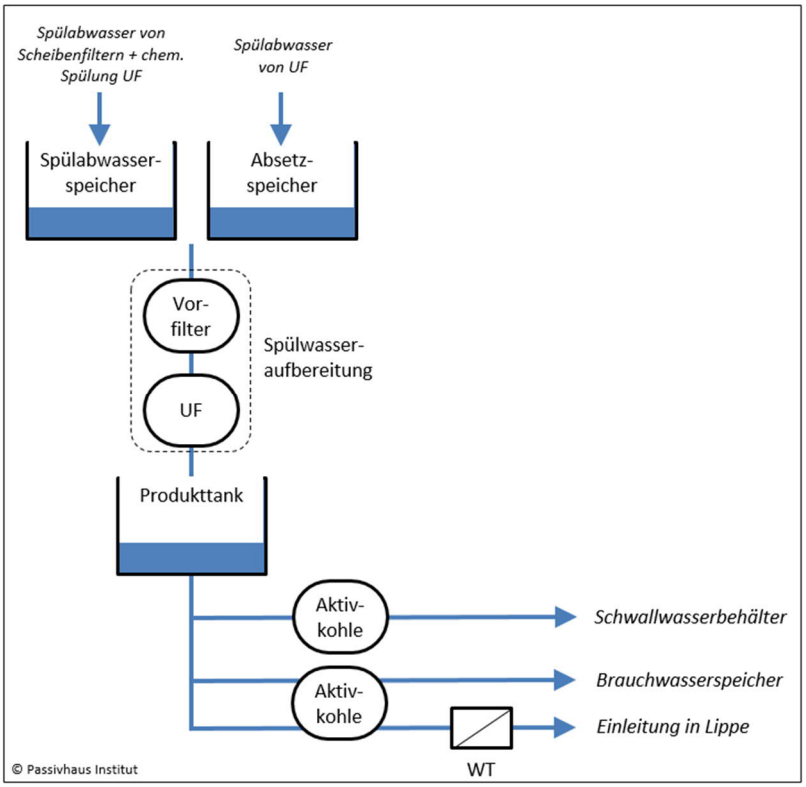

Fig. 77: Scheme of rinse water treatment.

The treated water in the Lippe bath can be used in three different ways (see Fig. 77): It can be used to fill the splash water tank. From an energetic point of view, this is the first choice because not only the water but also the heat of the water can be used. The treated water from the chemical rinse (at night) is, however, largely discharged into the lip as waste water (reduction in waste water costs) and to a small extent used as process water in the building. The water that is fed into the lip flows through a heat exchanger, so that part of the heat is recovered for the building.

evaluation

The following diagram shows the evaluation of the rinse water treatment in the Lippe bath for 2016. The left bar shows the total amount of rinse water (determined from measurement data and additional estimates). Part of the rinse water is treated and can be used (see right bar: basin, toilet, lip). Part of the rinse water is not treated, but is used directly for backwashing the pre-filter of the rinse water treatment system (approx. 8,000 m³ / a) and discharged as waste water. This is the largest part of the wastewater in the right column of the following graphic. The rest of the wastewater is created by using treated water for backwashing the rinse water treatment (UF).

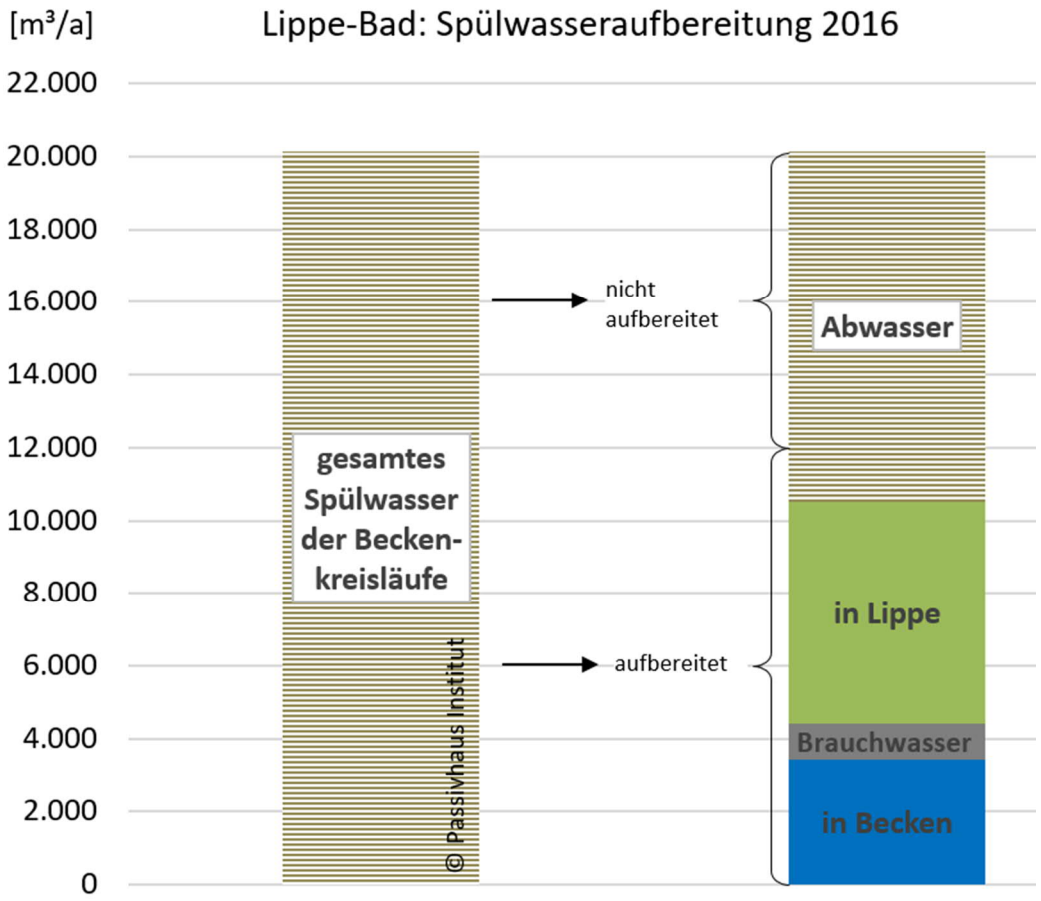

Fig. 78: Rinse water consumption in the Lippe bath and its use

The following diagram no longer considers the total amount of rinsing water, but only the rinsing water that is being treated. It shows how the treated water is divided between the uses mentioned. For comparison, the total amount of treated water (blue lines) is shown. The difference between this total amount and the total amount of treated water used (bar in the diagram) is used for backwashing the rinse water treatment (UF). The rinse water for the prefilter of the rinse water treatment system itself is not included in the diagram.

