Passivhaus Institut

Passive house indoor pool Bambados
Monitoring

Passive House Institute, August 2015

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1 introduction

1.1 Bambados passive house indoor pool pilot project

In June 2007 the Bamberg City Council decided to build a new indoor pool. The old listed indoor pool ("Hallenbad am Margaretendamm") was in need of renovation and renovation with a necessary expansion of the swimming areas was not economical. Therefore, the decision was made to build a new indoor pool and to close the old pool. The choice of location with a direct connection to the stadium pool (outdoor pool) should also increase the attractiveness of the new indoor pool. When planning, particular emphasis was placed on family friendliness, sportiness and ecology.

The Stadtwerke Bamberg are responsible for the operation of the swimming pools in Bamberg. The overall planning of the bath was carried out by a planning office. In order to ensure the future of the bathroom with low operating costs and at the same time consistently pursue the goal of ecology, the decision was made to strive for a very good efficiency of the entire building with the passive house concept. For this reason, Stadtwerke Bamberg commissioned the Passive House Institute Darmstadt to provide comprehensive energy advice including an energy balance and subsequent monitoring. The aim was to build a passive house indoor pool as a pilot project and thus enable the bathroom to be operated with high energy efficiency. For this purpose, the Passive House Institute has further developed an energy balance calculation (multi-zone PHPP). With the help of this energy balance, both the building envelope and the technical building equipment could be optimized. After the completion of the bath, an operational optimization of the system technology and an evaluation of the consumption data was carried out by the Passive House Institute as part of the monitoring.

Planning began in mid-2006 and construction began in the second quarter of 2009. On November 25, 2011, the Bambados was officially opened. The construction costs of the entire bathroom amounted to approximately 31.8 million euros net [StadtwerkeBA 2015].

After the implementation of the Bambado and the Lippe bath in Lünen as pilot projects, a wide range of experience can be used for future passive house indoor pools, which will result in lower costs and even greater energy savings. The aim of this report is to pass on the knowledge gained from Bambados.

Figure 1: Aerial view of Bambados during the construction phase ; Photo: Adolf Nüßlein (In the foreground on the right is the adjacent stadium b ad to see)

Figure 2: Exterior views of Bambados: Northeast, West , Northwest

Figure 3: Exterior views of Bambados: east, southeast

1.2 What is a passive house indoor pool?

Passive house stands for energy efficiency and a sustainable building concept.
This means that a given use of the building should be made as energy-efficient as possible. What is possible or useful? The possible changes and evolves with every project. In any case, it makes sense to take measures that are economical over the life cycle. In the passive house, energy efficiency affects not only the heating of the building, but all of the energy consumption in the building.

For residential buildings and other non-residential buildings such as schools and offices, there have long been criteria / limit values for passive houses (criteria on www.passiv.de). Other uses such as archives, museums, laboratories, fire stations, etc. were also realized as passive houses. The use of indoor pools can be very different: from the small school swimming pool with 50 hours of use per week to large leisure pools with 110 hours of use per week and other offers such as slides, spas, etc. For this reason, it would not be expedient to measure everyone against the same total limit. Rather, the optimization process is based on weighing individual measures to increase efficiency.

The basic passive house concept of energy efficiency and high comfort can be transferred to the indoor pool, as the basic investigation [Schulz 2009] has shown. It is important to analyze the desired use with all associated energy consumption and that

Then coordinate the concept. It has been shown that the passive house with a very good building envelope significantly reduces heating energy consumption and at the same time enables further measures to be saved compared to standard buildings. The higher interior surface temperatures increase the comfort for bathers and at the same time higher humidity levels are possible without condensate. Evaporation decreases and with it the energy requirement. The previous blowing of the facade in indoor pools is no longer necessary with thermally optimized passive house windows. As a result, the overall air volume flow can be reduced.

As it turns out, an energetically high-quality building envelope is the cornerstone of an efficient indoor pool - but it is not enough on its own. The optimization of the entire indoor pool operation (pool water heating, water treatment, ventilation) is important. This is where the great additional potential for energy optimization lies. When planning passive house indoor pools, the following aspects should therefore be considered [Gollwitzer 2011]:

- Very well insulated and airtight building envelope
- High minimum surface temperatures (window frame, glass edge)
- Zoning according to temperature ranges + internal thermal separation of the zones
- suitable air flow in the hall
- needs-based ventilation (reduce the amount of recirculated air, control sensors in the secondary zones)
- Ventilation duct networks and bath water circuits optimized for pressure loss
- Reduce evaporation (internal circulation at night, increase humidity as much as possible)
- suitable design of the pumps for the given operating points
- energy-efficient use of electricity in all areas of the building

After planning, construction and operation also offer the opportunity to reduce energy consumption. The following aspects are important when realizing passive house indoor pools:

- Quality assurance in the execution of the building envelope
- Airtightness test
- Building technology: Operation as possible according to specific needs (possibly deviating from design values according to standards)
- Quality assurance for the implementation of control technology
- Optimization of the control in operation

Further information on passive house indoor pools is available free of charge at www.passiv.de and www.passipedia.de: Basic research on passive house indoor pools [Schulz 2009] and reports on the Lippe Bad in Lünen: [BGL 2011], [Peper / Grove -Smith 2013]

2nd Project description

Table 1: Important key figures of the Bambado

Bambados in numbers	
Number of people (projected)	1,100 pers./d
Gross floor area (GFA) approx.	13,500 m²
Energy reference area (EBF)	10,743 m²
Gross volume (BRI)	93,500 m²
Pool area inside	1,742 m²
Outside pool area	61 m²
Envelope surface of the building	19,420 m²
A / V ratio	0.21
Average U-value of the building envelope (including windows, thermal bridges and reduction factor against soil)	0.164 W / (m²K)
n50 value	0.07 h_{1}
q50 value	0.21 m / h

use

The Bambados offers the following uses:

- Sports area: Sports pool (8 lanes of 50m each), can be divided and some with lifting floors
- Teaching area: 2 teaching pools in separate rooms, one of them with lifting floor
- Leisure area: leisure pool with grotto and bubble beds, parent-child pool
- Slide area: 2 slides
- Roof terrace: with outdoor pool
- Sauna area: 5 sauna cabins, 1 steam bath, 2 infrared cabins
- Leased area: used as a spa area
- Sauna garden: several sauna cabins, relaxation room and unheated bathing pond
- Gastronomy: for the leisure area and sauna area
- Changing rooms and showers: separate for sports pools, leisure pools and saunas
- Administrative area: offices
- Technical area: building technology + swimming pool technology
- Combined heat and power plant: as a separate building

As a pilot project for a passive house indoor pool, the focus was initially on advising the main building, ie external saunas, pools and CHP buildings are not part of the passive house.

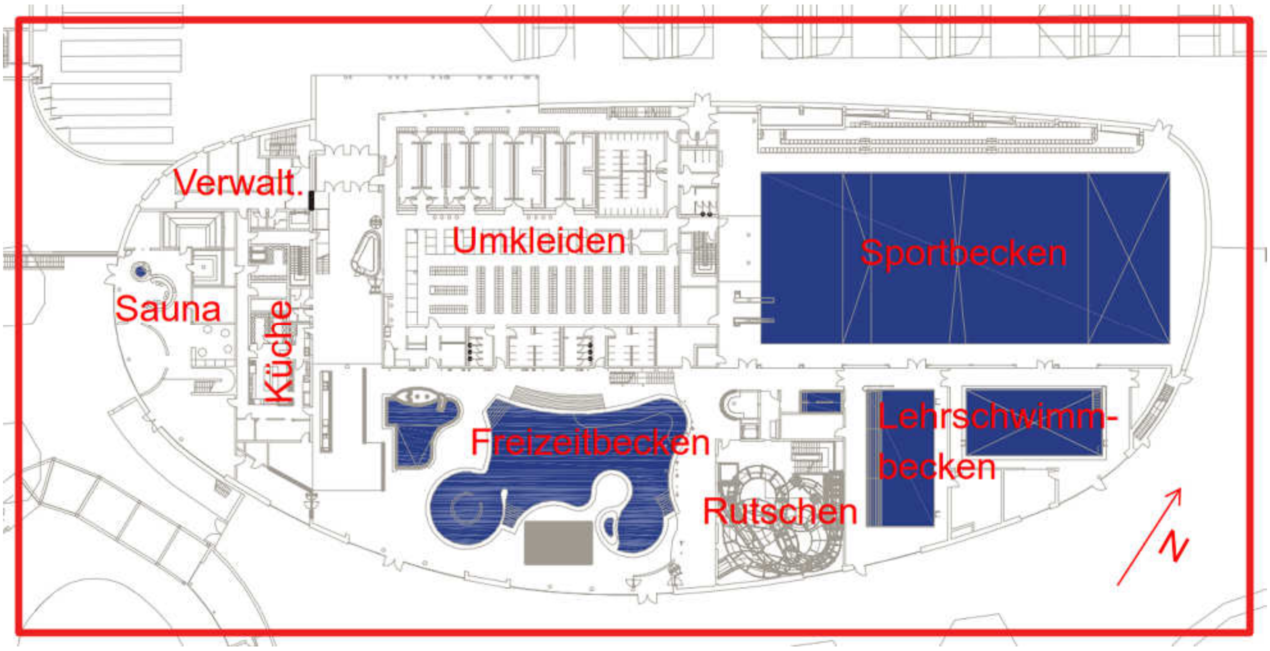


Figure 4: Usage areas on the ground floor

Figure 5: **Interior photos: foyer, parent-child-Bec ken, sauna, slides (Photos: Stadtwerke Bamberg)**

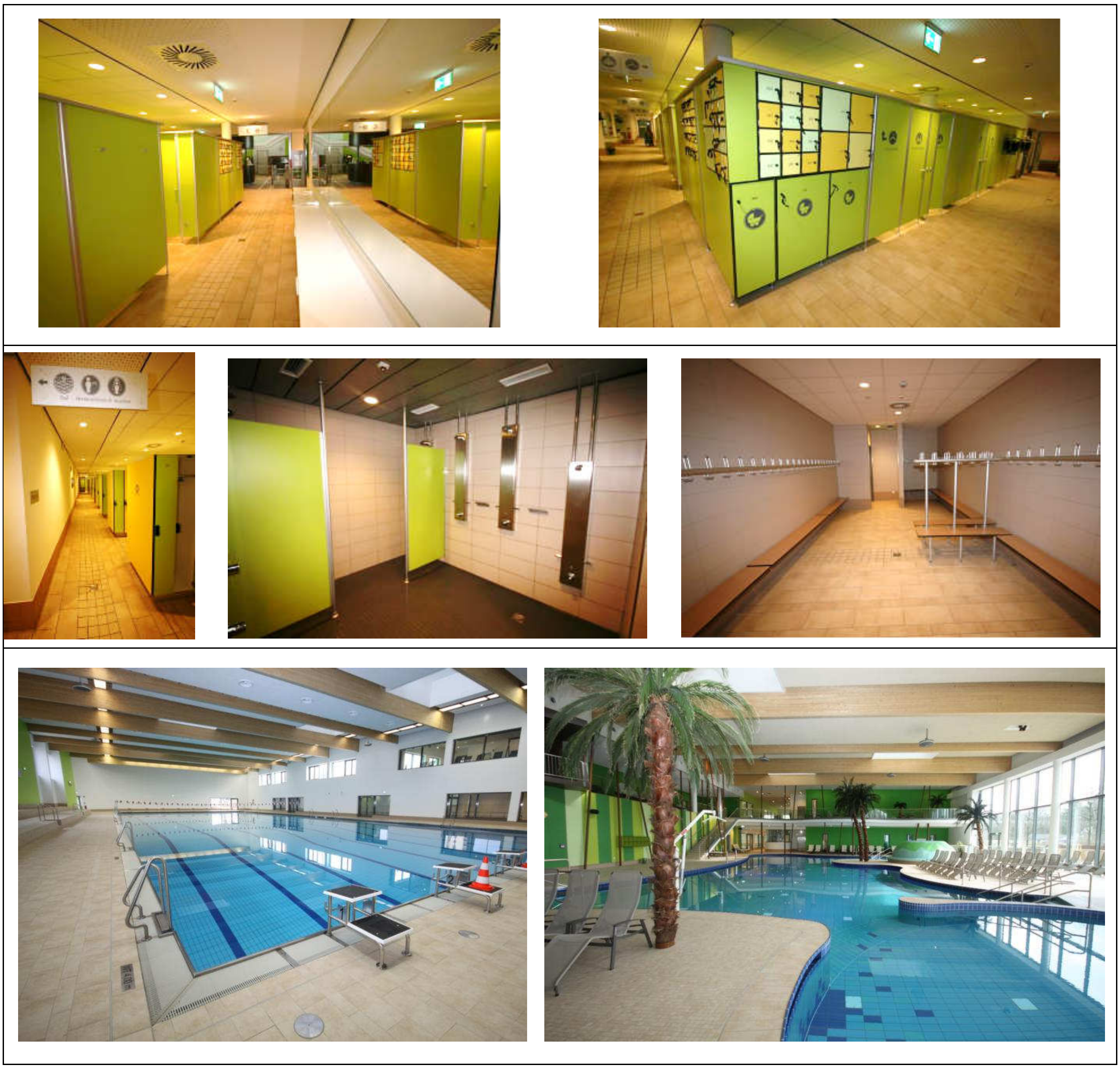


Figure 6: **Indoor shots:** **Changing rooms,** **To shower,** **Sa mmel changing room,** **Sports pool,** **Leisure pool**

Building design

The Bambados is a compact building that has a small amount of glazing to the north and opens to the open area to the south with generous glazing. In the north are the hall with sports pool, the changing room, the administration and the separate spa area. The leisure and educational swimming pool area faces south-east. The sauna zone is oriented to the southwest. Due to the size and the optimized oval shape of the building, the building has a very favorable A / V ratio (surface to volume). The pool areas are illuminated by attached shed roof hoods.

founding

Most of the building has a basement (technical level). The foundation was made with bored piles. The floor slabs in the basement and in the non-basement area are insulated. The bored piles at the edge of the building have accompanying insulation. The large footprint of the building would be suitable for an insulation apron solution. Unfortunately, this advantage could not be used because the necessary "thermal lake" in the ground below the building cannot occur due to high groundwater.

Building envelope

The thermal building envelope has an all-round insulation layer. The regular component structures are summarized in the following table.

Table 2: Component structures in Bambados

	Overall component		Insulation layer		
	thickness [m]	U value [W / (m²K)]	material	thickness [mm]	λ [W / (mK)]
Outer wall	0.55	0.135	mineral wool	300	0.035
Outer wall against soil	0.55	0.137	XPS	300	0.042
Base plate	0.75	0.142	XPS	300	0.045
Roof (wood)	0.38	0.097	EPS / XPS + mineral wool	280 + 80	0.035 / 0.040
Roof (concrete)	0.61	0.095	EPS / XPS	360	0.035

Figure 7: Wall insulation, filigree facade anchors u nd wooden attic construction

The design completely circumvented two weaknesses that were frequently realized in the building envelope of indoor pools: there is a swim-in tunnel to the outdoor pool, which starts in a wind-protected outer zone and thus does not penetrate the thermal envelope. By integrating the slide (from the 1st floor to the basement) into the building volume, significant transmission losses were avoided.

Airtightness

Airtightness in indoor pools is particularly important for building physics reasons. The airtight layer is largely formed by the building material concrete. In addition, attention had to be paid to the connections of the windows and the wooden roof and the joints of precast elements. The airtightness measurement gave an n_{50}- Value of 0.07 h_{1} or a q_{50}- Value of 0.21 m / h.

window

The client selected aluminum profiles for the mullion-transom facades and the window frames. Aluminum windows have the advantage of high surface temperatures at the edge of the glass compared to comparable wooden or PVC windows. PVC frames were only used in the basement. The glazing is implemented with triple thermal insulation glazing (average: Ug = 0.54 W / (m²K), g-value = 0.49).

Sun protection

Movable external sun protection was installed for the south-west sauna zone and the south-facing leisure area. In the sauna area, shading is useful for this special project (internal heat gain, large glazing). Shading in the leisure area is probably not necessary for the room temperatures, but can even slightly increase the heating requirement even with poor control. In practice it has been shown that there are technical devices (access control) that must be protected from direct sunlight, so they should not be positioned directly in front of a glass facade.

Heat

The swimming pool was planned and built together with an adjacent supply building with wood gasification (CHP). This local and renewable energy is another aspect that contributes to the overall ecological concept of the Bambado. In addition to the CHP (230 kW thermal, 150 kW electrical output), there are three peak load boilers (gas) with condensing technology each with 450 kW heating output. As was shown early in operation, the energy consumption of the building is so low that there is no continuous decrease in output for the CHP.

The heat is conducted from the heating center to the indoor pool via a local heat pipe. There is a common ring line inside the building, which supplies the individual heating circuits for domestic hot water, pool water heating and space heating. Further heat is generated by exhaust air heat pumps from the ventilation units. In addition, the waste heat from the cooling for the cold pools and the cold rooms is used with the help of a buffer storage to heat the pool water.

The building is mainly heated by supply air. Individual warming benches in the sports and sauna area are temporarily heated.

sauna

Since the usual direct electrical heating of sauna cabins leads to a high primary energy requirement, the saunas are heated with gas. There are already gas ovens available on the market. These work according to the dark radiator principle and require a separate room directly next to the sauna cabin and an exhaust duct through the roof. These rescheduling measures are brought to a late stage in that neighboring sauna cabins are jointly supplied by a technical room. It should be mentioned that these burners can be heard from the sauna cabin, but this did not lead to any complaints from the guests. The infrared cabins and the steam bath are electrically heated.

Ventilation swimming pools

Ventilation is the elementary part of the system technology that ensures air quality and dehumidification. In the Bambados, the sports area including slides and the leisure area are each supplied with two ventilation devices, so-called double axes. The devices are located in a technical room on the second floor. From there, insulated outdoor and exhaust air ducts (insulation thickness 76 mm) lead directly to the roof. Both rooms of the teaching pool are supplied by a ventilation device that is located in the basement. The ventilation units are special units for indoor pools with multi-stage heat recovery of the ThermoCond R 37 type from Menerga.

Ventilation sub zones

In addition to the five ventilation units for the swimming pools, there are six ventilation units for the secondary zones, all of which are in the basement:

- Changing rooms / showers on the ground floor
- Foyer / administration
- Warehouse / technology
- Kitchen / ancillary rooms
- Sauna EG / OG
- Changing room sauna upper floor

In these areas, a directional overflow was largely implemented in order to reduce the volume flows. The outside and exhaust air ducts for all devices in the basement open into collecting ducts that lead through the ground to a ventilation tower that is integrated in the sauna garden. The collecting duct is insulated inside the building with 100 mm insulating panels.