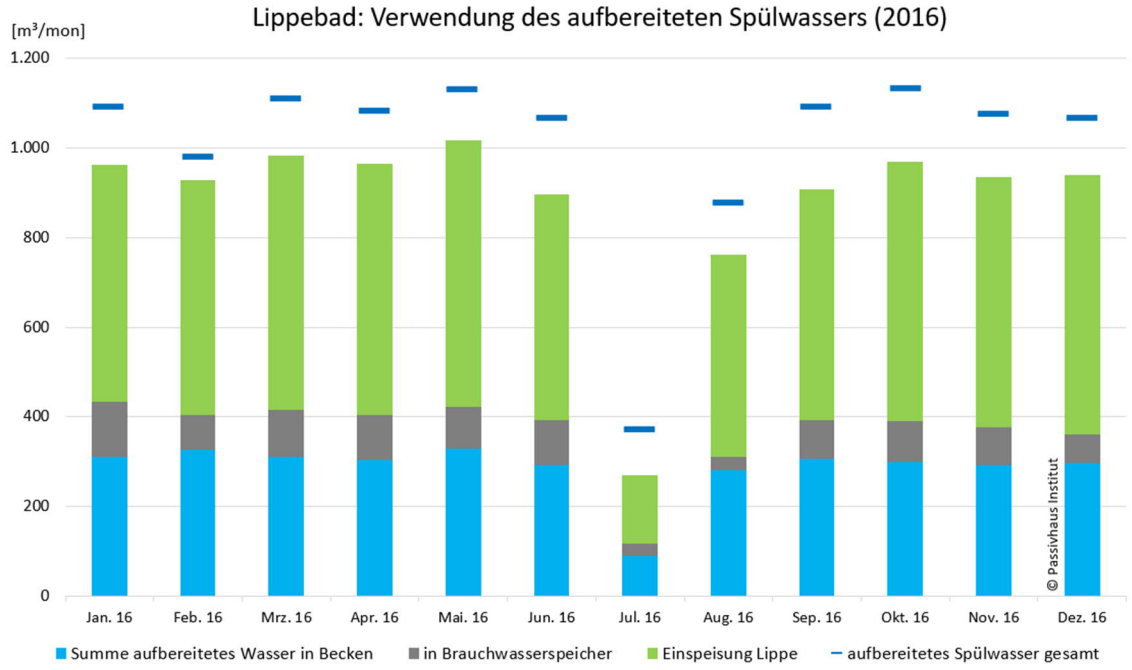

Fig. 79: Use of the treated rinse water in three areas of use and indication of the total amount of the treated rinsing water (monthly totals). The difference to the total amount is used for backwashing the rinse water treatment itself.

The make-up of the splash water tanks could be covered up to 15% from treated water. The exact breakdown is shown in the following diagram.

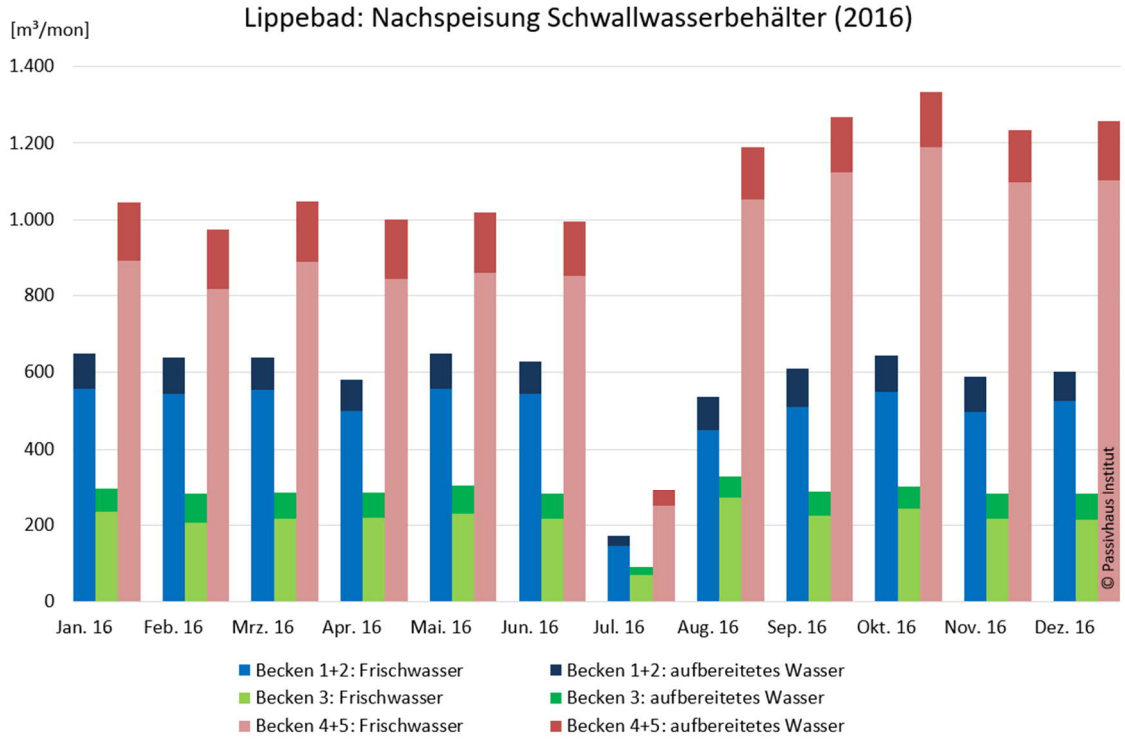

Fig. 80: Monthly representation of the pool water replenishment of the three pool water circuits. On average about the treated water covers 15% of the make-up in all circuits.

Operational changes

In operation, it was found out that the filters of the rinse water treatment need to be rinsed more so that they do not clog up so quickly. After a pump for the hot water circuit was defective, the operator decided not to use any more treated water than hot water (from mid-January 2017). As a result, the amount of treated water used for the pool circuits rose slightly in 2017 (15% compared to 2016). However, more fresh water was also used for pools 4 + 5 from August 2016.

Use and savings

The following savings were recorded for rinse water treatment in 2016:

- The wastewater was reduced by 6,117 m³ by introducing this amount into the Lippe as treated water (reduction of the wastewater costs).
- 4,410 m³ of drinking water were saved (13% of the total water consumption): By 3,432 m³ of treated water for the pools and 978 m³ as process water could be reused (saving drinking water costs). The reuse of this water saving also saves wastewater costs.

- Approx. 64 MWh of heating energy could be saved because the treated rinse water was returned warm to the pool circuits. That is approx. 15% of the heating energy consumption for the pools (saving heating energy).

- In addition, about 10MWh / a of energy could be extracted from the water that was introduced into the lip and thus remained in the building (saving heating energy).

The electricity used for all pumps for rinse water treatment was 9,092 kWh in 2016. This corresponds to an average output of approx. 1.1 kW.

Since the data evaluation is based in part on extrapolations and estimates, the following percentage evaluation is only conditionally reliable: Due to the installed rinse water treatment system, 30% of the rinse water was processed and led into the lip and 22% could be reused as pool or service water. In total, 52% of the total rinse water was treated. This means that the plant falls short of the 70% processing ratio forecast. Nevertheless, the cost-benefit analysis (see Chapter 9) shows that the rinse water treatment works very economically. For future bathrooms, the aim should be to further increase the use of the warm treated water in the building (for pools or showers). In this project, higher usage came up against the following limits: A large part of the rinse water was required for rinsing the pre-filter of the treatment plant. Due to the quality of the pool water, rinse water that is no longer processed should be used to make up the pool.

In general and as in the Lippe bath, the part of the treated water from the chemical backwashing should not be used for the make-up water. This means that the usage rate cannot be increased.

8.4 evaporation

The level of evaporation in an indoor pool has a significant impact on various areas: energy, comfort and not least the air quality. It is decisive for the dimensioning and operation of the ventilation units (see chapter 6.1) and has a significant influence on the evaporation enthalpy losses that arise

the

Heating demand.

For planning in indoor pools in Germany is used to calculate the amount of evaporation $M_{, BD / bu}$ in kg / h, usually the following formula according to [VDI 208] is used:

$$M_{, BD / bu} = \frac{b}{R_D} \times \left(p_{, WD} / T - p_{, LD} \right) \times A_{BLDWD}$$

b Water transfer coefficient [m / h] - indicator for pool occupancy

R_D specific gas constant for water vapor [J / (kgK)]

T Average pool water and air temperature [K]

$p_{, WD}$ Saturation pressure at pool water temperature [Pa]

$p_{, LD}$ Indoor air vapor pressure [Pa]

A_B Pool water surface [m²]

The specific evaporation rate [kg / m²] is therefore proportional to

a) occupancy; very variable depending on usage

b) vapor pressure difference ($p_{, WD} - p_{, LD}$); depending on water, air temperature, air humidity

c) medium temperature 1 ≈ 0.003— ; for indoor pools (28-32 ° C) quite constant

There are various alternative formulas in the literature on the basis of which the expected evaporation rate can be calculated (see eg [Shah 2014]). The vapor pressure difference on the water surface always plays a crucial role. Depending on the methodology chosen, it is more or less important (see Fig. 46).

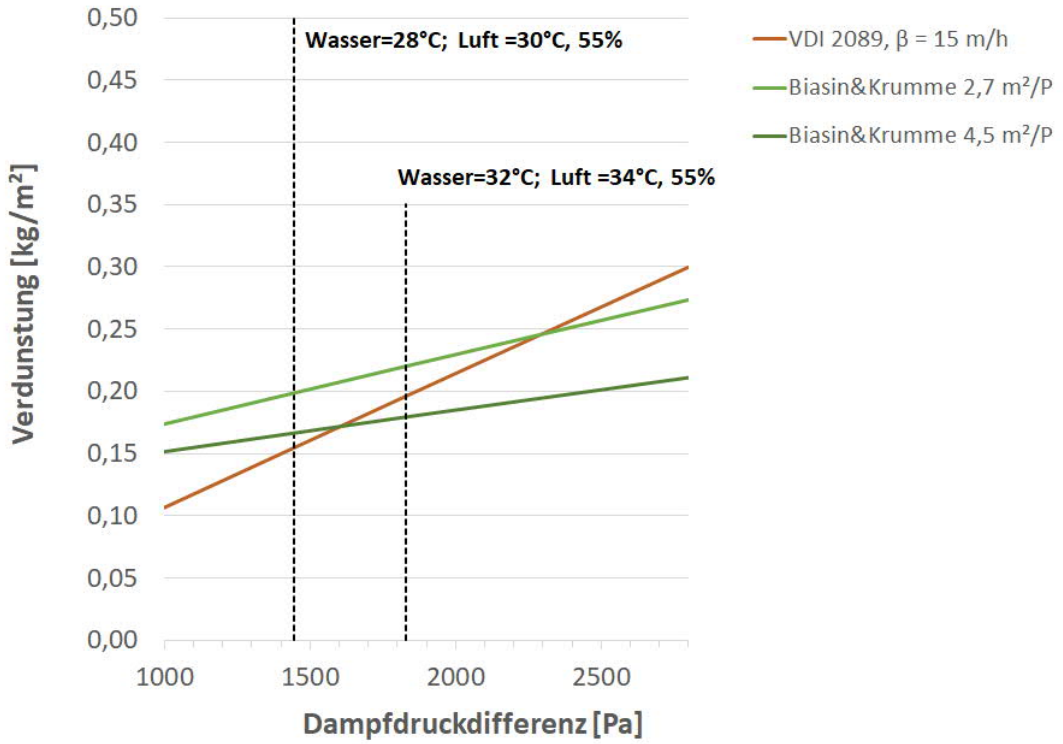

Fig. 81: Calculated evaporation per m² pool area depending on the vapor pressure difference. Calculated according to the VDI 2089 (usually used as a reference in Germany) with a water transfer coefficient β for average use and according to the formula from [Biasin, Krumme 1974] (used in England, for example, as a reference and for project design).

As already described in chapter 6.1 "Design of the swimming pool ventilation units" and in [Peper / GroveSmith 2013], the monitoring data of the hall ventilation units - conclusions about the amount of evaporation in the company can be made. Fig. 82 to Fig. 85 show the results of the evaluations of the Lippe bath for 2016 and 2017. Tab. 16 contains a summary of the average evaporation rates for the different pools. Hall 4 and Hall 5 are not spatially separated , This means that interactions between the ventilation systems are possible and it makes sense to look at the entire hall area (pools 4 + 5). As expected, the evaporation rates are highest in Hall 1 + 2, because the temperature and humidity conditions are the most unfavorable (highest vapor pressure difference).

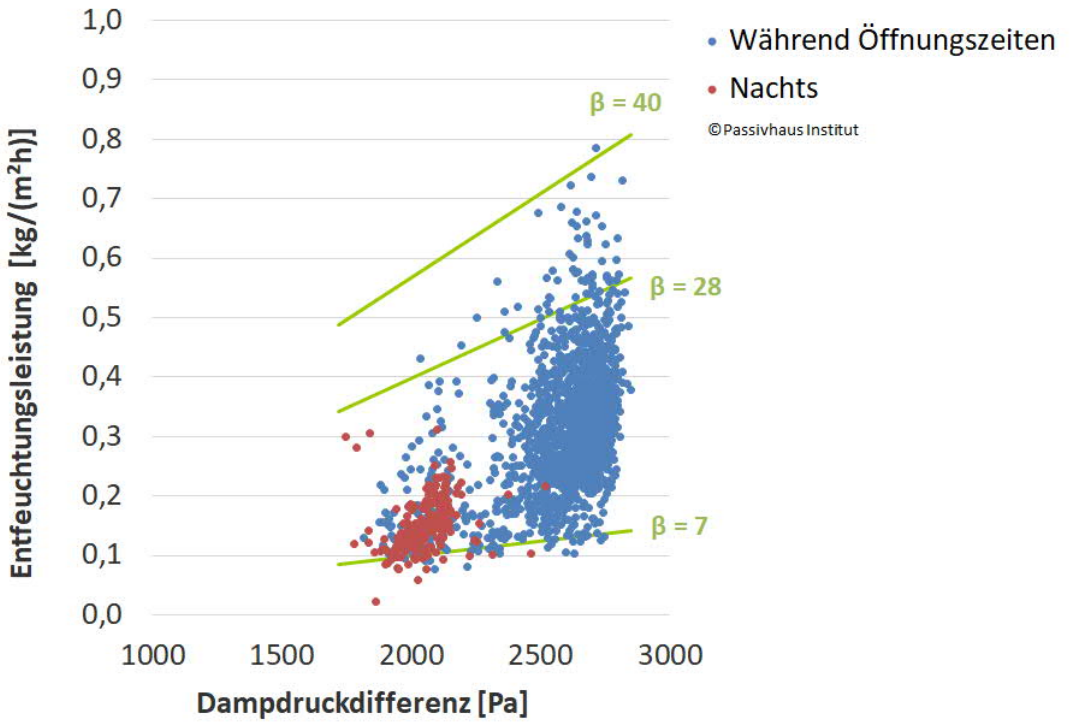

Fig. 82: Calculated dehumidification performance of the ventilation unit in hall 1 + 2 in 2016 (without Summer break). The green lines indicate the expected value according to VDI for the measured average hall conditions: 32 ° C water temperature, 32 ° C air temperature