Bathing water technology

The central task of an indoor pool is to provide clean and warm water for swimming. The operators decided early on in the planning phase for the relatively young technology of ultrafiltration. The cycle of pool water circulation includes the following stations:

- Overflow channel
- Splash water tank
- Flocculation
- Prefilter
- Activated carbon
- Ultrafiltration
- Heating by the heat pump of the ventilation unit
- Heating by regular heating circuit
- pH correction
- UV radiation
- Chlorination (chlorine gas bottles in the neighboring swimming pool building)
- Marble gravel (pH correction)
- Horizontal inflow into the pool

At night while the bath is closed, an internal circulation is carried out by taking the water directly from the pool and not passing it over the overflow channels. Both modes of operation are shown in Figure 90.

In addition to the pure swimming pools, the Bambados also has attractions such as slides, massage jets, bubble loungers and a flow channel. Additional pumps and a side channel blower were installed for these attractions.

lighting

The design of the facade is adapted to the use of solar gains and can be shaded if necessary. The facade is largely closed from northwest to northeast. The south facade with predominantly floor-to-ceiling glazing offers good daylight use in the sauna and leisure area. The sports area, the leisure area and the foyer are supplied with daylight via shed-like roof structures located in the roof. In many areas, the electrical illuminance is reduced accordingly with daylight control when the outside brightness is high. There are three brightness sensors on the roof (orientations east, south and west).

T5 fluorescent tubes or LED lamps were largely used in the building. This enabled good energy efficiency to be achieved with a calculated average (weighted by area and illuminance) of 2.37 W / (m² * 100lx).

3rd measuring technology

A building management system (GLT) is installed in the Bambados to record and control the technical operating conditions. This was set up and maintained by the company Aumasys GmbH. Numerous additional counters and sensors have been installed for scientific monitoring, for example for more detailed consumption and precise temperature and humidity detection. In addition, the PHI set up its own M-Bus system to read sensors in all eleven ventilation units for detailed energetic assessment. The most important measuring groups are described below.

3.1 Temperature and humidity measurements

3.1.1 Indoor air

The continuous air temperature and humidity measurement in the swimming pools and the other rooms of the Bambado is carried out at almost all points using temperature-humidity combi-sensors of the type Hygrasgard RFTF from the manufacturer S + S Regeltechnik GmbH with measurement inaccuracies of ± 0.1 K and ± 3% rh in the relevant area.

3.1.2 Calibration

Since the temperature and humidity readings are to be used for scientific monitoring, calibration measurements were carried out at all accessible measuring points on June 11th and 12th, 2012. For this purpose, data loggers of the type HOBO Pro v2 from Onset, previously calibrated in the climate chamber of the PHI, were used. These were attached to the respective sensor housings for measurement (measurement interval: 5 minutes) for at least one hour in order to be exposed to the same conditions as exactly as possible. This enabled 27 measuring channels to be checked and calibrated. The measured data were then compared and offset values were determined. The GLT measurement data used were offset against the corresponding offset values.

Figure 8: left: wall sensor For temperature and r elative humidity, right: wall sensor with data logger for calibration (temporary)

3.1.3 Window surface temperatures

The surface temperature of the window is measured at six points on the edge of the glass using surface sensors with an aluminum housing from S + S. Four of the six sensors could be calibrated, the other two are not accessible.

3.1.4 Outside air and global radiation

The outside air conditions and global radiation are recorded with the help of a weather station approximately in the middle of the roof approx. 2.5 m above the roof level. A weather and radiation-protected "Hygro-Thermogeber compact" from the manufacturer Adolf Thies is used for air temperature and humidity measurement. Global radiation is measured using a CM 11 pyranometer from Kipp & Zonen BV.

Figure 9: Weather station on the roof of the Bambado s

3.1.5 Pool water temperatures

The water temperatures of the different pools are recorded using the continuously flowing chemical measuring cell Depolox Pool from the manufacturer Wallace & Tiernan GmbH. Comparative measurements carried out directly in the individual basins showed a very good agreement with the measured values of the measuring cells.

Figure 10: Chemical measuring cell for monitoring d it pool water

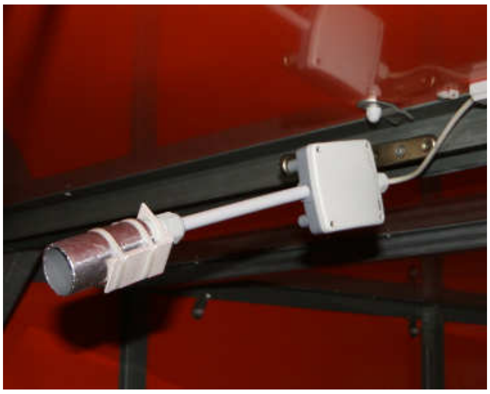
3.1.6 Cold water temperatures

As there was no permanent measuring point for the cold water temperature (drinking water), a temperature data logger with a contact sensor was installed on the pipe of the main tap for drinking water for the measuring time of the monitoring.

Figure 11: Temperature data logger for recording ng the cold water temperature (left), (right is the main water clock)

3.2 ventilation units

To record the conditions in the ventilation units, the manufacturer has installed temperature and humidity sensors as well as differential pressure sensors for recording the volume flow. In addition, positions of ventilation flaps and valves of the heating register and, if applicable, the heat pump are recorded. The air conditions within the various chambers (supply, exhaust, outside and exhaust air; supply air, if necessary, before and after the heat pump) of the ventilation units are additionally monitored by means of shielded temperature and humidity sensors of type EE21 from the manufacturer E + E Elektronik GmbH via the separate M-Bus -Measured network, since the manufacturer does not record all the quantities required for monitoring. The manufacturer has installed sensors of the type Sensirion SHT 75 for air temperature and humidity measurement in the exhaust air.



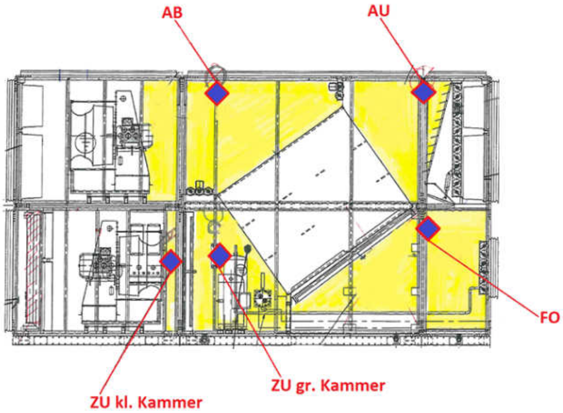


Figure 12: left: sensor for temperature and rela tive humidity with radiation shielding in one Ventilation unit, right: positions of the sensors in the S Cut of a ventilation unit

3.3 Consumption measurement

3.3.1 Power consumption

The electrical power consumption is recorded using commercially available electricity meters with a digital interface and is divided into the areas

- Electricity bath water technology
- Electricity ventilation
- Electricity lighting
- Strom Divers (for other technology and other consumers kitchen, sauna, administration, cash registers etc.)
- Electricity outdoor applications (sidewalk heating, ventilation unit outdoor sauna, outdoor pool with pool water technology, parking lot lighting & other outdoor lighting)

3.3.2 Heat consumption

The heat generated by the wood gas CHP plant, which is supplemented by natural gas boilers for higher heat consumption, is recorded individually for all consumers using a conventional heat meter with a digital interface. The heat consumption can be broken down into the following areas:

- Heat pool water heating
- Heat water heating
- Heat air heating (RLT)
- Warmth outside

3.3.3 Gas consumption

The three sauna cabins inside the Bambado and two sauna cabins in the sauna garden are heated with gas. Due to the low gas pressure, only one main meter could be installed. The following distribution of gas consumption was estimated based on the size of the cabins, the inside temperature, the insulation quality and the temperature difference to the surroundings: 70% of the energy is used for the outdoor saunas and 30% of the energy is used for the indoor saunas.

4th Energy balance calculation

The goal was to increase the energy efficiency of the building. Different energy flows mutually influence each other, particularly in the indoor pool. An energy balance is therefore irreplaceable for the optimization process during the planning phase.

The proven PHPP (Passive House Planning Package) had to be significantly expanded for the indoor pool. While the PHPP is a 1-zone model, several PHPPs were linked together for the Bambados (multi-zone PHPP). This makes it possible to map the different temperature zones in the building and to calculate the cross-heat flows and thus the total energy balance through iterations. Individual aspects were examined in more detail using dynamic building simulation (summer ventilation and shading).

During the planning phase, the energy balance was carried along, refined and was an important tool for optimizing the building. Different options and their effects could be examined. Based on these decision aids, the total energy requirement could be reduced step by step.

During the construction phase, the ventilation zone was changed briefly. Instead of continuing to track the energy balance, the available time was used to intensify the regulation of building technology - especially ventilation technology. The optimization then took place with the help of access to the measurement data via the building management system. The following table shows the different zones of the PHPP with the associated temperatures.

Table 3: The different zones of the PHPP with associated energy reference areas and temperatures

Zone	designation	EBF [m²]	projected target temperature [° C]	Max. temperature [° C]
1	administration and foyer	1,012	22	25th
2	sauna area	771	26	30th
3rd	Shower and changing rooms	1,410	26	30th
4	swimming pool	2,886	32	34
5	cellars	2,993	15	30th
6	pools (water)	1,671	28.5	30th

5 Evaluation monitoring

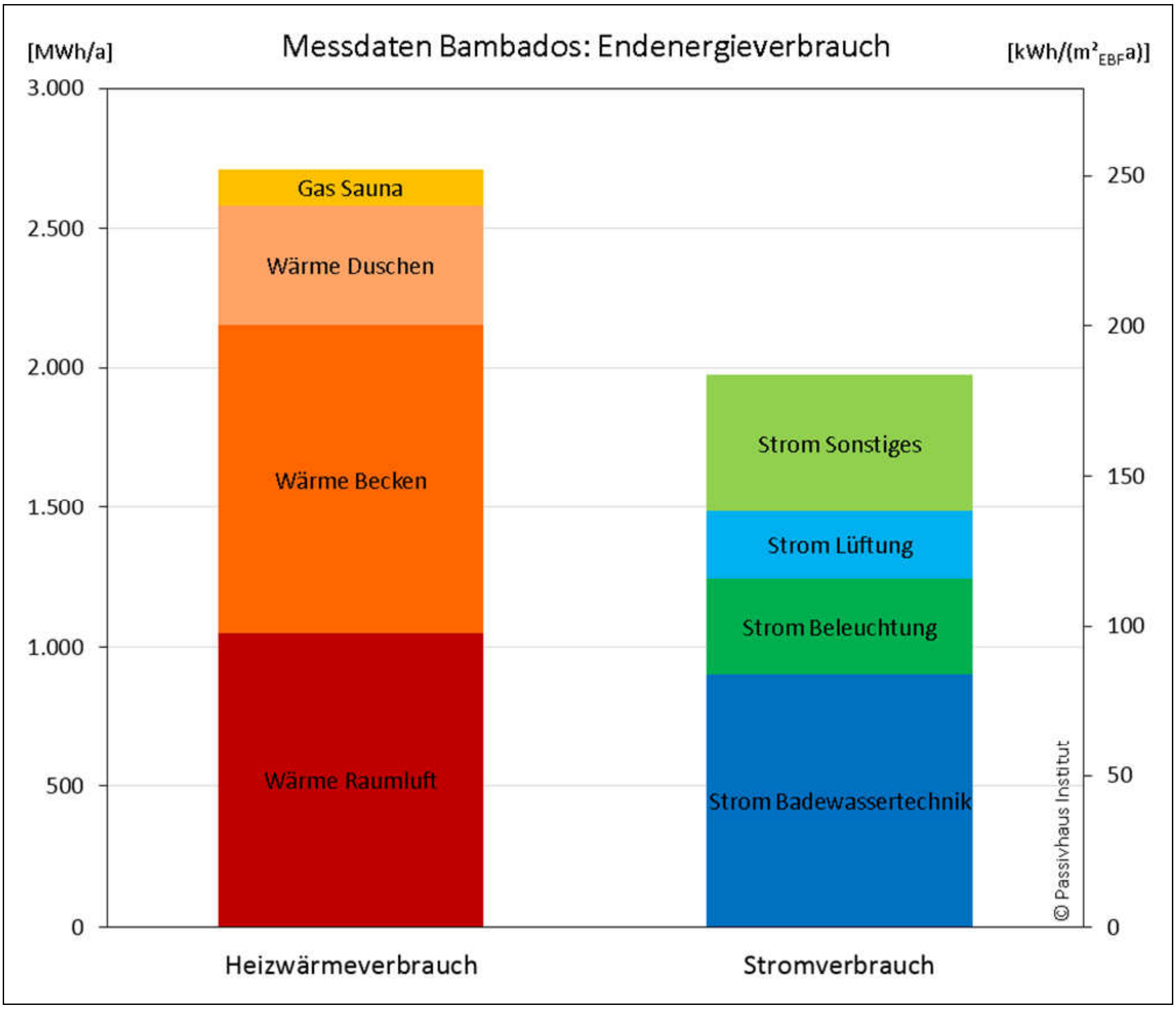


Figure 13: Composition of the year-end energy supply usage (May 2014 to April 2015) for the entire indoor pool (without outside areas) (EBF = energy reference area of the building)

The aim of the monitoring was to check the concepts and measures for increasing efficiency in practice. In addition, the monitoring served to check the modes of operation and the optimization of operations. Figure 13 shows the composition of final energy consumption. The heating consumption is 252 kWh / (m^2_{EBF} a) higher than the electricity consumption of 184 kWh / (m^2_{EBF} a). In the area of heating, consumption for heating the air and the pool dominates. The largest share of electricity consumption is generated by bathing water technology. Further potentials for this are shown in Chapter 5.10. Chapter "5 Monitoring Monitoring" first shows the total consumption (heat, electricity, water) and energy generation and then examines the various areas of the indoor pool in more detail. At the end of the report in chapter "6.1 Overall results", the consumption data of the Bambado are compared with the data from other baths.

5.1 Heating consumption

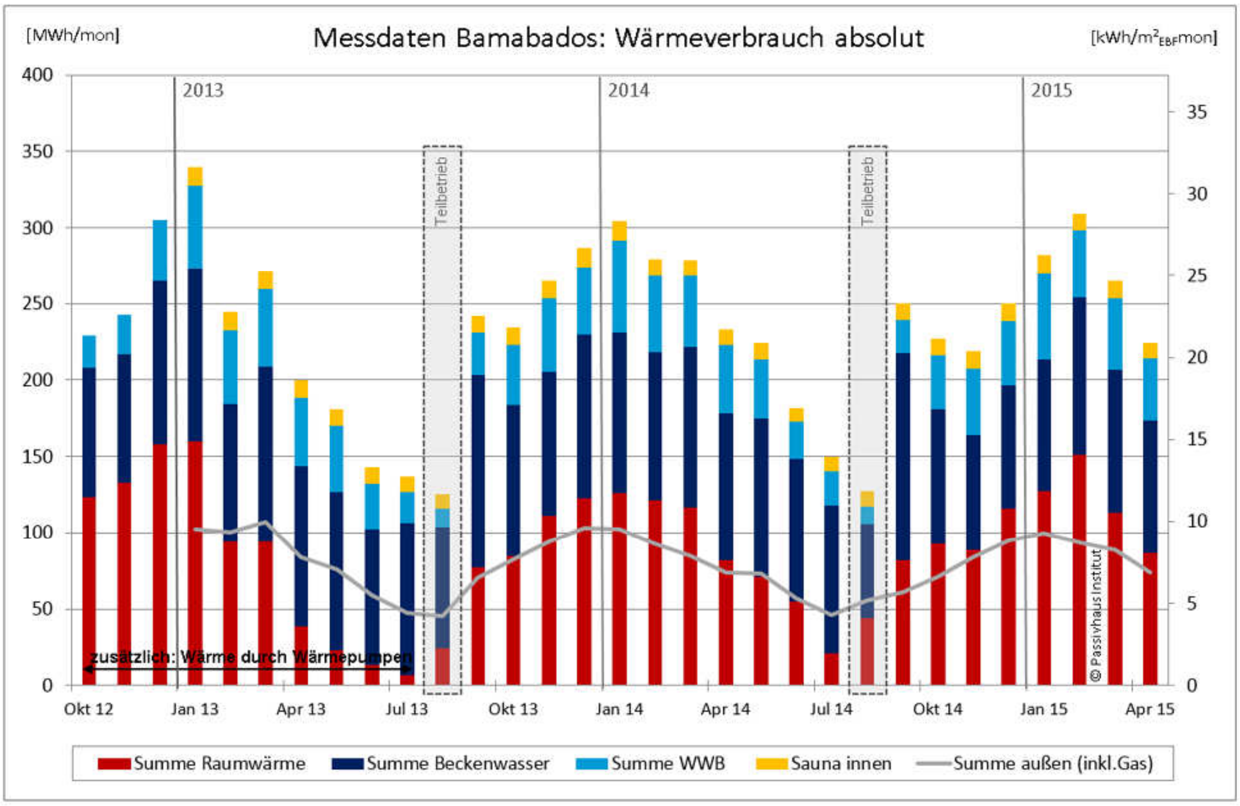


Figure 14: Monthly Heating consumption For there s complete bath (WWB = hot water preparation showers) Not shown It is the heating of the Sauna cabins.

As a pilot project, advice from the Passive House Institute at Bambados related to energy efficiency in the main building. Nevertheless, the consumption outside (e.g. sauna garden, outdoor pool) was measured and is shown in Figure 14 in addition. The seasonal fluctuations in energy consumption can be clearly seen.

5.1.1 Heating consumption for rooms

The rooms are almost exclusively heated by reheating the supply air. The heating energy consumption for the individual zones is very different. This is based on the different uses and target temperatures. As expected, the highest consumption is in the hall area with room temperatures of 30 to 32 ° C (see Figure 15, upper diagram).

The shower / changing room area and the kitchen require lower heating consumption (see Figure 15, middle diagram). The room temperatures of the changing rooms / showers are with 28 to 30 ° C significantly higher than in most other building uses. However, the zone is also heated by the adjacent swimming pools. It is striking that the heating consumption for the changing rooms / showers on the ground floor is significantly higher than the consumption for the

Changing / showering is upstairs. The background is the spatial association to the foyer with entrance doors on the ground floor. In order to reduce these cross-heat flows and to be able to individually control the temperatures in the changing area as well as in the foyer area, it would be advisable to separate the rooms.

Warm supply air is introduced into the changing rooms, flows into the showers and is discharged there as exhaust air. This concept has proven itself in practice and shows that an active overflow to the showers with reheating is not necessary. This saved both investment costs, space requirements and operating costs.