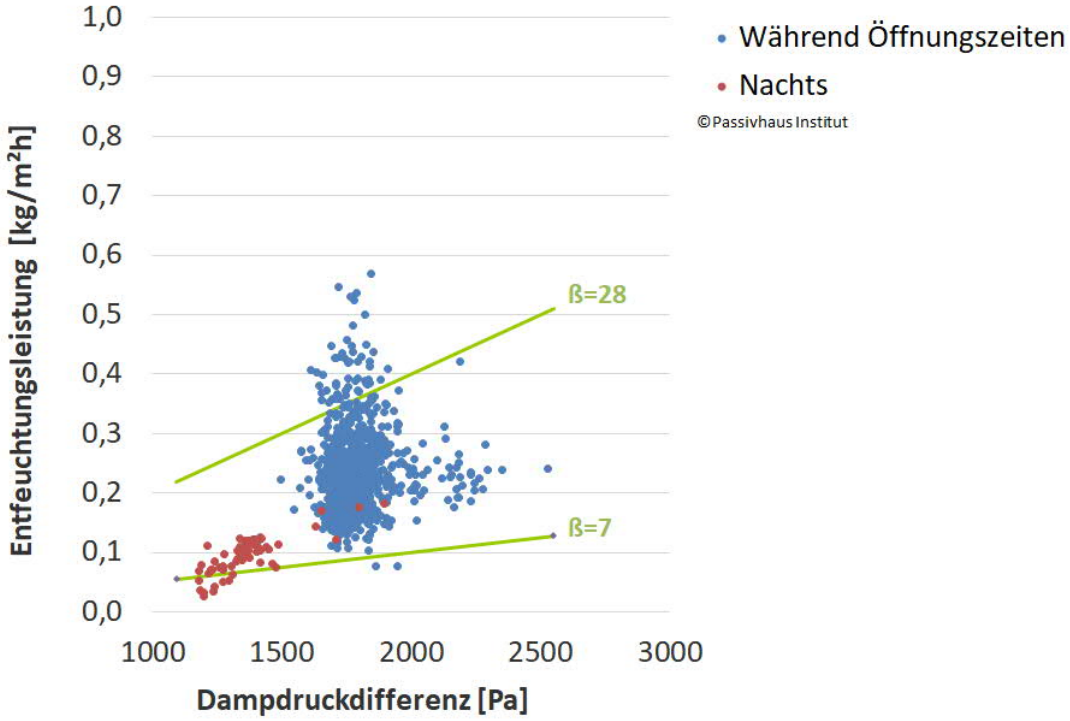

Fig. 83: Calculated dehumidification performance of the ventilation unit in hall 3 in 2016 (without Summer break). The green lines indicate the expected value according to VDI for the measured average hall conditions: 30 ° C water temperature, 32 ° C air temperature

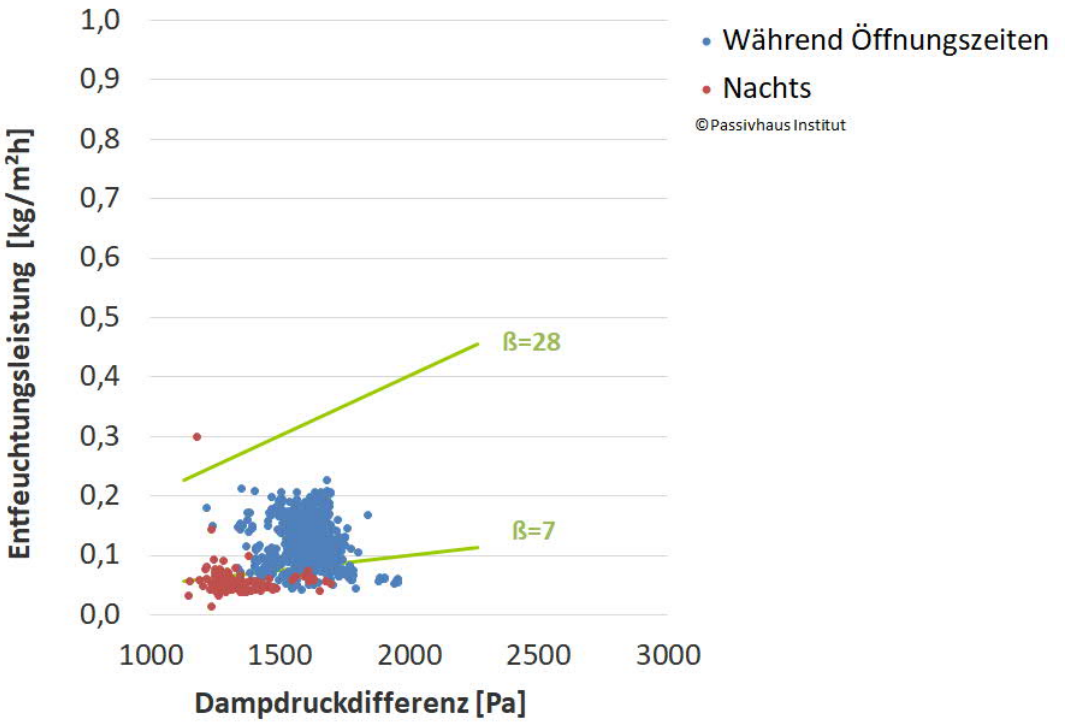

Fig. 84: Calculated dehumidification performance of the ventilation unit in Hall 4 in 2016 (without Summer break). The green lines indicate the expected value according to VDI for the measured average hall conditions: 28 ° C water temperature, 30 ° C air temperature

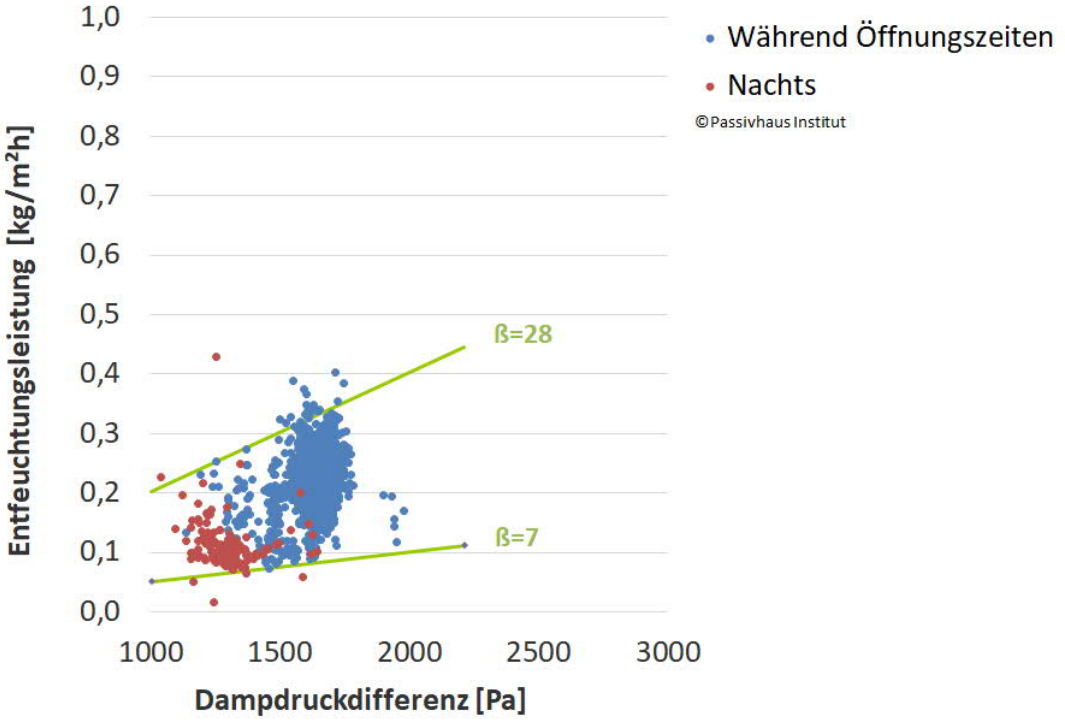

Fig. 85: Calculated dehumidification performance of the ventilation unit in hall 5 in 2016 (without Summer break). The green lines indicate the expected value according to VDI for the measured average hall conditions: 28 ° C water temperature, 30 ° C air temperature

Tab. 16: Overview of the results of the evaporation rates in 2016 in the Lippe bath.