The heating energy consumption of the kitchen zone is based on the high air exchange without heat recovery through the exhaust hoods. There would be further potential here in the operation of induction hoods with cold supply air.

All other sub-zones (storage / technology, administration / foyer, sauna) have subordinate heating consumption (see Figure 15, bottom diagram). There are various reasons for this in the Sauna Zone: Increased internal heat gains from sauna cabins, common ventilation system for sauna cabins and anteroom (deviating recommendation see

5.8 ventilation secondary zones) and high solar gains due to large west-facing glazing.

The different needs of the zones result not only from the different target temperatures, but also from different internal heat gains and the location of the zone in the building. While the temperature grading of changing rooms - showers - swimming pool proves to be favorable, a better thermal separation, for example between the sauna zone and the administration area, would be recommended. This has the advantage that the room temperatures can be better controlled. If this reduces unnecessary cross-heat flows, this can also lead to a further reduction in the total heating consumption.

Figure 15 (upper diagram) shows two changes in the operating mode:

- February 2015, ventilation unit leisure: The target temperature of the leisure hall was increased from 32 ° C to 34 ° C at the request of the guests. As a result, the heating requirement increases more than twice.

- February 2015, ventilation unit sport: Due to a maintenance error, the ventilation unit runs for 13 days with an increased volume flow (approx. 22,000 m³ / h instead of approx.
  10,000 m³ / h). This increases the ventilation heat losses and the heat consumption is significantly higher during this time.

The high energy consumption of the sports area in June, August and September 2014 must be due to a technical defect, because despite the valve being displayed, the heater was closed. This is clearly confirmed by the exhaust air temperature.

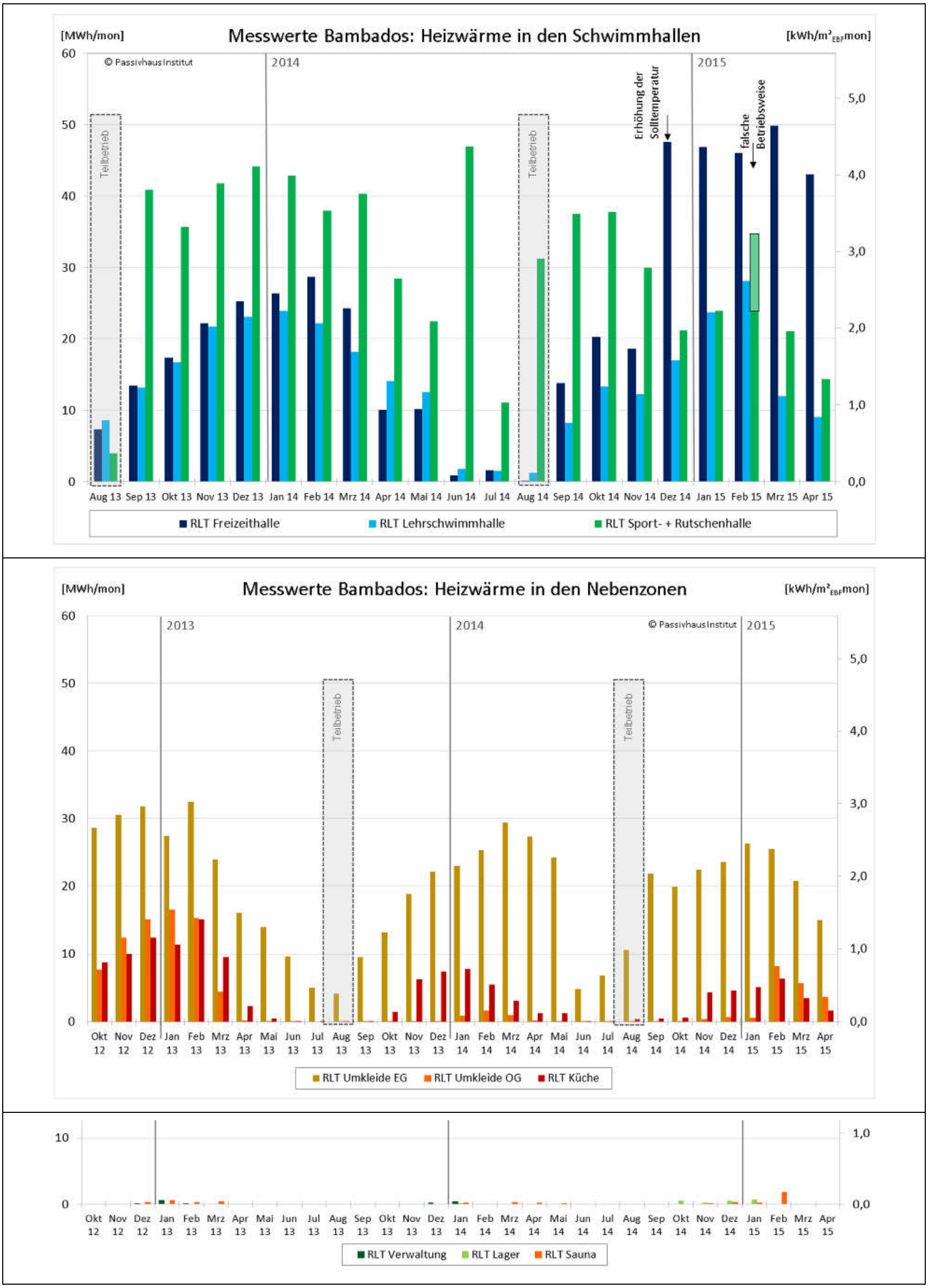


Figure 15: Monthly heating consumption for He The rooms are divided into zones (all three diagrams with the same scaling of the y-Ac hse)

Type of heating

In addition to heating via the supply air, there are heated benches next to the sports pool and in the sauna anteroom. These were not chosen to heat the rooms, but to provide a pleasant surface temperature. In operation, it was found that the warm benches were almost never switched on in the sports area and only in phases in the sauna area. It can be assumed that a difference in the surface temperature can be perceived. However, there was no question or complaint in the Bambados if the heated benches were not heated. There is nothing wrong with it energetically if part of the room heat is covered by heated benches. However, care should be taken to ensure that increased heat consumption can occur if the heat banks are switched on at times when there is no heating requirement.

The passive house concept results in high surface temperatures on the inside of the components. For this reason, underfloor heating could be dispensed with in the Bambados. Sometimes the floor temperature is raised by the warm basement below. Practice shows that there is nothing left to be desired in terms of comfort.

The sauna cabins are heated by gas stoves, the steam bath is heated by surface heating (floors + benches) and by steam (electrical). In the period from August 2013 to April 2015 inclusive, the heating energy consumption of the surface heating in the steam bath was on average less than 0.15% of the total heating energy for room heating.

5.1.2 Heating energy consumption for pool water

The pool water is heated by the CHP or the gas peak load boilers. There is also the option of heating the water via the condenser and refrigerant subcooler of the heat pumps. In the period shown, heating takes place exclusively from CHP or peak load boilers.

The comparison of the measured consumption is shown separately in Figure 16 for the individual hall areas. The absolute heat consumption can be read on the left y-axis, which is scaled equally for all three halls, and the specific heat consumption per m² pool area can be read on the right y-axis. In the leisure and educational swimming pool halls, more energy is used to heat the pool than to heat the air. Only when the target temperature of the indoor air in the leisure area has increased from 32 ° C to 34 ° C does the relationship turn partially.

The situation is different in the sports sector. The sports pool is operated at a set temperature of 27 ° C and therefore has extremely low heating consumption. This also coincides with the measurements in the Lippe Bad in Lünen [Peper / Grove-Smith 2013]. Various causes will probably work together here:

- Since the basement is warmer than the pool water, there are no transmission losses, but gains.
- The pool water in the pipe network and in the surge water tank is heated by the warm cellar.

- The fresh water is already warmed up by the warm cellar and the waste heat from the pumps. Due to the low target temperature of the pool, only a small or no temperature difference has to be overcome.

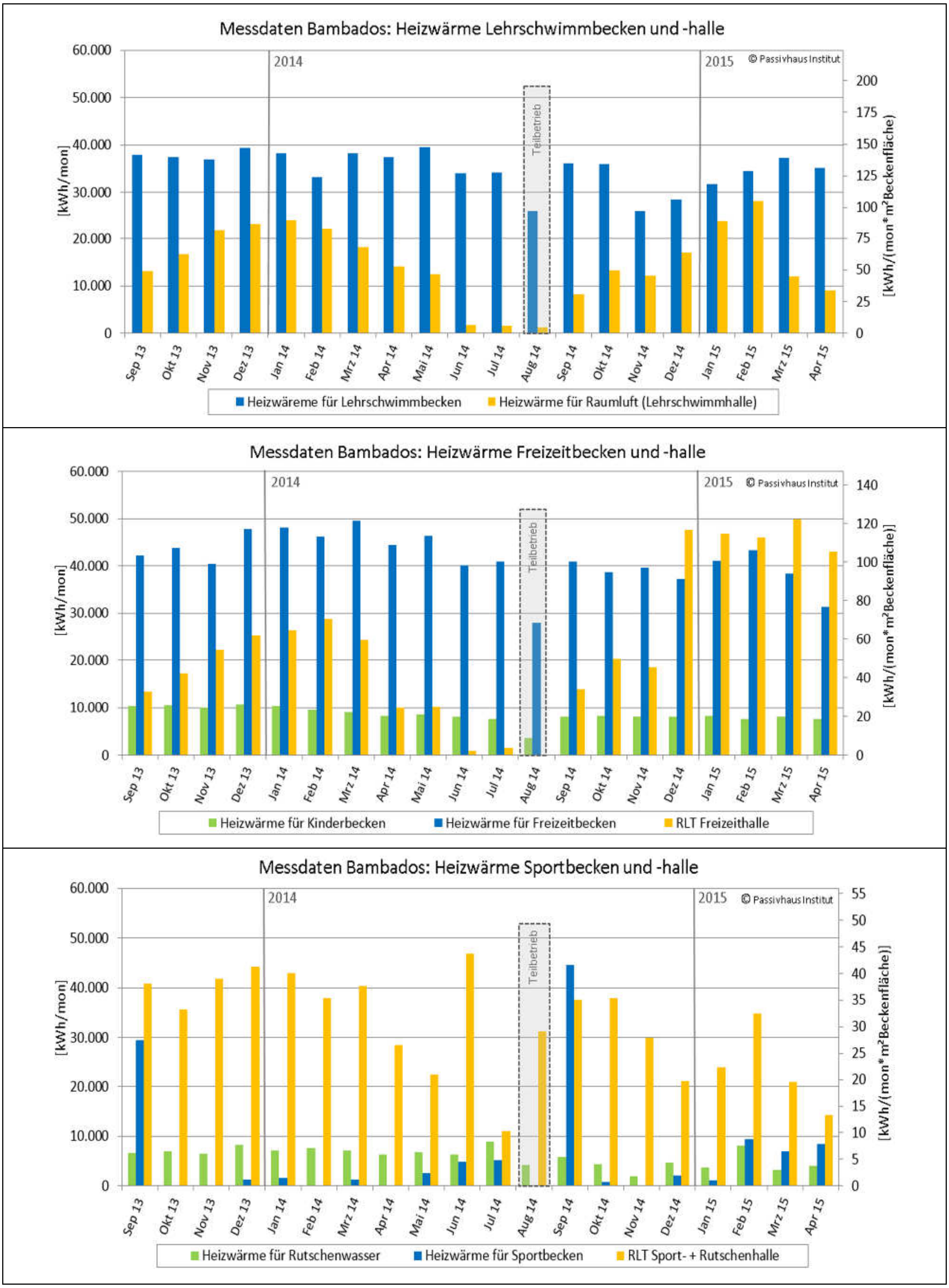


Figure 16: Comparison of heating energy consumption for Pool and indoor air divided between the three Hall areas. (The left y-axis with the absolute values is in all three Diagrams scaled equally on the right y-axis is the consumption per m² pool area shown.)

The heat consumption of the pools shows no seasonal fluctuations. This means that the amount of energy required to heat the fresh water is subordinate. This also coincides with the calculations: approx. one fifth of the energy is used to heat the fresh water and approx. four fifths are used to “maintain” the pool temperature. Figure 17 shows the change in heating consumption for air and pools for all halls. Some changes in the operating mode can be clearly seen (see explanations below). Other changes (e.g. in evaporation) have no discernible effects even in hourly data.

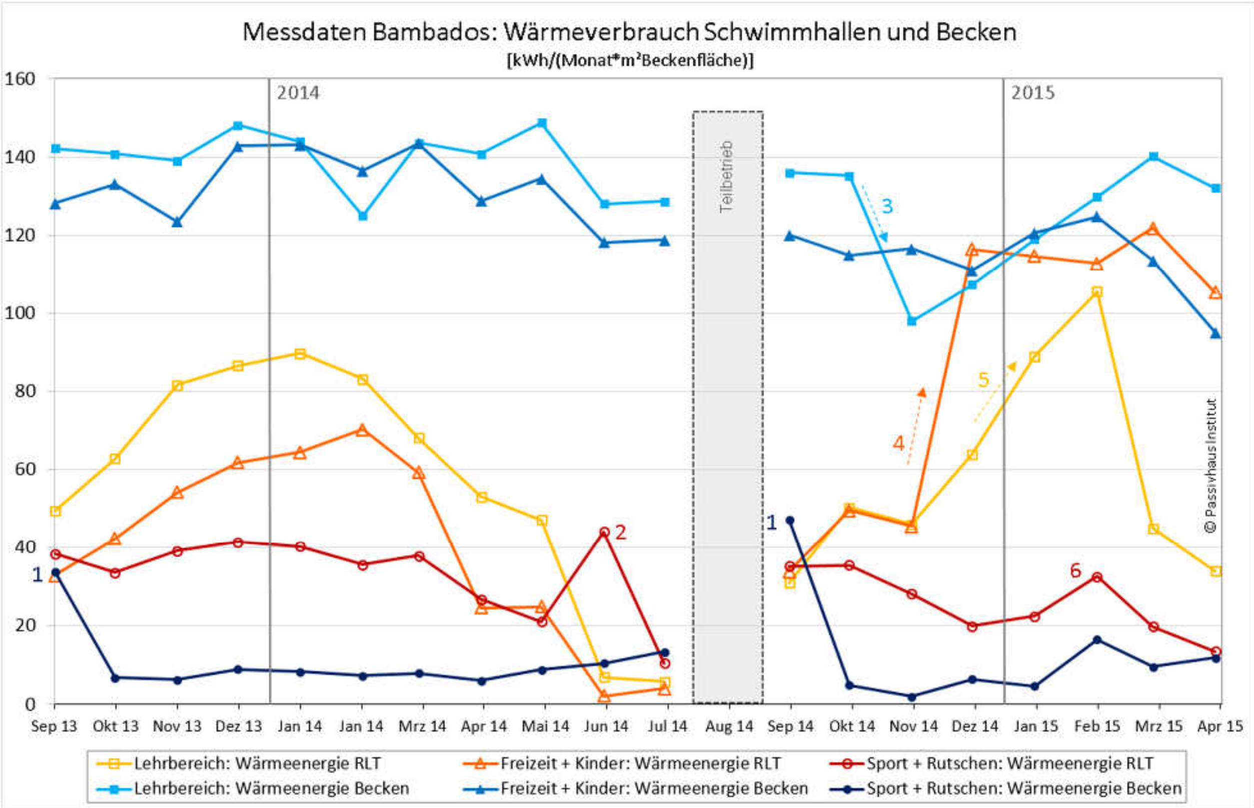


Figure 17: Comparison of the heat consumption of the Swimming pools and pools (explanations of changes see below)

Explanations to Figure 17 (assigned by number):

1. Increased heat consumption to heat up the pool after a summer break
2. Technical defect, so that the air was partially heated to 36 ° C
3. The temperature of the teaching pool drops, which results in a lower heating consumption.
4. At the request of the guests, the target temperature of the leisure hall was raised from 32 ° C to 34 ° C. As a result, the heating requirement increases more than twice.
5. The regulation of the ventilation devices in the teaching pool is not carried out correctly, which can be seen from the fact that an increased volume flow was sometimes used without the need for dehumidification. As a result, heating energy consumption also increases significantly.

6. After the maintenance of the ventilation units, one of the sports ventilation units was operated with an increased volume flow. Thereby the ventilation losses and the Heating consumption.

Part of the filter backwashing water can be reused by treating the sludge water. This reduces water consumption and heating consumption at the same time. Unfortunately, no data is available for a detailed evaluation.

5.1.3 Heating energy consumption for domestic hot water (showers)

Warm water is mainly used for showering and in smaller quantities for the kitchen and for cleaning. Since there are three independent systems for water heating in the Bambados (see Chapter 2), the water and energy consumption for the areas of leisure showers, sports showers and sauna showers can be evaluated in detail. When interpreting, it must be taken into account that the hot water preparation of the sauna also supplies the kitchen.

Figure 18 shows that the absolute water consumption, especially in the leisure and sport showers, is subject to seasonal fluctuations, with the consumption being higher in winter. This correlates with higher visitor numbers in winter. The question arises whether there are other influences. Figure 19 shows the water consumption per person: there is a slight tendency towards higher consumption, ie longer shower time per person in winter. The water consumption in the sauna showers fluctuates less strongly (approx. 10 - 21 l / person at 60 ° C) and is clearly below the shower water consumption of leisure and sports guests (approx. 15 - 44 l / person at 60 ° C), even though the hot water requirement of the kitchen is included in the determination of the water consumption of the sauna showers.