***For halls 4 + 5, the results are given as the area-weighted average of the two pools, since the two halls are spatially linked and cannot be viewed separately.**

	Basin 1 + 2	Basin 3	Basin 4 + 5 *
Dehumidification performance during the day [kg / (hm²)]	0.31	0.23	0.17
Equivalent β [m / h]	17th	18th	15
Dehumidification performance at night [kg / (hm²)]	0.15	0.08	0.09
Equivalent β [m / h]	11	7	9

Reference values

The data evaluation for the Lippe bath essentially confirms the findings from [Peper / Grove-Smith 2013] and [Gollwitzer et al. 2015]. An average water transfer coefficient of β = 15 m / h can be used to calculate the average evaporation quantities during the periods of use. This corresponds approximately to 50% of the design according to VDI 2089 for sports pools (β = 28 m / h). As in the previous investigations, no significant difference between the water transfer coefficients of the different pool types could be identified in the Lippe bath; the differences between the individual pools are within the scope of the uncertainties in the evaluation. This confirms the examinations and descriptions in 6.1 "Design of swimming pool ventilation units",

8.5 Energy consumption heating pool water

41% of the total heat consumption was required for the pool water heating of the Lippe bath in the period 2013-2017 (see chapter 3.1 "Long-term heat consumption"). For this main consumer, it is important to understand the energy balance as well as possible in order to identify and exploit potential savings. Already during the first monitoring period in the Lippe-Bad 2012/2013, the various factors influencing the energy balance of the pool water were analyzed in detail ([Peper / Grove-Smith 2013] p.95 ff.). Fig. 86 shows schematically the various influencing factors that lead to heat gain or heat loss. The solar radiation listed is neglected in the following calculations because the pools inside the building are not exposed to direct radiation.

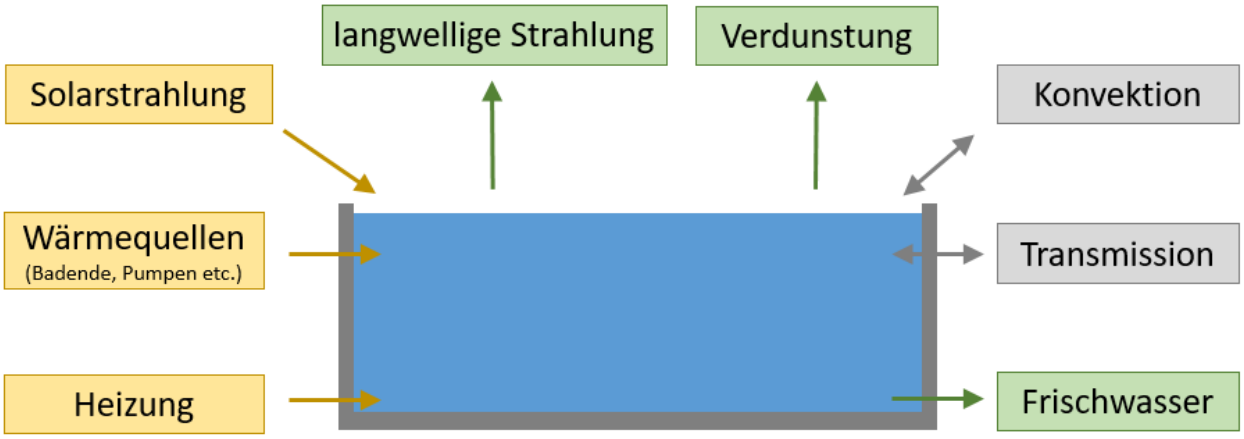

Fig. 86: The essential parameters for the energy balance of a swimming pool (indoor pool).

One aim of this project was to determine guideline values for energy-efficient solutions and reliable calculation bases. Measurement data from 2016 was used for the analyzes. Table 17 lists the corresponding consumption of the three pool circuits of the Lippe bath as absolute and specific values.

Tab. 17: Overview of the three pool circuits and their heating consumption in 2016.

	Basin 1 + 2	Basin 3	Basin 4 + 5
Water area [m^2_{WF}]	175	100	575
Water volume [m^3]	185	230	1074
Average temperature [° C]	32	30th	28
Heating energy consumption [MWh / a]	203.3	31.1	124.5
Specific heating consumption [kWh / (m^2_{WF} a)]	1162	311	217
Equivalent specific average heating output [W / m^2_{WF}]	133	36	25th

Fig. 88 to Fig. 92 show the calculated energy balances of the individual pool circuits compared to the monthly measurement data for heating consumption. The following assumptions were made for the calculations (see also [Peper / Grove-Smith 2013]):

- Temperatures and relative room humidity according to the monthly average measurement data
- Evaporation corresponding to 80% of the dehumidification performance determined from the measurement data via the respective ventilation systems (see chapter 8.4).

- Pool occupancy based on the measurement data of the people counting in pool 1 + 2. These were transferred to basin 3 and basin 4 + 5 via the water areas and nominal load factors. 700 W heat emission per bath guest for all pools.
- Fresh water according to the monthly measurement data (see chapter 8.2.)
- Filling water from rinsing wastewater treatment according to the measurement data (see chapter 8.3)
- Heat recovery from wastewater from rinsing wastewater treatment for pools 1 + 2 and pool 3: Effective degree of heat supply approx. 7%. This follows from an estimate based on 70% efficiency of the heat exchanger, as well as taking into account that heat is only recovered from a small part of the wastewater (Lippe river) and this does not always coincide with the fresh water replenishment.

- 90% of the measured current consumption of the circulation pumps as heat dissipation to the pool water (see chapter 8.1)
- As an estimated surcharge for additional heat gains (additional swimming pool technology, lighting, etc.): Another 50% of the current consumption of the circulation pumps
- Convection at the water surface and transmission through the pool walls according to the physical relationships (see [Peper / Grove-Smith 2013] for further explanations -
  stakes).
- The surface temperature of the ceilings is essentially relevant for the effects of long-wave radiation, but was not measured separately. The main influencing factors at this point are the temperature stratification (depending on the air flow) and the insulation -
  strength of the roof (transmission losses). As an approximation, the air temperature of the hall was used as the ambient temperature.