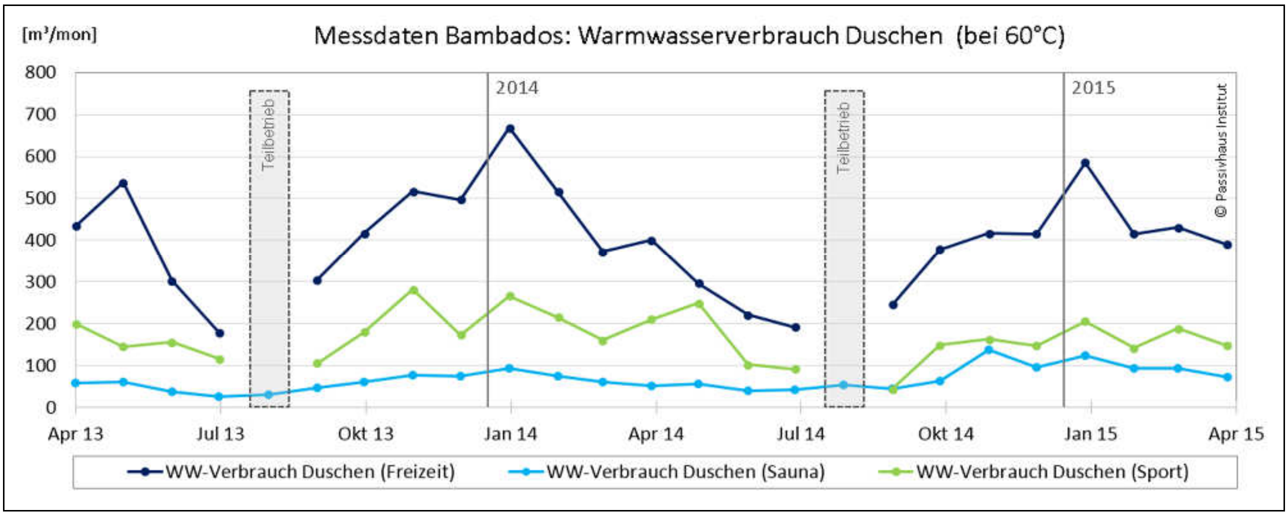


Figure 18: Absolute hot water consumption for the Domestic hot water preparation (use mainly for showers)

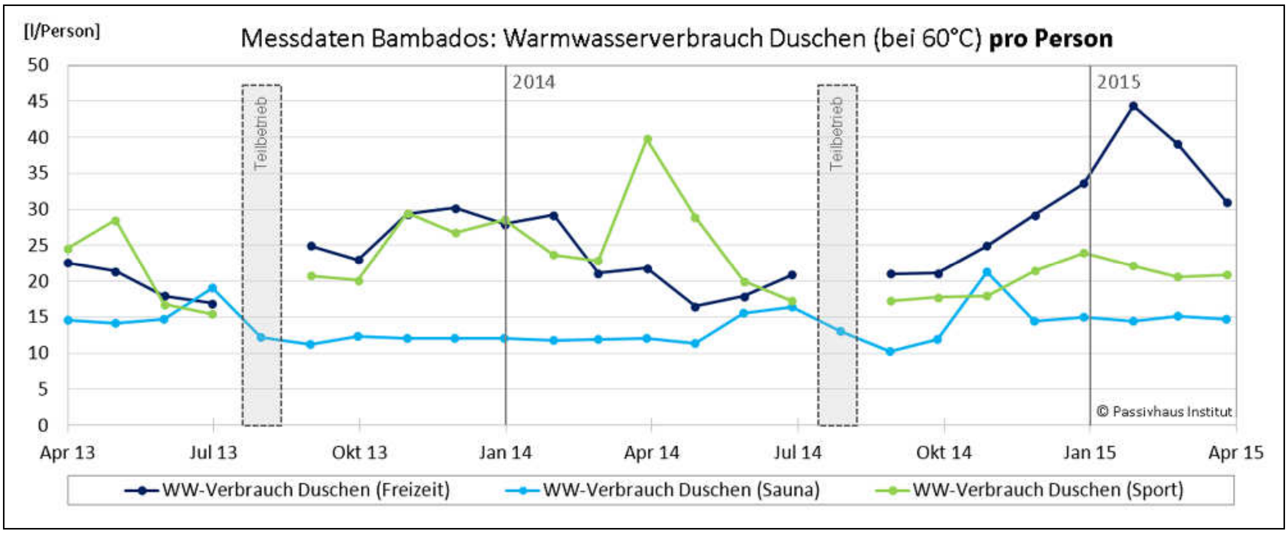


Figure 19: Specific hot water consumption for domestic hot water preparation (use mainly for showers)

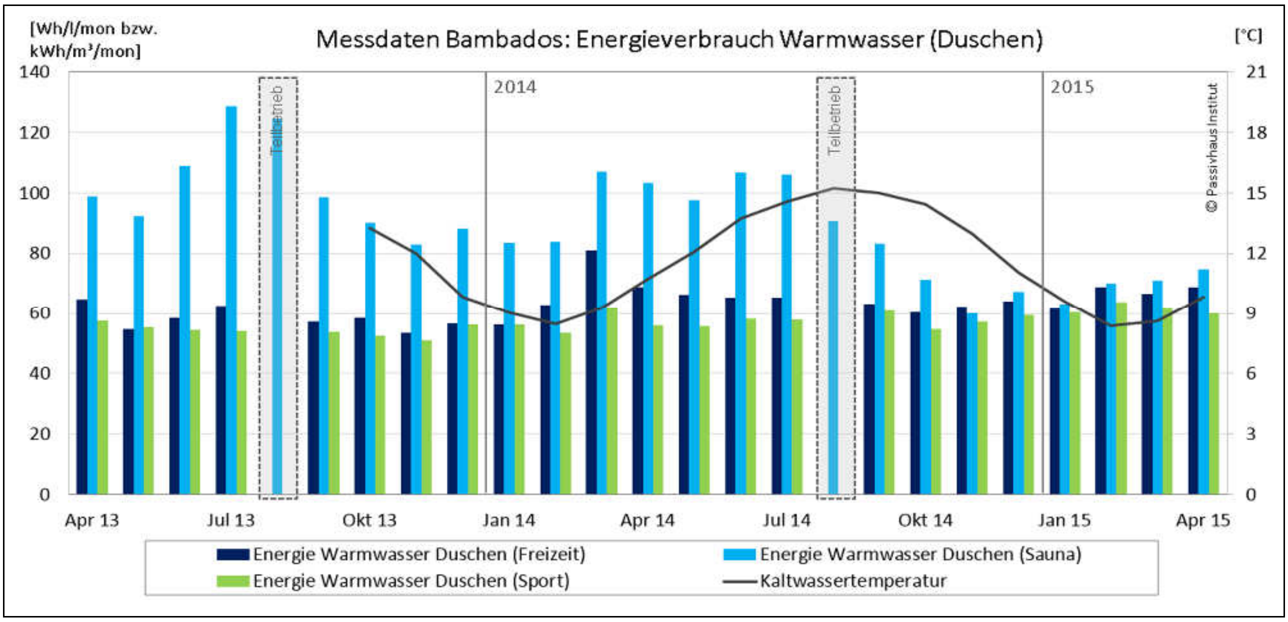


Figure 20: Energy consumption for domestic hot water water heating (use mainly for To shower)

The specific energy consumption for heating the hot water is shown in Figure 20. It shows a relatively uniform energy consumption per liter between 50 and 70 Wh / l or kWh / m³. The outlier is the hot water preparation of the sauna until autumn 2014. After that, the number of visitors to the sauna area increases and with it the efficiency of the hot water preparation. If one compares the total hot water consumption of the sauna hot water preparation with the specific energy required (see Figure 21), the opposite is the case. With lower water throughput, the specific energy consumption increases, among other things, due to storage and distribution losses. If the water throughput increases, the efficiency of the system increases. This dependency is less obvious when it comes to hot water preparation for sports or leisure showers, Distribution lines is lower. In any case, care must be taken to minimize distribution and storage losses.

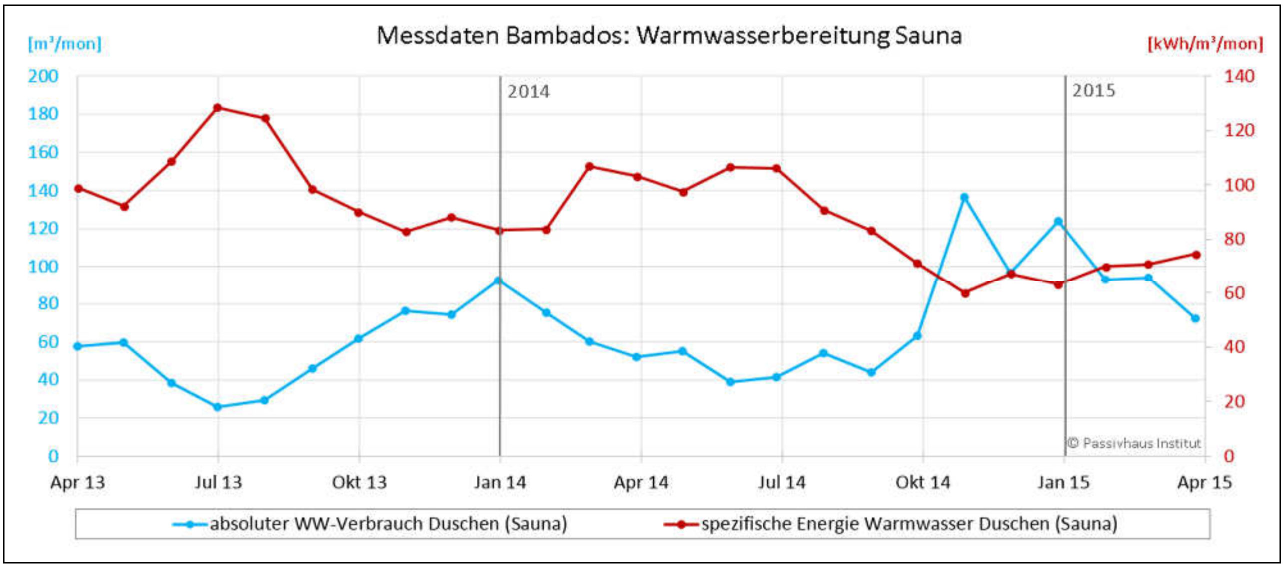


Figure 21: Hot water preparation for the showers i m sauna area (also contains the Hot water for the kitchen)

Based on the experience of other projects, a sensor was retrofitted to the cold water inlet in the house connection room. The evaluation shows that the cold water temperature is subject to strong seasonal fluctuations (approx. Between 8 ° C and 15 ° C, mean value 12 ° C). However, there is no correlation between cold water temperature and energy consumption. This means that various influences overlap. The cold water is partially preheated on the way to the heat exchanger by the ambient air, and the storage and distribution losses are probably more important than the cold water temperature. A shower time of 3 minutes, a tap with 8 l / min flow and thus a water consumption of 24 liters per person at 40 ° C were used for the energy balance. Only the amount of water was measured, with which the hot water storage tanks are filled. Roughly estimated, this results in an actual water consumption of 40 to 50 liters of hot water at 40 ° C per person. For a more precise analysis, a measurement of six shower heads was carried out on July 28, 2015 (see table below). At the push of a button, the showers run on average around 26 seconds with a flow of 14 l / min. This results in an average calculated shower length of approx. 3 minutes. The deviation of the water consumption from the planning is clearly attributable to the flow of the showers. Optimization would be desirable. In 2015, six shower heads were measured on site (see table below). At the push of a button, the showers run on average around 26 seconds with a flow of 14 l / min. This results in an average calculated shower length of approx. 3 minutes. The deviation of the water consumption from the planning is clearly attributable to the flow of the showers. Optimization would be desirable. In 2015, six shower heads were measured on site (see table below). At the push of a button, the showers run on average around 26 seconds with a flow of 14 l / min. This results in an average calculated shower length of approx. 3 minutes. The deviation of the water consumption from the planning is clearly attributable to the flow of the showers. Optimization would be desirable.

During the measurement it was striking that individual showers deviate greatly in both the length of the interval and the flow. The function of the showers is checked every day due to the severe calcification of individual shower heads. The measurement took place immediately before the revision. In order to reduce the scaling of the shower heads, it is planned to install a descaling system. The flow rate may increase again as a result.

Table 4: Measurement of shower water quantities and times on six exemplary shower heads

	Amount of water [l]	Shower interval [s]	calculated flow [l / min]
Showers free time			
	6.0	26.6	14
	1.8	25.9	4th
	6.5	26.3	15
Showers sport			
	1.3	5.7	14
	6.0	26.5	14
	6.5	27.2	14

5.2 Power consumption

The Bambado is supplied with power - as is the operation of the bath - by the Bamberg municipal utility. Part of the electricity consumed is provided by the attached wood gas CHP and the photovoltaic system on the roof. The different consumption areas are shown and analyzed in the following section. Unless otherwise noted, the measurement period for electrical power consumption extends from August 2012 to April 2015.

5.2.1 Total consumption and generation

The annual electricity consumption for the main building and all outdoor applications (outdoor pool, outdoor sauna, parking lot etc.) amounts to 2,095 MWh in the year from May 2014 to April 2015, corresponding to a specific 195 kWh / (m^2_{EBF} a).

The electricity is measured with sub-meters, separated according to the areas of pool water technology, ventilation, lighting, various (other technology and other consumers including kitchen, sauna, administration, cash registers etc.) and outdoor applications. The annual electricity consumption is shown in Figure 22 compared to the electricity generated by the photovoltaic system on the roof and the associated wood gas CHP in the same period.

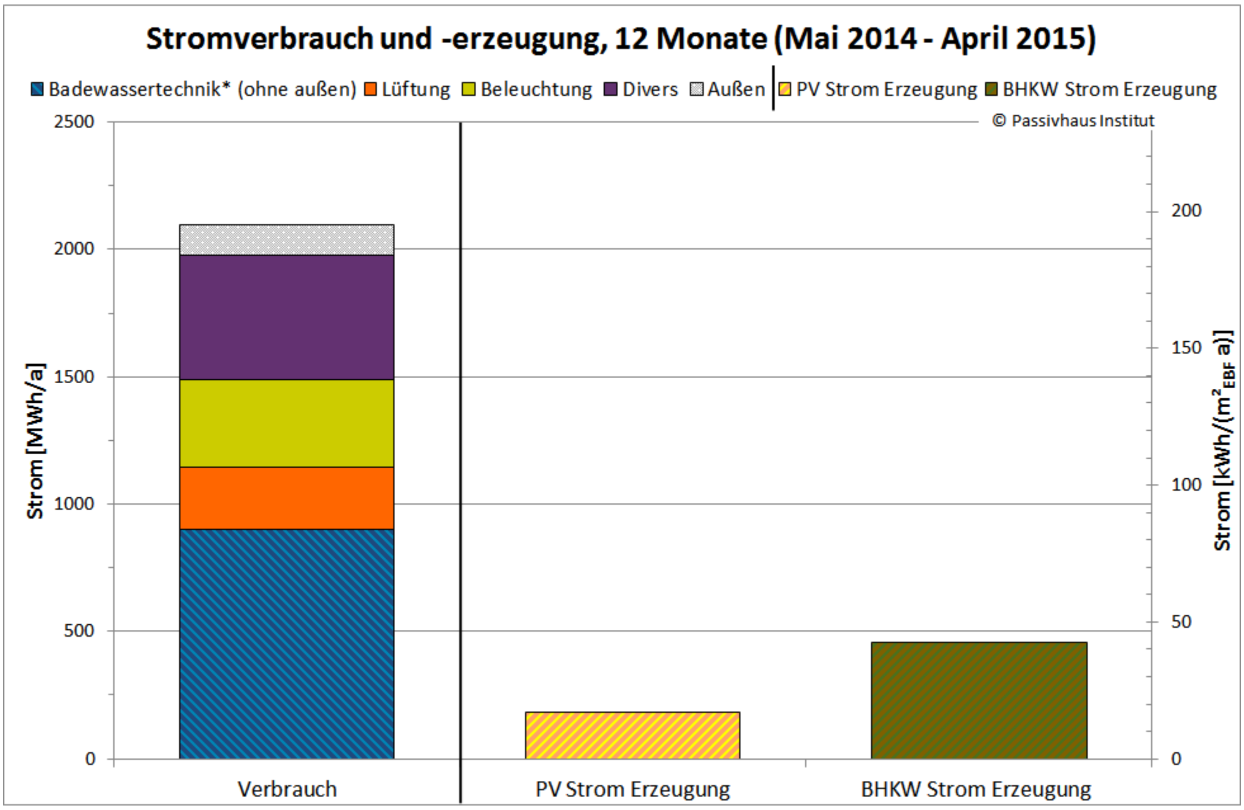


Figure 22: Total electricity consumption different ch applications in buildings and Outdoor area (outdoor pool, outdoor sauna, parking lot et c.) for the year from May 2014 to April 2015 compared to the generation of electricity by photovoltaics and wood gas CHP. All of the electricity generated was immediately in the Bambados consumed. (* When using pool water technology it is a audited projection. See chapter 5.2.2)

The areas of ventilation and lighting are detailed direct measurements of electricity consumption. All applications outside the building envelope are also measured directly and include a surcharge for the bathing water technology of the outdoor pool, which was determined on the basis of a tracked planning value, since this was not measured separately. The consumption for the "Divers" sub-area is composed of meter readings and a marginal remainder, the

indirectly as a difference to total consumption. The

Bathing water technology was not recorded separately by electricity meters (see section "Electricity consumption by sub-area"). The specified annual and monthly totals correspond in all cases to the real measured total consumption of the bath.

Electricity generation totaled 640 MWh in the year from May 2014 to April 2015, of which 185 MWh were for solar power and 455 MWh for power from the CHP. The remainder was obtained from the local power grid. The electricity generated (PV and CHP) was used directly in the Bambados, according to the operator. In terms of connection technology, however, feeding into the local power grid is also possible.

Figure 23 shows the monthly course of the total electricity consumption of the different application groups. Periods in which the annual revision and no regular operation took place are highlighted in gray.

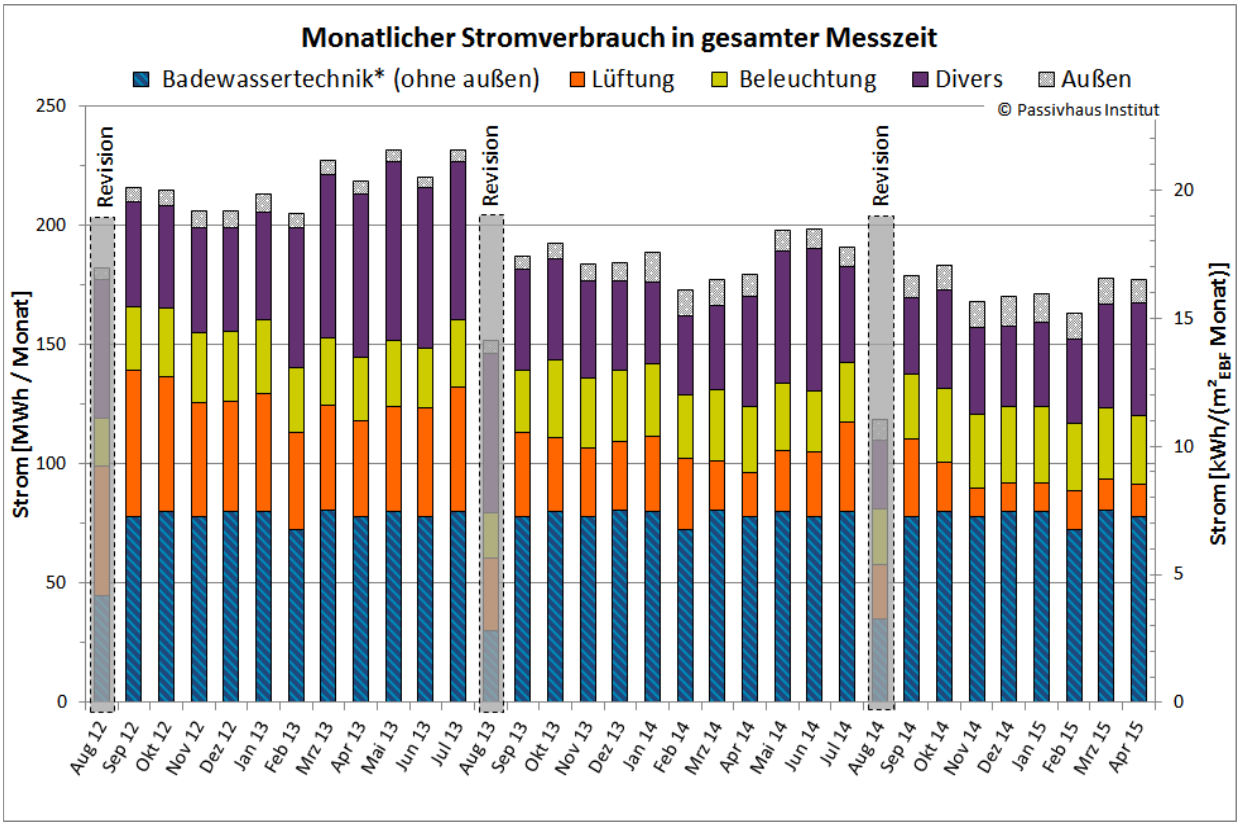
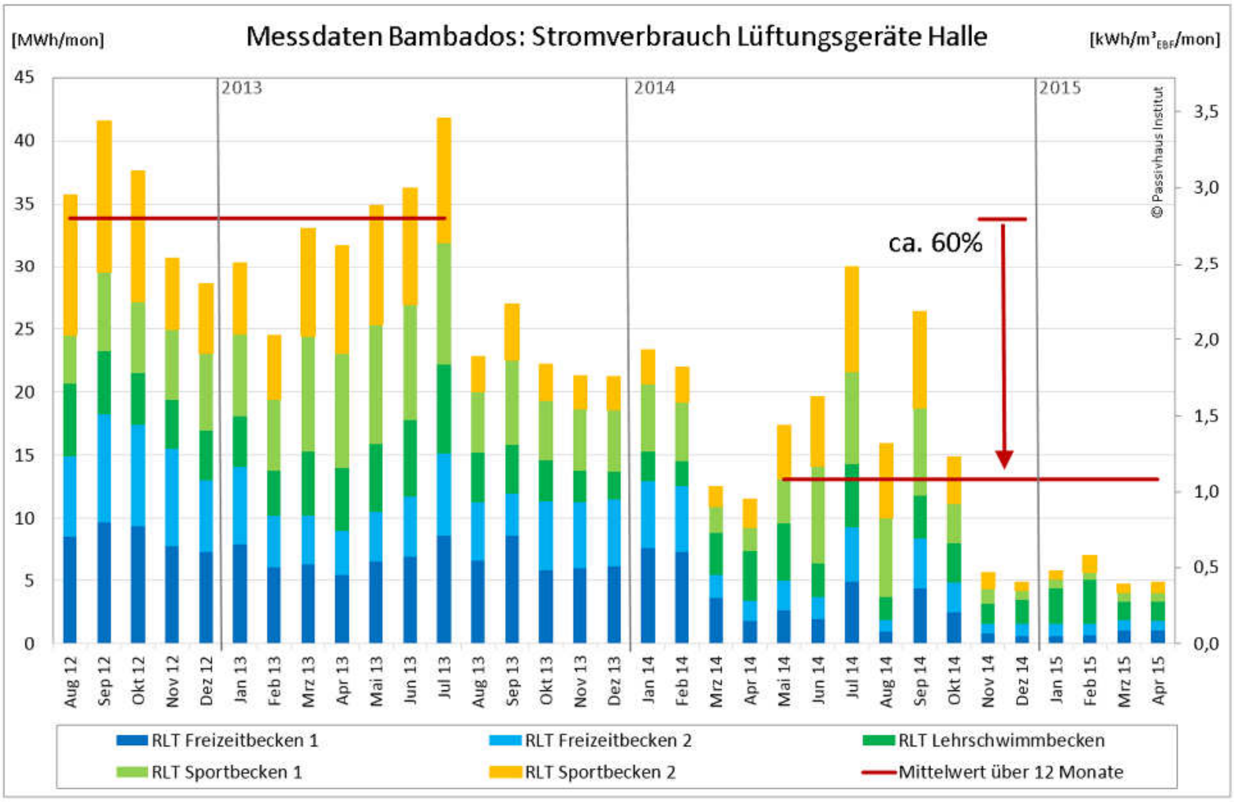


Figure 23: Monthly total electricity consumption below differ according to applications in Buildings and outdoor areas (outdoor pool, outdoor sauna, Parking lot lighting etc.) for the period from August 2012 to April 20 15 (* The consumption of the bathing water technology is a tested one Projection. See Chapter 5.2.2)

5.2.2 Electricity consumption by sub-area

ventilation

As described in Chapter 2, the building has eleven ventilation units with heat recovery with a possible maximum total volume flow of up to 210,000 m³ / h. The power consumption of all devices, including the manufacturer's measurement technology, control and regulation, are measured in detail. As can be seen from the monthly electricity consumption of the ventilation units in the swimming pools and the adjoining areas in Figure 24, their electricity consumption could be significantly reduced by optimizing the controls. The details for successful ventilation optimization are described in 5.7 "Ventilation hall". The total electricity consumption of all ventilation units was 244 MWh / a in the year (May 2014 to April 2015). This corresponds to 12% of the total electricity consumption in this period.



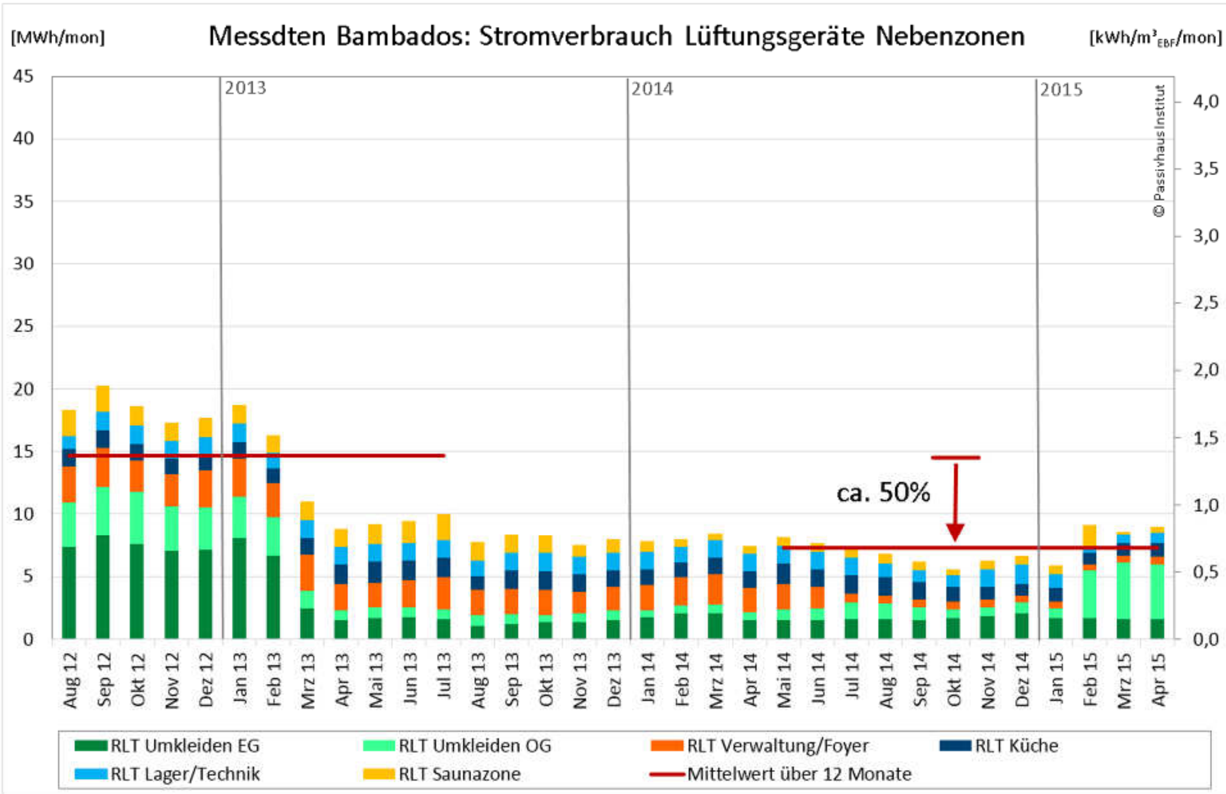


Figure 24: Power consumption of the ventilation units: De r consumption could both for the Indoor swimming pool (see upper diagram) as well as for the Subzones (see lower Diagram) can be reduced. (Both diagrams have the same scale. The average monthly values are shown in red averaged over one year)

lighting

Largely efficient T5 fluorescent tubes or LED lamps were used in the building. This enabled good energy efficiency to be achieved in the planning with a planned average (weighted according to area and illuminance) of 2.37 W / (m² * 100lx). 343 MWh / a of electricity was used for the entire lighting of the Bambado in the year (May 2014 to April 2015). This corresponds to 16% of the total electricity consumption in this period. The current for the lighting in the Bambados is measured separately for the individual zones - with the exception of the lighting for restaurants and spas, which make up a marginal share. The exterior lighting is assigned to the "Outside" section, with the exception of the lighting of the outside pool. This is placed on the lighting counter of the sports area and is therefore taken into account here.

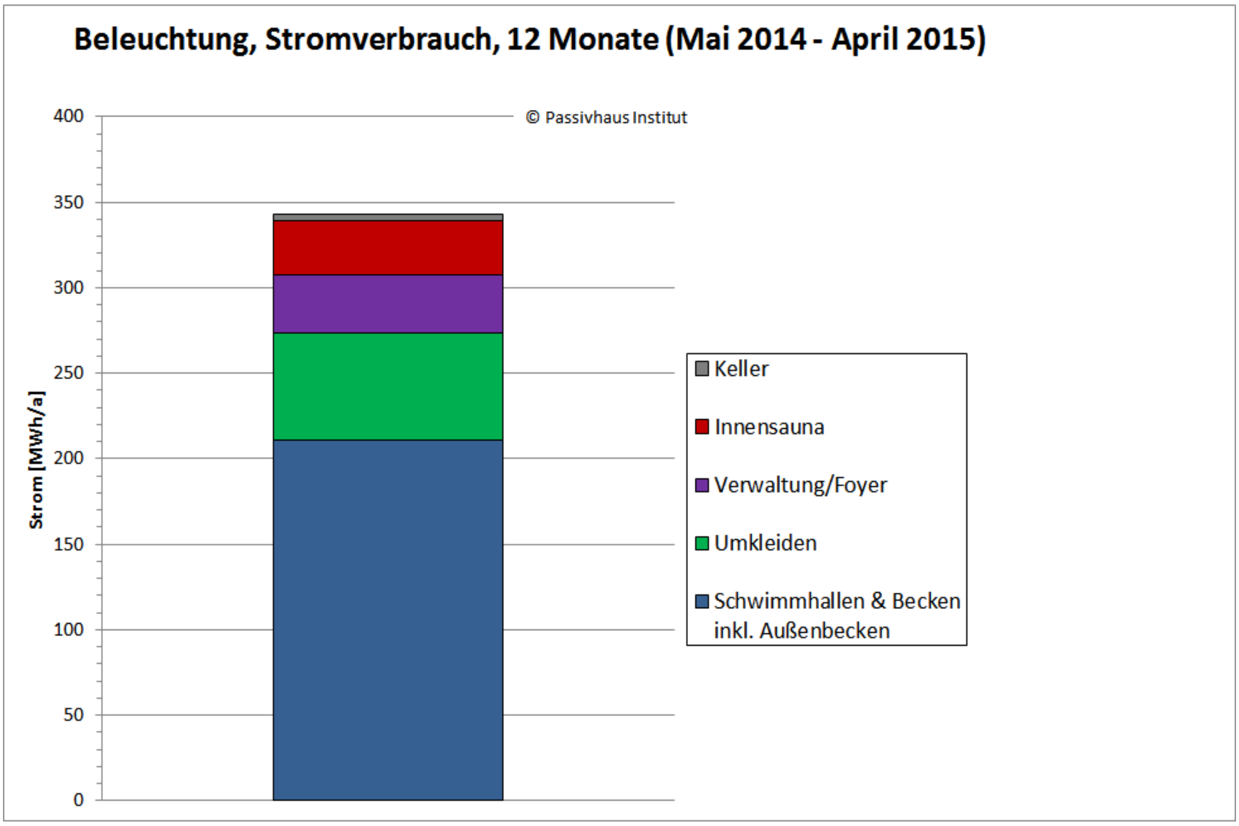


Figure 25: Current consumption of lighting under differ according to areas in the building (without outside areas, spa area and gastronomy) for r the year period from May 2014 to April 2015.

The dominance of the lighting in the hall areas is shown with 59% of the lighting consumption, which also make up the largest part of the building. The second highest partial consumption for the changing rooms is clearly 21%. The remaining 19% are used together by the administration / foyer, indoor sauna and cellar areas. Operating hours for the lighting were used to create the energy balance in the planning phase. These can be compared with the measurement results (see table).

Table 5: **Measured (day and night, 0-24 a.m. & during opening hours, 7 a.m. - 11 p.m.) as well as full load hours estimated during the planning phase the (0-24 h) of the lighting**

Illumination year period (May 2014 - April 2015)	Swimming pools & pools including outdoor pool	Changing room	- the administration / Foyer	Indoor sauna	basement, cellar
Full load hours / year measured (0-24 h)	6283	7132	4660	5319	3768
Full load hours / year measured (7-23 h)	4288	5140	3136	3464	3182
Full load hours / year planned (0-24 h)	4440	4063	3707	3085	1701

In the planning phase, it was assumed that most of the lighting would be switched off at night. The comparison shows that the full load hours measured during the opening hours (723 h) correspond relatively well with the values that were assumed for a whole 24 h during the planning period. This does not apply to the basement. However, since this has a comparatively very low lighting output, this has little impact on overall consumption. The values of the total measured full load hours (0-24 h) are much higher than the planned ones. The lighting is thus operated significantly longer than the energy balance. This indicates that there is clear potential for reducing lighting use in times outside of opening hours.

The electrical lighting is switched on and off using various time programs and daylight control, which are implemented in the BMS, but can also be done manually if required. The influence of daylight control can be clearly seen from the decrease in lighting performance during lunchtime in the areas of the swimming pools, indoor sauna and administration and foyer (see Figure 26, yellow markings). However, it can also be seen that outside of opening hours the lighting for all areas (except the basement) is partially switched on. The time switch program provides at least an extensive shutdown between 23:00 and 1:45, which can be seen in the night from March 8th to March 9th, 2014. The previous night this was probably overridden by the cleaners. From 1: 45 almost full lighting is used in all areas (except the basement) until the bathroom opens. Since cleaning is not carried out in all areas at the same time during this entire time, it is advisable to adapt the plaster lighting to further save electricity in the future - especially in the hall and changing areas that have the highest lighting output.

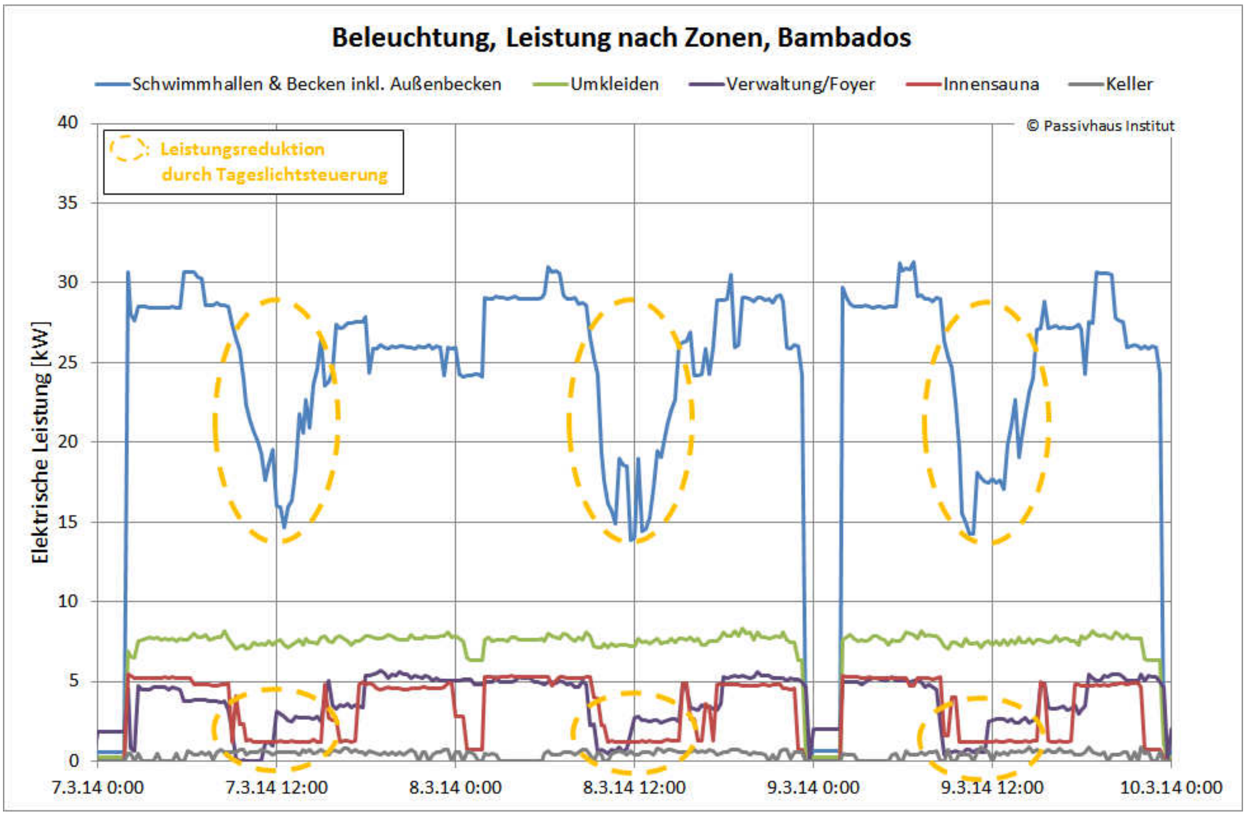


Figure 26: Course of the electrical power of the Lighting divided by zones across exemplary 72 hours. The daylight-controlled reduction of the lighting output for the areas of the swimming pool is marked in yellow II, the indoor sauna as well of administration and foyer.