The trends in the course of the year between the calculation and the measurement data are in good agreement for all three pelvic circuits (see Fig. 88, Fig. 90 and Fig. 92). In the case of pools 1 + 2 (Fig.
87), the pool circuit with the highest specific heating consumption, the calculated average heating output is 4 W / m² higher than the measured value (3% deviation). In the case of basin 3 (Fig. 89) and basin 4 + 5 (Fig. 91), the calculated values are 20 or 25 W / m² higher than the mean measured heating output (overestimated by 57% for basin 3 and 96% for Basin 4 + 5). The cause of these not inconsiderable deviations could not be finally clarified, since the usage and boundary conditions cannot be determined in more detail. As can be seen in the energy balances, the heat given off by the bathers, for example, has a considerable influence. The actual pool occupancy is not known, however, and the heat output per person can only be estimated. It is quite possible that the heat output during sporting activity is higher (cf.

The general tendencies and influencing factors can be mapped in detail using a newly developed calculation tool for the pool water energy balance. This can serve as a helpful support during planning in order to better understand the energetic impact of the boundary conditions (e.g. temperature and humidity), as well as the selected components (e.g. filter technology and corresponding rinse water requirements).

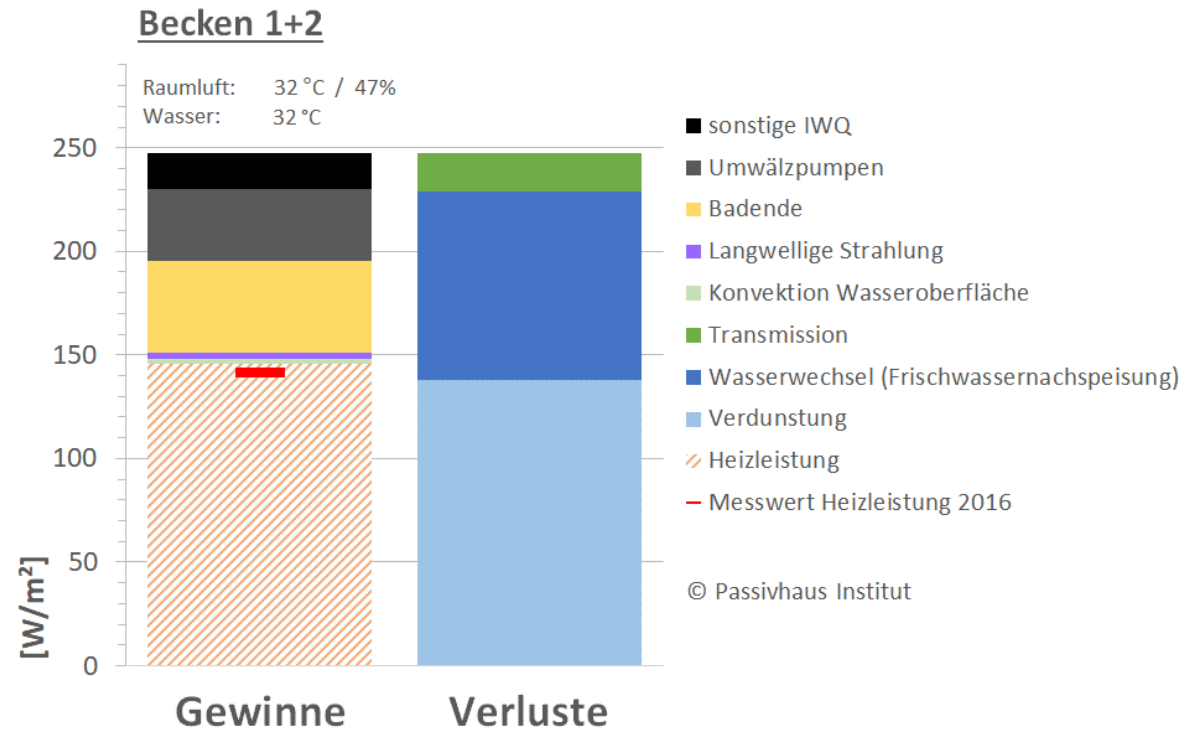

Fig. 87: Calculated energy balance for basin 1 + 2 under the measured operating conditions of the Year 2016 (except summer break July and August). (Note: The effects of heat recovery from the wastewater, as well as the fill water from the rinsing wastewater treatment are taken into account in the fresh water make-up).

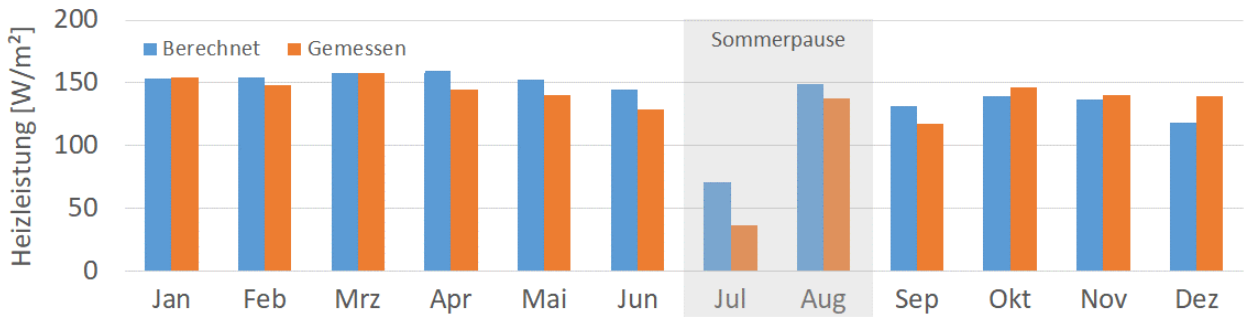

Fig. 88: The calculated monthly heating output for pools 1 + 2 compared to the measurement data from 2016.