Bathing water technology

Bathing water technology (see also chapter 5.10) includes all circulation and heat exchanger pumps in the pool water circuits as well as large pumps for slides and attractions (flow channels, splash water showers, massage jets etc.) as well as metering pumps and small consumers, such as chemical measuring cells. These consumers are in the basement of the building. Since the electricity consumption of the bathing water technology is not recorded via its own meters, an additional measurement was carried out. For this purpose, the currents and voltages on the supply lines of the control cabinet, to which all electrical consumers of the bathing water technology are connected, were monitored for twelve days using a mains current analyzer (Fluke 1735 Power Logger with flexible current transformers and direct voltage taps), measured and from this the active powers and active energies (electricity consumption) are calculated. The course of the active power is shown in Figure 27.

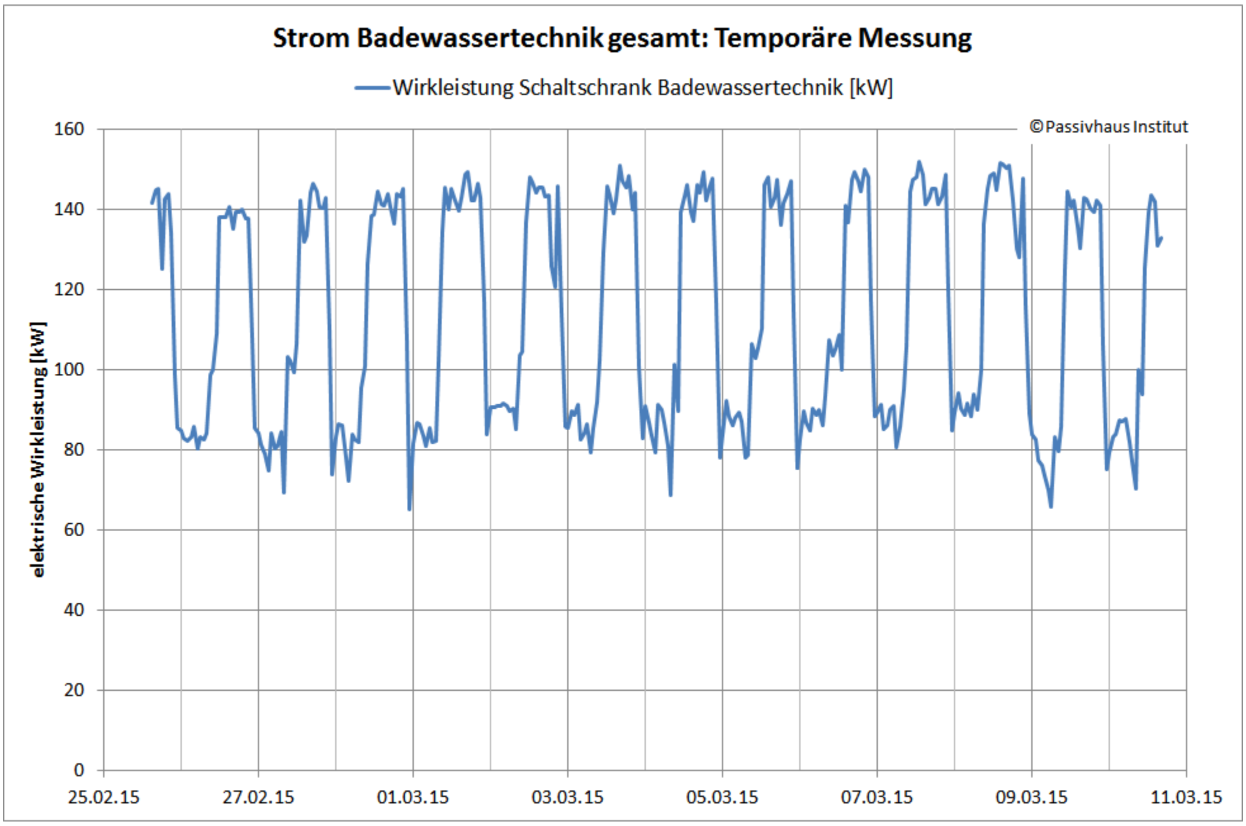


Figure 27: Temporary power consumption measurement of the Control cabinet of the entire Bathing water technology. The course of the is shown Total active power of all three Phases of the supply of the bath cabinet water technology measured with a mains power analyzer over a period of z twelve days.

The additional measurement clearly shows the day-night fluctuations in the electrical output of the bathing water technology. During the day, peaks up to 150 kW are reached. During the night hours (10 p.m. to 9 a.m.) between 80 and 90 kW are required. This is due to the nightly switching off of the slide and attraction pumps as well as the internal pool circulation, which takes place at night.

Since the bathing water technology, with the exception of the month of the revision, has a largely constant driving style with day-night operation and filter backwashing at the same intervals throughout the year, values for the monthly power consumption can be estimated using the exemplary measurement. A comparison is made with the need values from the planning that are updated with regard to real operation. This shows a very good agreement (94%). The total electricity consumption for the annual period (May 2014 to April 2015) extrapolated from the measurement concept is approx. 900 MWh / a. This corresponds to 43% of the total electricity consumption of the bath during this period.

Outside

All electrical outdoor applications are included in the "Outdoor" section. As part of this pilot project, the energy efficiency potential in this area was not considered in detail, so there is probably further potential for savings. They are made up of the consumption of

- electric walkway heating,
- Outdoor sauna area with ventilation unit,
- Swimming pool technology, outdoor pools and
- Parking lot lighting and other outdoor lighting.

This separation enables a distinction to be made according to consumption inside and outside the thermal envelope of the building. With a total consumption of 119 MWh / a in the annual period (May 2014 to April 2015), 6% of the total electricity consumption is used outdoors.

Divers

The "Divers" section consists of other technical applications and consumers that are not assigned to the other sections. These include

- Gastronomy (with complete kitchen and scullery including fridge and freezer and bar including lighting),
- Indoor sauna area (with electric steam bath, Infrared cabins, cold pools, and Ice maker etc.),
- the leased separate spa area (including lighting),
- Administration (with offices and kitchenette) and
- Other (cash registers, automatic payment machines, hair dryers, electro-acoustic systems, servers, GLT and various sockets and small consumers).

The electricity consumption of the “Divers” sub-area accounts for 489 MWh / a in the annual period (May 2014 to April) 2015, 23% of the total electricity consumption. Of this, 88 MWh / a go to the catering trade, 69 MWh / a to the indoor sauna area, 11 MWh / a to the spa area, 6 MWh / a to the administration and 315 MWh / a to "other".

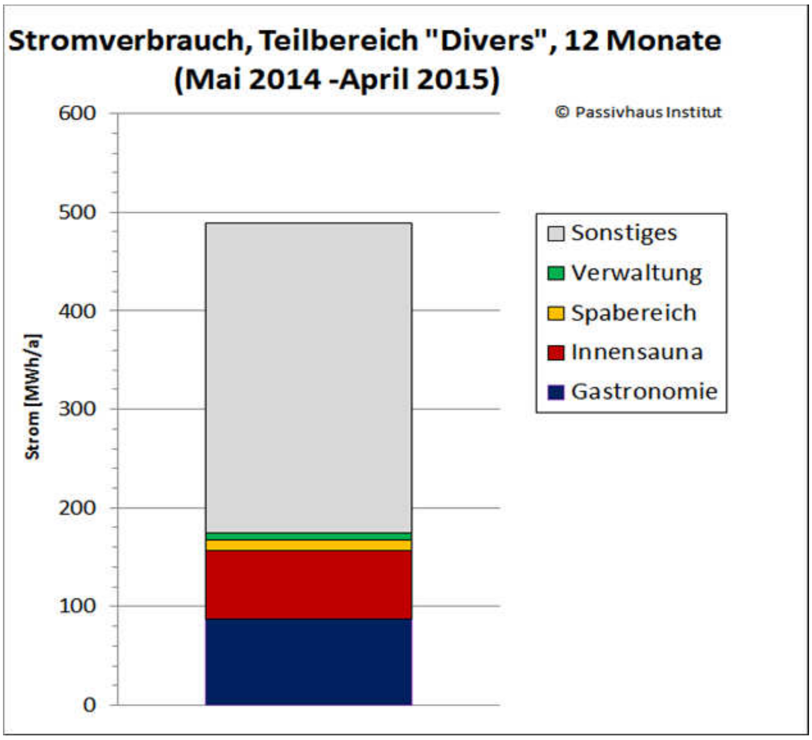


Figure 28: Power consumption of the “Dive rs ”divided into individual consumers Gastronomy, indoor sauna, separate spa area, administration and other (cash registers, Cash machines, Hair dryer, various sockets and Small consumers) for the period from May 20 14 to April 2015.

5.3 Water consumption

The Bamberg municipal utility company compared the water consumption with the old Bamberg swimming pool: despite the fact that the water in the Bambados is four times as large, the water consumption is the same. This is not only due to the use of water-saving fittings, but also the water-saving combination of ultrafiltration with a sludge water treatment system. The total annual water consumption compared to other baths is shown in chapter 6.1. Figure 29 shows the distribution of water consumption. The water consumption for showers and for refilling the pools is clearly dominant, while the water consumption for the sauna areas is lower. The evaluation has shown that the water consumption in the kitchen is very low, so that it is shown in the diagram under Other.

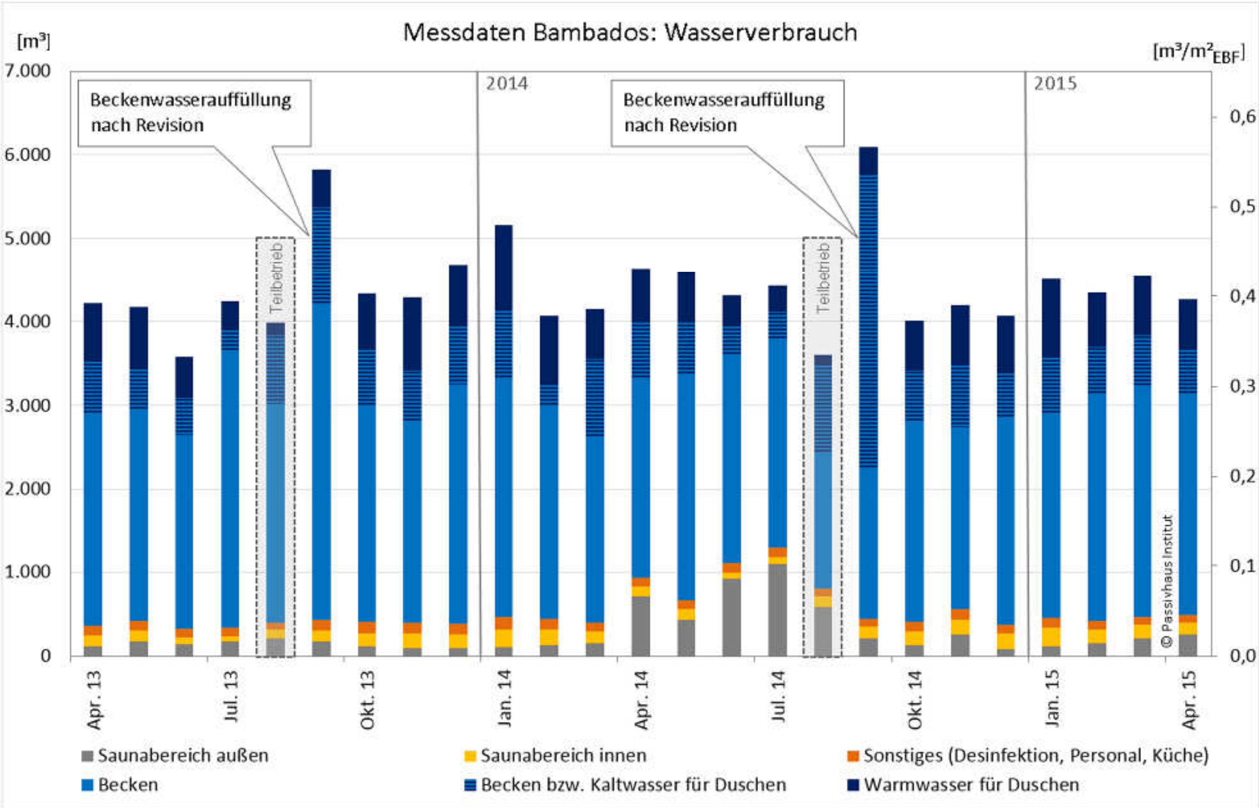


Figure 29: Monthly water consumption (due to sensor defects, the blue-streaked portion not clearly assigned to the pool or the showers be net)

5.4 Building envelope

A building envelope in passive house quality is a basic requirement (see chapter 1.2) for the passive house indoor pool. The operation of the bathroom shows the good insulation effect as well as the high air tightness first of all through the realized low heating energy consumption. Even in the weakest parts of the building envelope, the windows, no condensate was detected by the operators in the cold winter, although the usual air flow from the glass facades was avoided in the bathroom.

5.4.1 Airtightness

For energy-efficient buildings, an adequately airtight building envelope is the prerequisite for low energy consumption and the function of the ventilation system (keyword: "Directed Flow "). An indoor pool has in large areas over significantly higher Indoor air temperatures and higher indoor air humidity. Therefore, a further increased requirement for airtightness is necessary, in particular for reasons of building protection. For this reason, the requirement value for passive houses with n50 = 0.6 h-1 for the Bambados in the

Planning phase tightened to n50 = 0.2 h-1. This is necessary not only because of the use as an indoor pool, but also because of the size of the building.

For large buildings, the q50 value with respect to the envelope surface is the more sensible size instead of the usual n_{50}- Value with reference to the volume of the room. The reason is the much better A / V ratio for large buildings. The entire Bambados indoor swimming pool, including the basement, has an internal volume of 61,218 m³, an enveloping surface of 19,420 m² and thus a favorable A / V ratio. Because the size q_{50}- However, the value is more unusual, since the requirement value was considered n_{50}-
Value formulated.

Figure 30: Airtightness measurement: the fans were in the area of the entrance doors built-in. For the measurement of airtightness despite the large interior volume only one fan needed

In order to achieve good airtightness and to be able to carry out the measurement smoothly, a short training session was carried out for the executing companies and the site management a few weeks before the measurement date. The airtightness was measured by employees of the Passive House Institute on April 15, 2011. With such a large building, it is not easy to find the right time for the measurement if it makes sense to make improvements. For this reason, temporary seals are sometimes necessary if, for example, exterior doors are still missing. Specifically, it was glazing of the shed-like roof structures, individual doors and glazing. In several bushings for ventilation ducts and cables, the fittings were still missing and were therefore also temporarily covered with foils or the like. taped.

For the measurement, four fans were installed in the main entrance door in order to be able to promote a sufficiently large air flow. First, the building was systematically searched for leaks under a vacuum of 50 Pa with 11 people. The following minor residual leaks were found:

- Mullion-transom system: regular small leaks at the connection points of the profiles
- Bottom end mullion-transom system to the concrete floor (systematic)
- Glazing beads in the perforated window in the administration area: small leaks

- Basement: connection of concrete wall basement to concrete structure for ventilation duct
- Roof connection (lightweight construction) to concrete wall (leisure pool area)
- Mullion-transom facade on concrete ceiling (sauna area): sealing tape partly wrinkled / detached

Only one of the four fans was required for the actual measurement of the airtightness, since the building has a high airtightness. The result was with

$$n_{50} = 0.07\ h^{-1} \text{ corresponding to } q_{50} = 0.21\ m^3 / (h\ m^2)$$

a very good result.

This corresponds to a leakage volume flow of only 4,034 m³ at 50 Pa. To get an idea of the size of the various small remaining leaks in the building envelope, the sum of these leakage areas can be calculated in a simplified manner. In Bambados this corresponds to an area of approximately 45 cm x 45 cm. That is 0.001% of the envelope area. Overall, it is clear that a very well airtight building envelope has been erected.

BlowerDoor-Prüfbericht

Berechnungsgrundlage EN 13829, Verfahren A

Minneapolis BlowerDoor Modell 4, APT

Objekt :	Hallenbad Bamberg Bambados 96050 Bamberg	Prüfer/in:	Søren Peper
		Datum:	15.04.2011 FLIB-Nr: 24400

Klimadaten

Innentemperatur:	12 °C	Luftgeschwin. Anemom.:	0,8 m/s	Referenzdruckmessstellen:	1
Außentemperatur:	12 °C	Windstärke:	2	Gebäudestandort:	B
Luftdruck (Standard):	101325 Pa			Zusätzliche Messunsicherheit infolge Wind:	2 %

Unterdruck / **Überdruck**

Natürliche Druckdiff.	Δp_{01+}	Δp_{01-}	Δp_{02+}	Δp_{02-}	Natürliche Druckdiff.	Δp_{01+}	Δp_{01-}	Δp_{02+}	Δp_{02-}
	0,5 Pa	-0,3 Pa	1,0 Pa	-1,2 Pa		0,5 Pa	-1,1 Pa	0,4 Pa	-0,2 Pa

Messreihen

Reduzier-blende O ABCDE	Gebäude-druckdiff. [Pa]	Gebläse-druckdiff. [Pa]	Volumen-strom V_r [m³/h]	Abwei-chung [%]	Reduzier-blende O ABCDE	Gebäude-druckdiff. [Pa]	Gebläse-druckdiff. [Pa]	Volumen-strom V_r [m³/h]	Abwei-chung [%]
Δp_{01}	0,0	—	—	—	Δp_{01}	-0,6	—	—	—
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0	-65	46	4618	1,01	A	36	151	3276	-2,24
0	-54	36	4063	0,62	A	22	79	2374	-0,04
0	-41	23	3295	-2,83	A	17	52	1939	-1,81
0	-25	14	2532	1,04	0	86	83	6190	0,66
					0	75	66	5539	-1,26
					0	62	50	4790	-2,86
					0	45	31	3810	-2,71
Δp_{02}	-0,6	—	—	—	Δp_{02}	0,3	—	—	—

Korrelationskoef. r:		0,999	Vertrauensintervall (95%)		Korrelationskoef. r:		0,994	Vertrauensintervall (95%)	
C_{env}	[m³/(h Paⁿ)]	327	max. 408	min. 262	C_{env}	[m³/(h Paⁿ)]	273	max. 364	min. 205
C_L	[m³/(h Paⁿ)]	330	max. 412	min. 264	C_L	[m³/(h Paⁿ)]	275	max. 368	min. 206
n	[-]	0,63	max. 0,69	min. 0,57	n	[-]	0,70	max. 0,77	min. 0,62

Ergebnis, Kenngrößen V = 61218 m³ A_F = A_E = 19420 m²

	V_{50} m³/h	Unsicher-heit %	n_{50} h^{-1}	Unsicher-heit %	w_{50} m³/m²h	Unsicher-heit %	q_{50} m³/m²h	Unsicher-heit %
Unterdruck	3872	+/- 7 %	0,06	+/- 8 %			0,20	+/- 8 %
Überdruck	4196	+/- 7 %	0,07	+/- 8 %			0,22	+/- 8 %
Mittelwert	**4034**	+/- 7 %	**0,07**	+/- 8 %			**0,21**	+/- 8 %
Anforderungen nach: Passivhaus Inst.			0,2	1/h	***		***	

Die Anforderungen der Vorschrift werden erfüllt.