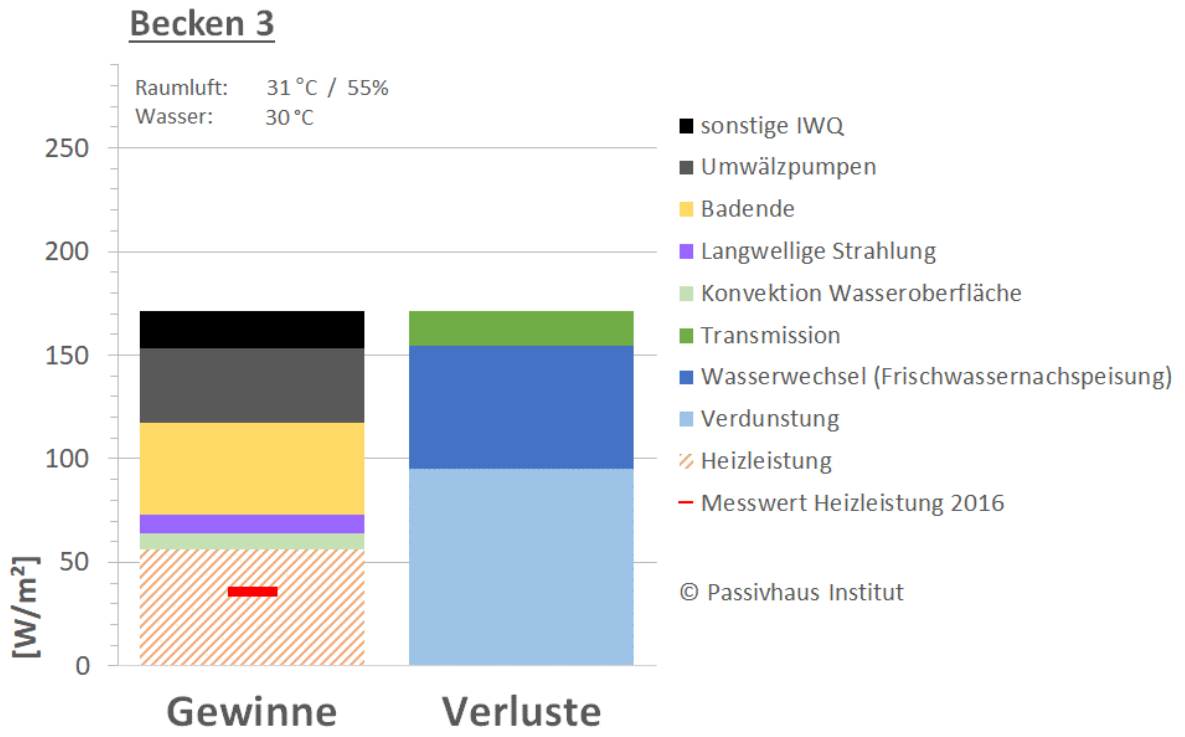

Fig. 89: Calculated energy balance for pool 3 under the measured operating conditions of the Year 2016 (except summer break July and August). (Note: The effects of heat recovery from the wastewater, as well as the fill water from the rinsing wastewater treatment are taken into account in the fresh water make-up).

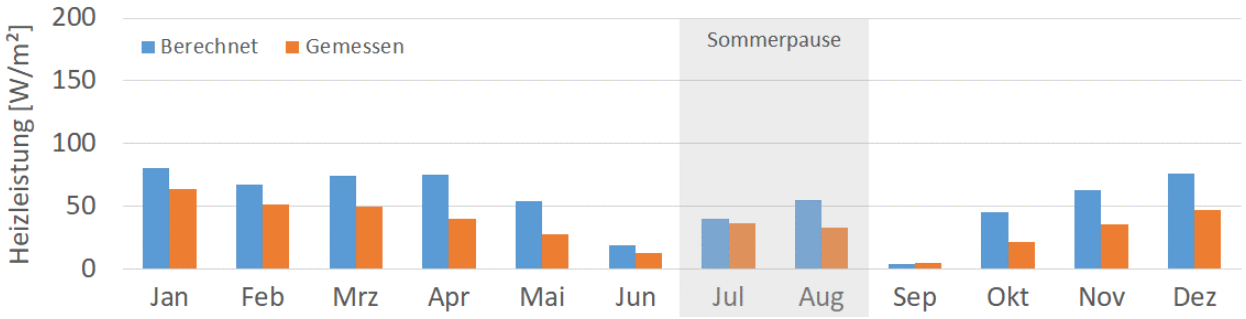

Fig. 90: The calculated monthly heating output for pool 3 compared to the measurement data from 2016.

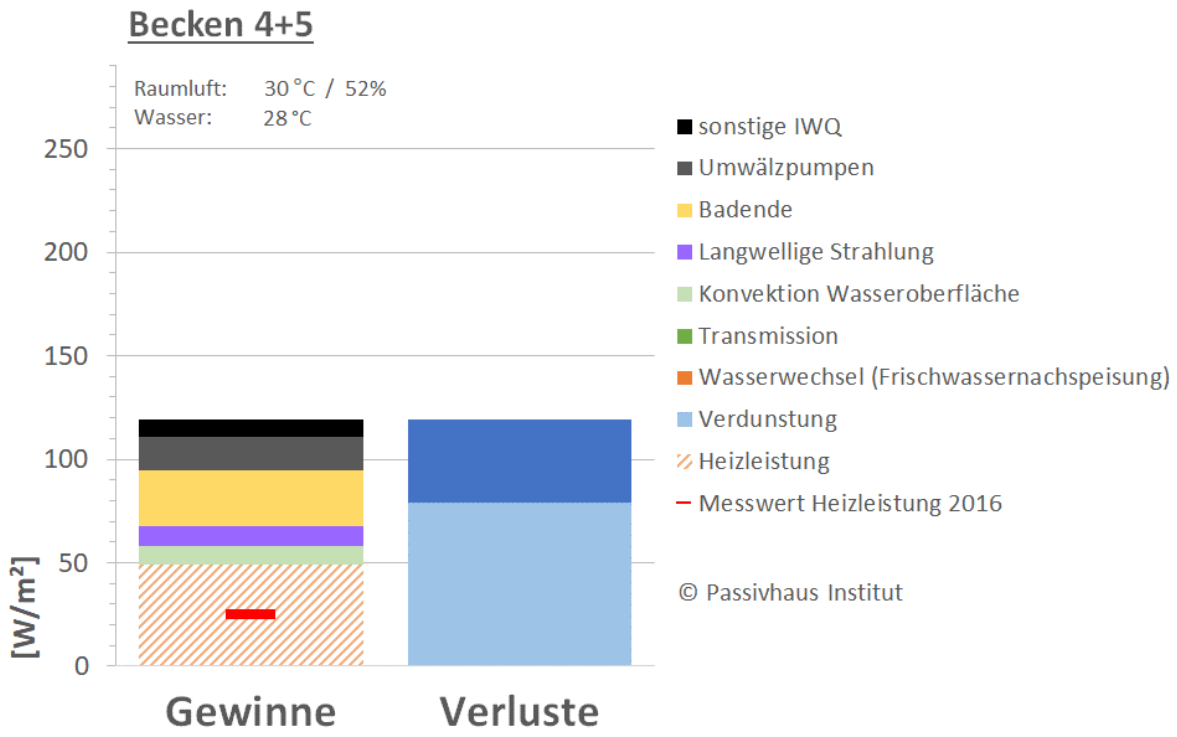

Fig. 91: Calculated energy balance for pools 4 + 5 under the measured operating conditions of the Year 2016 (except summer break July and August). (Note: The effects of heat recovery from the wastewater as well as the fill water from the rinse wastewater treatment are taken into account in the fresh water make-up).

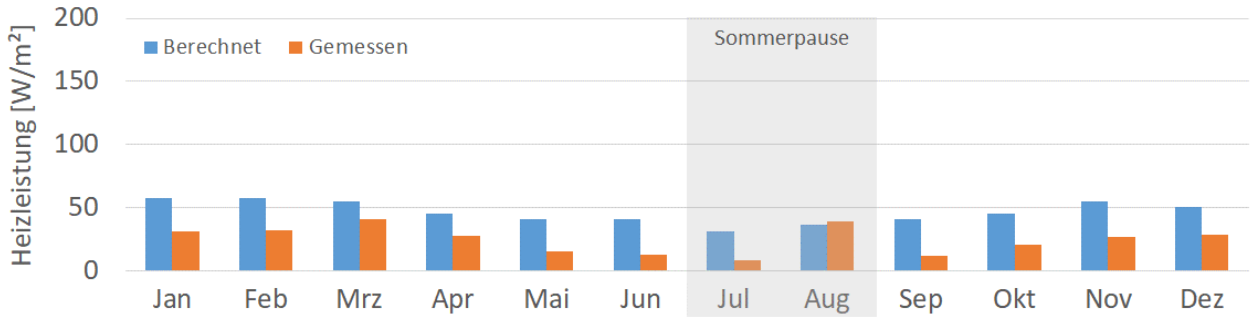

Fig. 92: The calculated monthly heating output for pools 4 + 5 compared to the measurement data from 2016.