Bemerkung: Das Messergebnis schließt (verdeckte) Mängel in der Konstruktion nicht aus.

Figure 31: Protocol sheet of the airtightness measurement **April 15, 2011**

5.4.2 Thermographic examination

To check the construction and quality of the high-quality, thermally insulated building envelope of the bathroom, an infrared thermography examination was carried out on the outside and inside on January 17, 2013 by PHI employees. It should be checked whether there are deviations from the planned quality or other abnormalities.

In order to avoid the disturbing influence of the solar radiation during the examination and also to minimize the influence of the radiation from the previous day, the examination was started in the early morning from 4:45 a.m. and ended at around 8:15 a.m. Then the interior examination was carried out. The weather conditions were very good with outside temperatures around -4 ° C and a day before with only low solar radiation in order to be able to take high-contrast pictures. To calibrate and control the camera, Pt100 surface sensors were fixed on glazing and the adjacent wall surface and masked with masking tape. The masking tape is used to adjust the emission coefficient of the usual building materials. Glass and bare metal have significantly different emission coefficients compared to the materials normally used in construction (plaster surface,

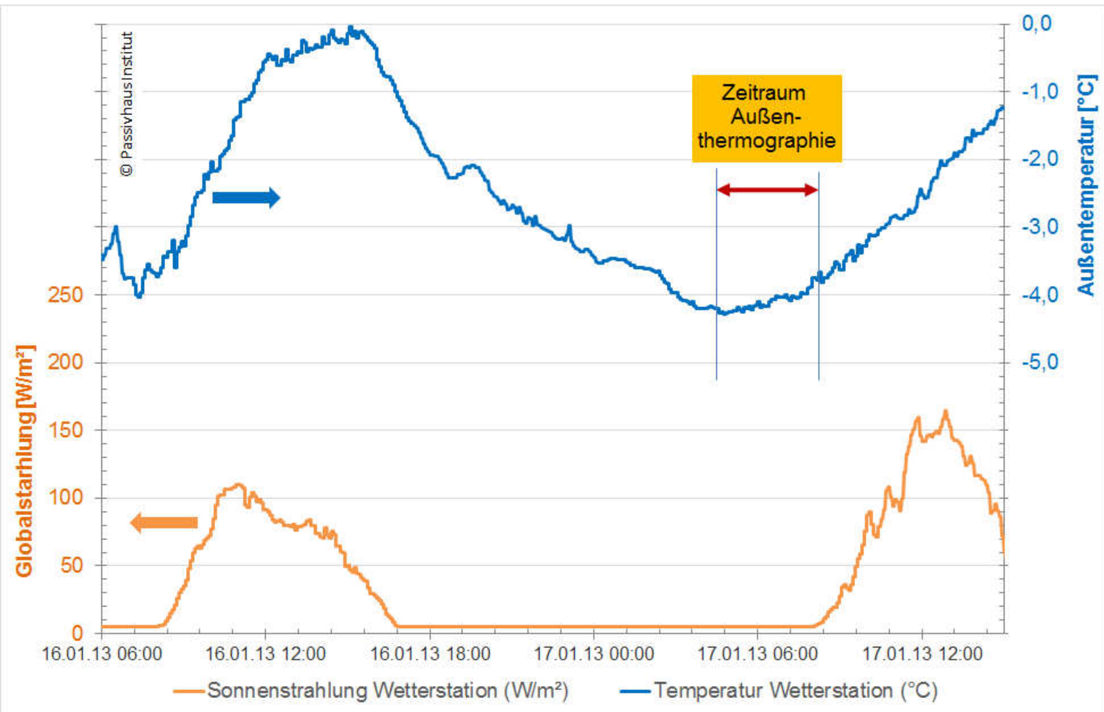


Figure 32: Weather conditions in the time range of Thermographic examination of the Indoor swimming pool on January 17, 2013

Table 6: Boundary conditions of the thermographic investigation

Outside temperature the day before (16.01.2013; average)	- 2.0 ° C
Outside temperature Jan 17, 2013 (Average 4:45 to 8:15 h)	- 4.1 ° C
Wind conditions	weak wind
Precipitation	no precipitation
rel. Air humidity (average 5:30 a.m. to 8:00 a.m.)	95.3 %

The thermographic recordings were made with the high-resolution thermography system "VARIOSCAN high resolution" from Jenoptik (Jena). The program IRBIS + V2.2 from InfraTec GmbH (Dresden) was used to evaluate the images.

Table 7: Device parameters of the Thermog used raphy systems

Device parameters of the thermography system	
Measuring device	VARIOSCAN 3021 ST, Jenoptik
Spectral range	8 to 12 µm
Recording system	Scanning system
Detector material	HgCdTe
Temperature resolution at 30 ° C ± 0.03 K image format	
	360 x 240 pixels

With external thermography, the entire building was examined from the outside: external walls, windows, doors, connections and the roof area. For this purpose, over 250 thermograms were made. The temperature scale of the images shown is always scaled the same for images that belong together to ensure direct comparability. Each color is accompanied by a color temperature scale as a legend. If possible, the corresponding daylight photo is compared to the thermogram from a similar perspective. These photos were only taken later on the same day (daylight).

Due to the predominant outer wall construction with ventilated, curtain Facade panels give their surface temperatures only indirectly information about the thermal quality of the wall. If there were weak spots, warm air plumes or similar effects would be visible on the butt joints and / or on the roof connection.

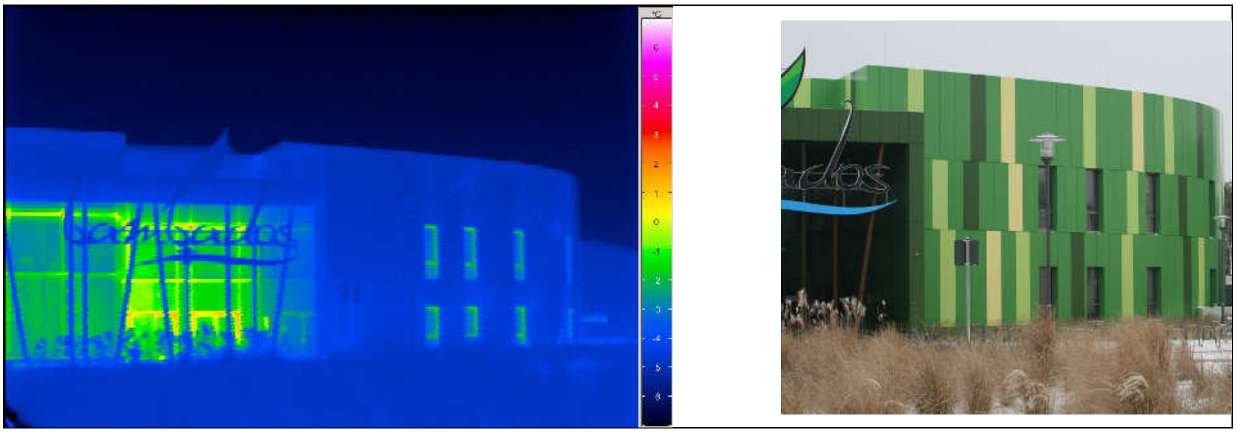


Figure 33: Thermogram and photo of the exterior ssade from the entrance as well Administrative area

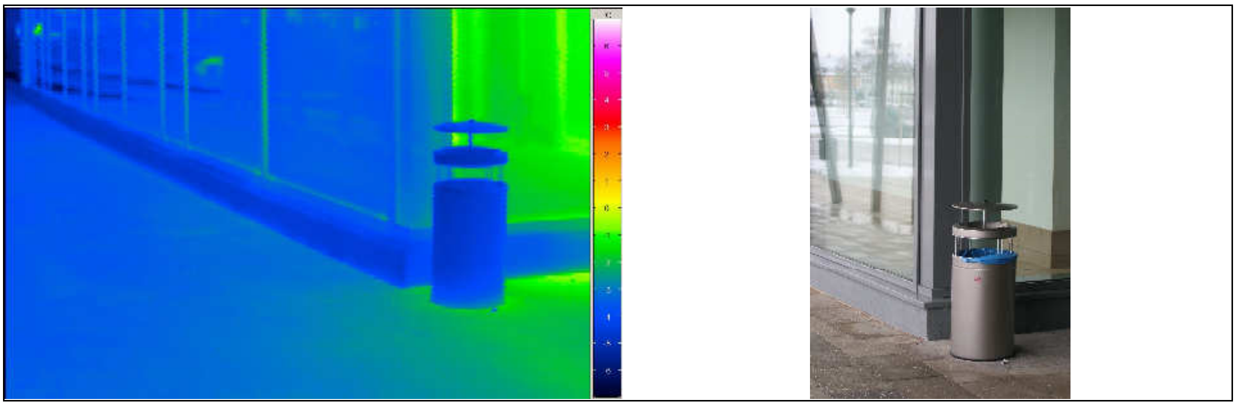


Figure 34: Entrance area and facade to the park bib (mullion-transom)

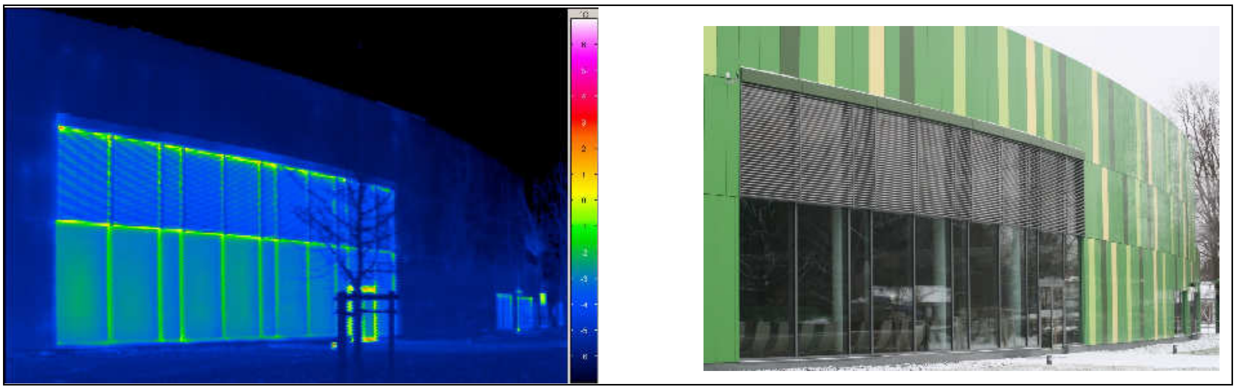


Figure 35: Facade in the leisure pool area

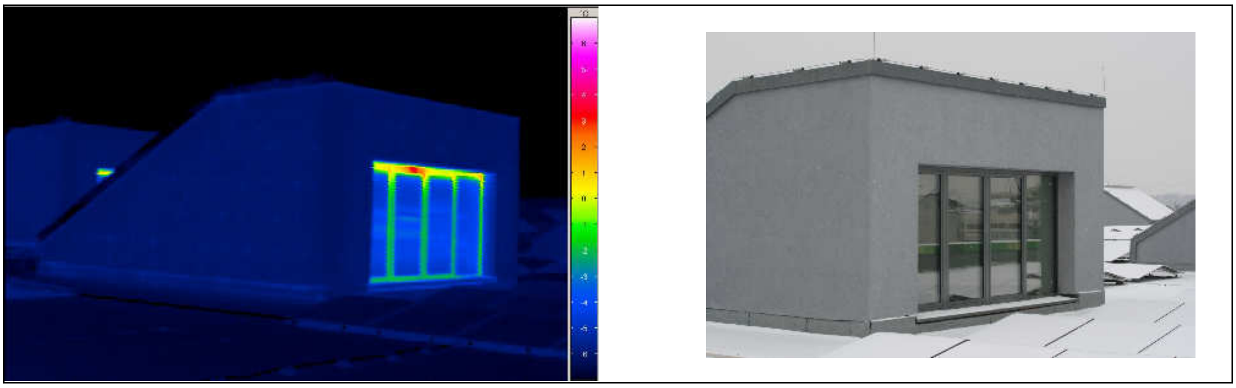


Figure 36: Shed-like roof structure (Surface thermal insulation composite system: -5.7 ° C)

The representations in Figure 33 to Figure 36 impressively show the high quality of the building envelope: The outer surface is uniformly 'cold', ie the surface temperatures are, as expected, uniformly low. Only the windows with their higher U values are warmer. There are higher temperatures in the area of the roof of the entrance, since the roof leads to a shielding (“shading”) of the cold night sky. This allows the surface temperatures in the protected area to cool down less. Only at the window in the roof shed can a certain elevated temperature be determined, which indicates a weak point.

Some abnormalities ("hot spots") are shown below. However, it must be emphasized that the building envelope is of a very high quality overall. In the delivery area in the basement there are concrete walls in the direction of the parking lot / heating center or the outside sauna area. The transition to the insulated building facade had to be carried out against pressing water. The insulation therefore has a weakening in the area. These areas are clearly visible in the thermal image (Figure 37), especially in the lower area. Maximum surface temperatures of +6.7 and +3.4 ° C are determined. The insulated wall (ETICS), on the other hand, shows a high insulation quality with temperatures of -4.5 ° C.

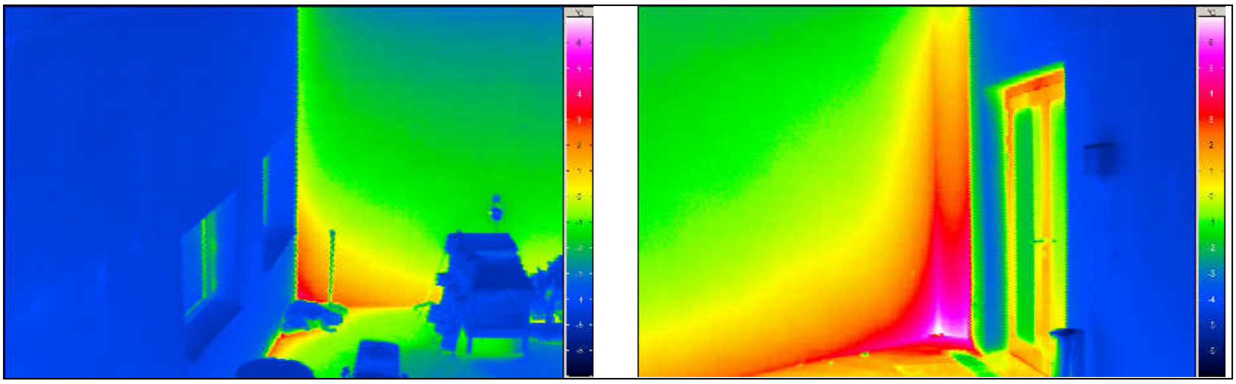


Figure 37: Both connections of the concrete walls to di e Insulated building envelope in the area the delivery in the basement

A maximum of +11.4 ° C on the door frame of the teaching area (Figure 38) shows that there is a weak point on this door. The door is probably not closing properly. If you look at the same door from the inside (internal thermography Figure 39), the lower surface temperature on the frame is clearly evident compared to the mullion-transom construction. A minimum of +13.7 ° C is measured on the threshold and on the lower frame. Due to the requirements of an emergency exit door, the required thermal quality could not be achieved. So far, according to the operator, no condensate has occurred. The other exterior doors of this type (sports pool, second teaching pool) also show the low surface temperatures, which shows the thermal optimization potential.