In general, the specific heating consumption for swimmer pools is generally lower than for non-swimmer, fun and leisure pools (see also [Gollwitzer et al. 2015]). On the one hand, this is understandable due to the lower temperatures (typically 28 ° C, for leisure pools 30-32 ° C), which are also associated with lower evaporation rates. In addition, swimmer pools have a lower load on people, which means that the circulating volume flow and the filter surfaces can be designed to be smaller, and consequently the specific fresh water consumption is also comparatively low. In Fig. 93 two energy balances are shown as an example, in comparison for a swimmer pool and a non-swimmer pool with 55% indoor air humidity. The guideline values from the previous chapters were used for this (e.g. Power requirement of the circulation pump, hygienic fresh water requirement, pool occupancy). These example cases serve as an indicator for the expected heating output for pools. In the example: approx. 50 W / m² or approx. 430 kWh / (m²a) for the sports pool and 80 W / m² or approx. 700 kWh / (m²a) for the non-swimmer pool. In addition, it can be clearly seen that the evaporation accounts for a large part of the heat losses, and that the heat sources in the water (by bathers and swimming pool technology) have a significant influence. The higher the electricity consumption of the pumps (and thus the waste heat to the pool water), the lower the heating requirement for the pool water - although the overall system can be inefficient. This makes it difficult to independently assess the efficiency of pool water heating based on consumption values, and thus the comparability between different bathrooms. The examples also make it clear that measures to reduce heating requirements, such as heat recovery or rinsing wastewater treatment, are particularly interesting for leisure pools.

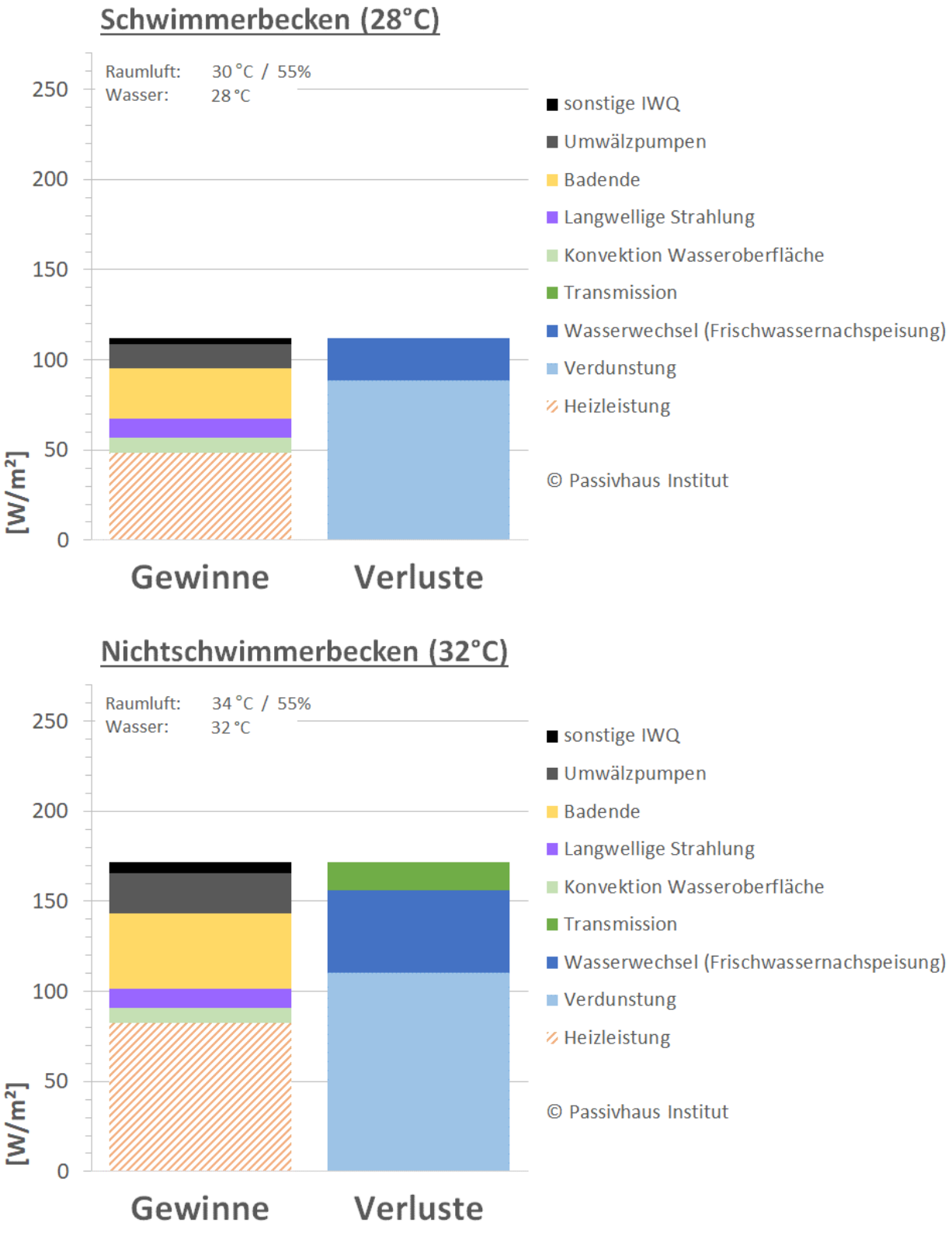

Fig. 93: Examples of energy balances for a swimmer pool and non-swimmer pool. The Specific heating requirements are generally higher for non-swimmer pools due to the higher water temperature and higher personal load.

8.6 Lippe bathroom: shower use

When planning an indoor pool, the number of sanitary objects must be specified. According to the KOK guidelines, the following figures result for the Lippe bath due to the water area of the Lippe bath (850 m²) (without sanitary rooms for staff):

- according to [KOK 2002]: 34 showers, 2 women's toilets, 1 men's toilet and 2 urinals
- according to [KOK 2013]: 29 showers, 3 women toilets, 2 men toilets and 3 urinals With 33 showers, 3 women toilets, 2 men toilets, 2 urinals and 2 separate toilets, the LippeBad is in the order of magnitude of the guidelines.

A flow measurement was carried out on site for the analysis of the shower usage in the Lippe bathroom and protocols of the shower fitting software were evaluated via remote access. The flow of three shower heads was measured on January 11, 2017 by collecting the water in a bucket and draining it. There was a flow of approx. 6 l / min. This was a very good confirmation of the good value from the product data.

Herrenduschen Messung 11.1.2017				
	sec	Liter	l/min	Mittelwert l/min
Dusche a	30,38	3,00	5,9	
	30,31	2,90	5,7	
	30,35	2,80	5,5	
	30,34	3,13	6,2	
	30,29	3,05	6,0	5,9
Dusche b	30,50	3,30	6,5	
	30,41	3,40	6,7	
	30,50	3,40	6,7	6,6
Dusche c	30,63	3,45	6,8	6,8
				6,4

Fig. 94: Shower flow measurement and measurement log

In the Lippe bathroom, various valve data are recorded using the Aqua software from Franke. The software could be viewed and meter readings remotely. Since the counters at 65,536 (eg 65,536 seconds running time, corresponds to 18.2 hours) jump back to zero, only short evaluation periods were possible. From 5 December until 12.12.2016 the values of all 63 fittings were read at noon on working days. The following diagram shows the distribution of the runtimes between public showers, staff showers and washstands / toilets.

The evaluation for the public showers shows an average shower duration of 4 minutes per visitor. The staff showers run on average 18 minutes a day. The fittings' shutter speeds were mostly set to 30 seconds for public showers. If one uses the exemplary flow rate of 6.4 l / min, the result is pro