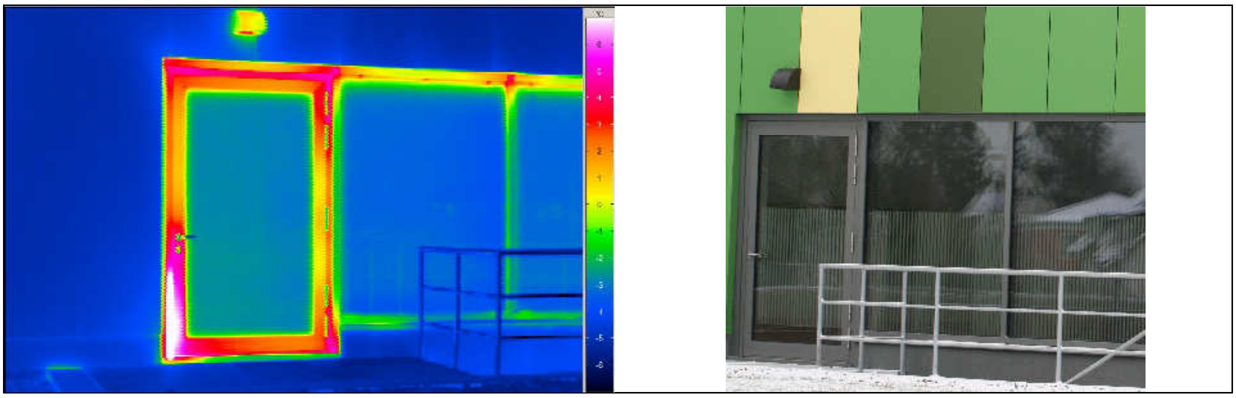


Figure 38: Exterior door and mullion-transom system as well as basement exit in the area of the teaching swimming pool

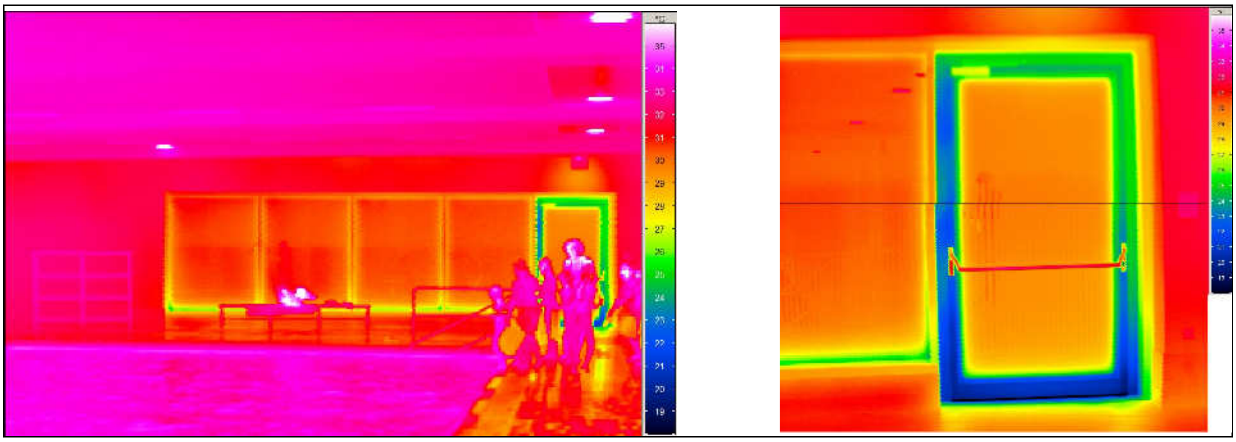


Figure 39: Internal thermography of the area of the T ür and the mullion-transom facade in Area of the training pool and detailed picture of the outside for

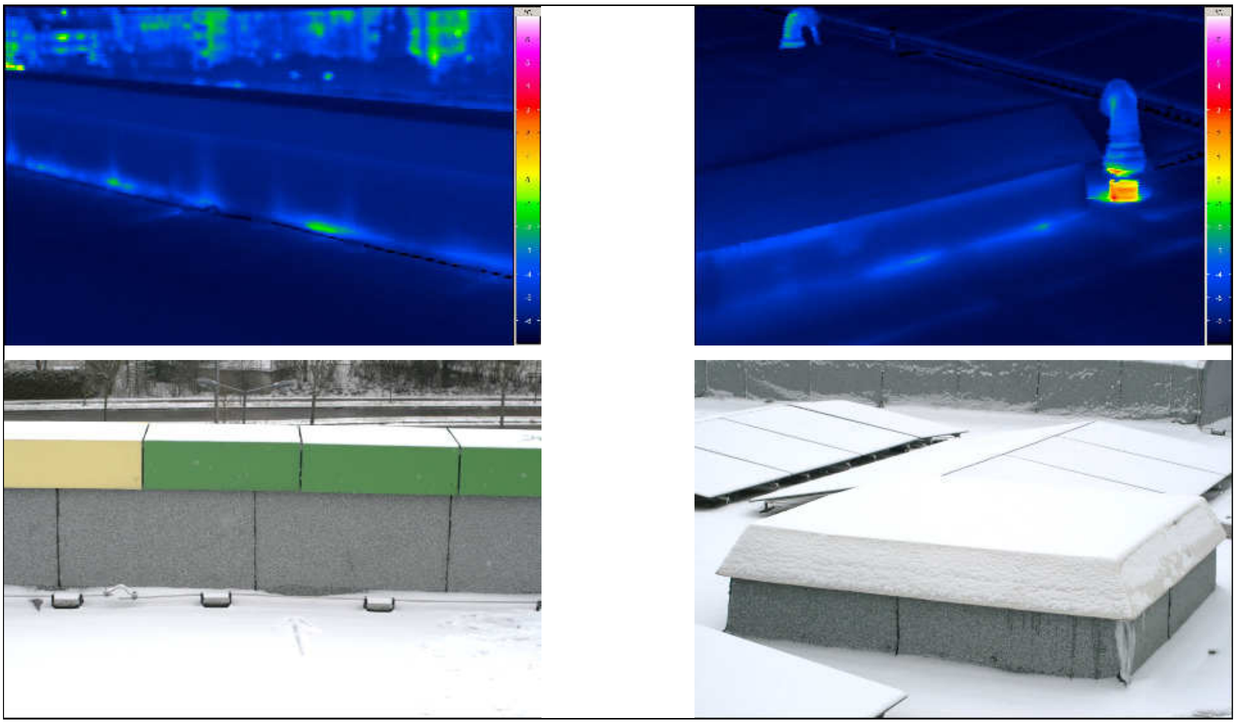


Figure 40: Minor abnormalities in the roof area ch (parapet and RWA)

The examination of the roof area shows harmonic low surface temperatures in the surface, which confirms the successful implementation of the high-quality insulation. There are some minor weak points in the cable entries, a jump in height (to the spa / sauna area), the SHEV flaps and repeated at the transition to the parapet. These points appear to be design-related, slight weakening of the insulation.

The transition from the building to the outdoor pool on the 1st floor takes place through a buffer zone with a plastic housing. For thermal reasons, there was no continuous indoor-outdoor pool for swimming directly out. The area is of course noticeable in thermography, as the open water surface and the plastic housing show high temperatures as expected.

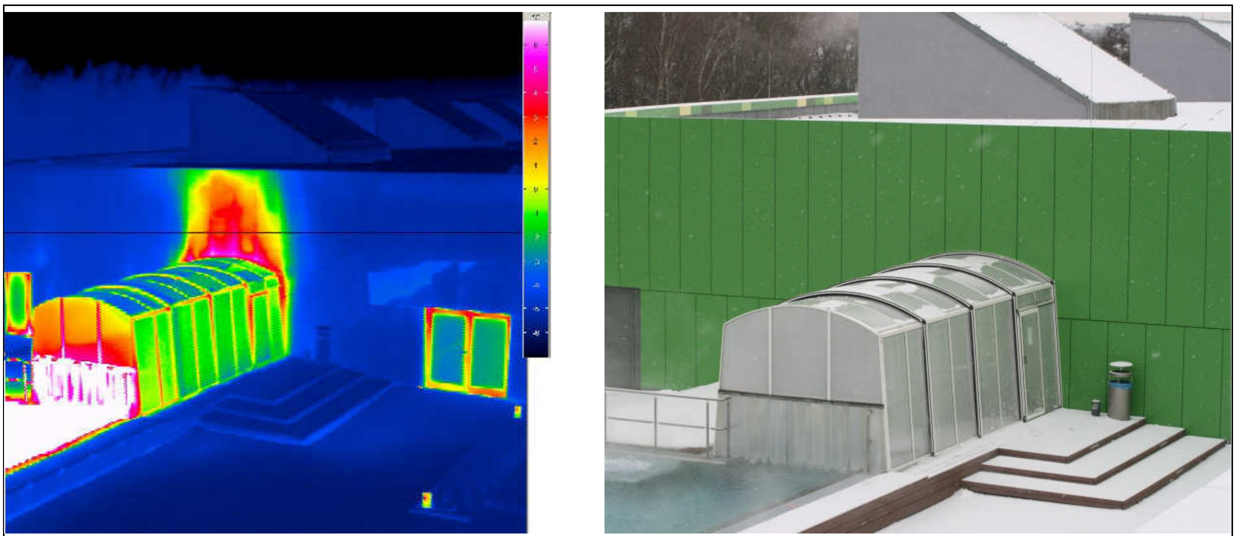


Figure 41: Transition to the outdoor pool (area go not for the thermal Building envelope)

After the external investigation, 165 thermograms were recorded within the entire building, including the basement. These also impressively show the high quality of the building insulation through uniform internal surface temperatures of the outer walls. In the area of the outside facade in the leisure hall (Figure 42), high temperatures of the outside walls of approx. 30 to 31 ° C can be seen. An outer door is again the area with the lowest temperature.

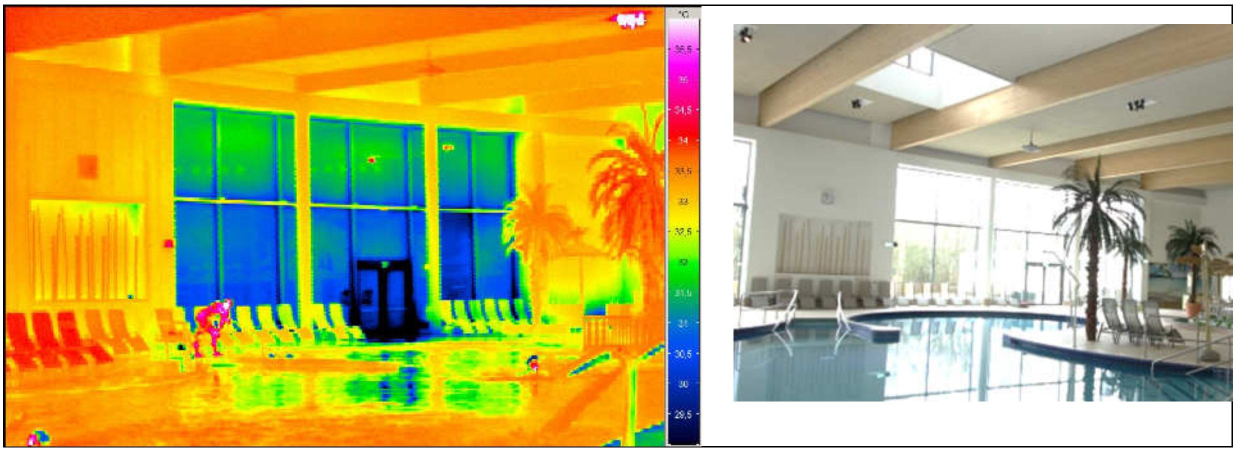


Figure 42: Leisure hall with a view of the outer barrel **goodbye**

One of the shed-like roof structures in the leisure hall is examined as an example. Here, too, there are harmonious surface temperatures of the wall surfaces (Figure 43). The frames of the windows (from this unfavorable perspective) with temperatures well above 25 ° C are of sufficient quality to ensure that there is no condensation in the prevailing air conditions.

The area above the suspended ceilings in the halls represents a “dead space” in terms of ventilation, since there is no active flow. For this reason, sensors for checking the air conditions (temperature and humidity) are also occasionally installed in these areas. As expected, thermography shows somewhat lower surface temperatures in the area. Figure 44 shows the uncritical minimum temperature around 27.7 ° C measured in the optically accessible area.

Figure 43: View of a roof shed with glazing . The photo shows the roof structure (Shed) with a grate for maintenance; the thermogram is another shed without gratings.

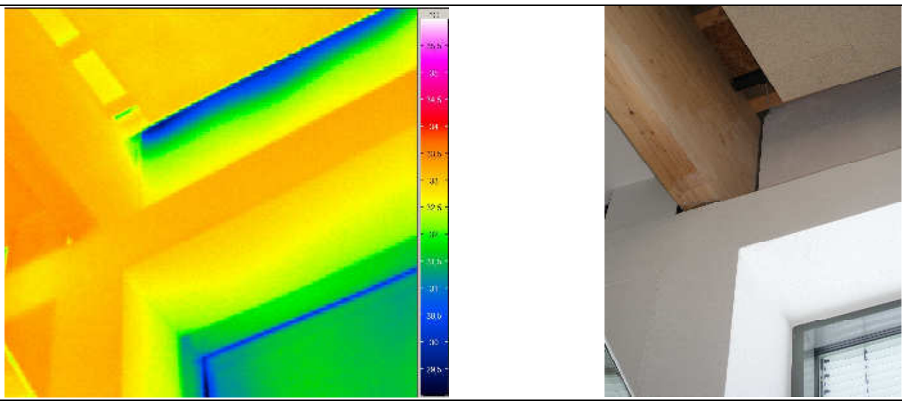


Figure 44: Area of the suspended ceiling / outer wall in the leisure hall

In the sports area, the wall quality can be checked well, since the outer wall and inner wall merge directly into one another. Figure 45 shows part of the south-east wall of the sports hall. Only in the upper left area does the wall border on the outside air (area of the outside pool on the 1st floor), below and right border other hall areas (area of the training pool and leisure hall). The difference in the surface temperature in the different areas is clearly visible when the thermographic image is selected. What is so striking is actually only a difference of 0.8 K. This shows the high quality of the outer wall insulation.

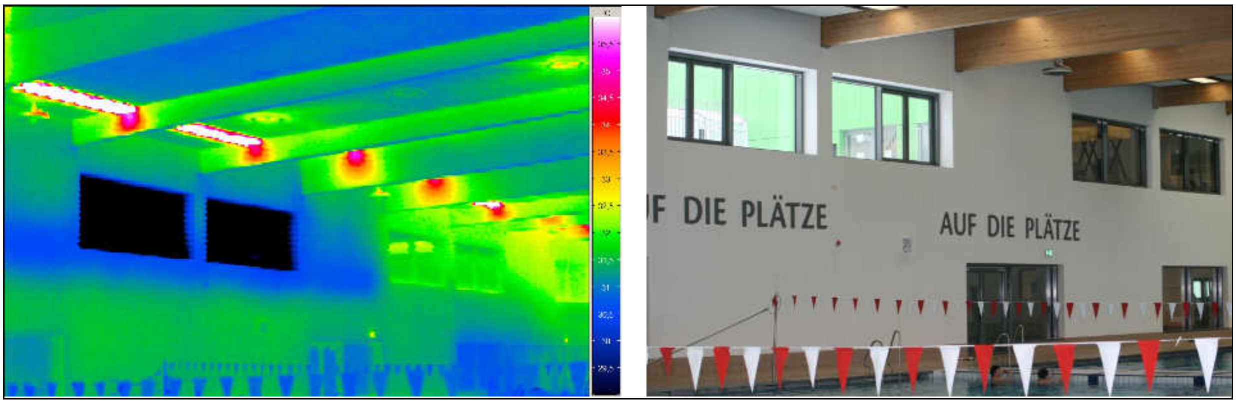


Figure 45: South-east wall in the sports area. In the upper The area borders the wall Outside air, in the lower area the teaching swimming pool at. The Temperature difference of the surface is only et wa 0.8 Kelvin.

No major abnormalities were found in the basement of the building. Prefabricated insulation shells would make sense on various fittings, as is often the case, as is often the case, unfortunately, there is no insulation. A further improvement in the thermal quality would be desirable on pipes and the surfaces of the ventilation units. The impact of a tilted window in the basement is striking (Figure 46). Surface temperatures down to a minimum of 7 ° C are determined, even the basement floor area in front of the window has cooled down. Despite the high indoor air temperatures, it can therefore only be recommended to keep the windows in the basement permanently closed.

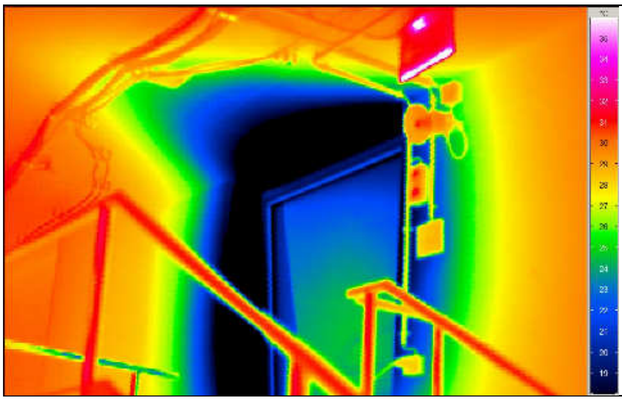


Figure 46: Basement window (tilted) in the area from r the slide systems

5.5 Weather data / external conditions

The weather data relevant for the evaluation are shown below in their courses. Daily and monthly averages as well as monthly totals for the entire measurement period (March 2013 to April 2015) were selected for the display.

The monthly totals of global radiation (Figure 48) show that the years 2013 and 2014 (March to December) have similar totals. The mean outside temperatures (Figure 49) also predominantly show comparable annual trends. Only the winter 2013/2014 is significantly milder than the measured winter months of the previous year and the following year.

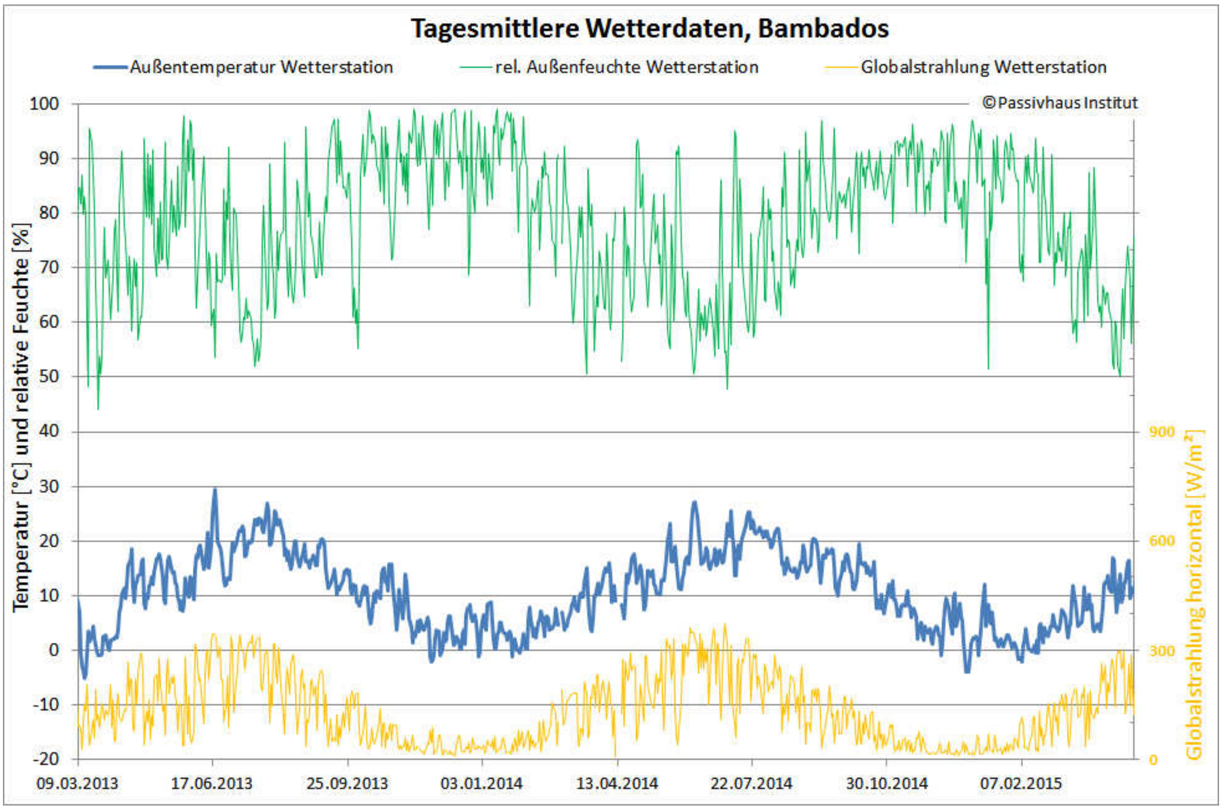


Figure 47: Average daily outside temperature measured uren, relative humidity and horizontal Global radiation for the entire measurement period (March 2013 to April 2015)

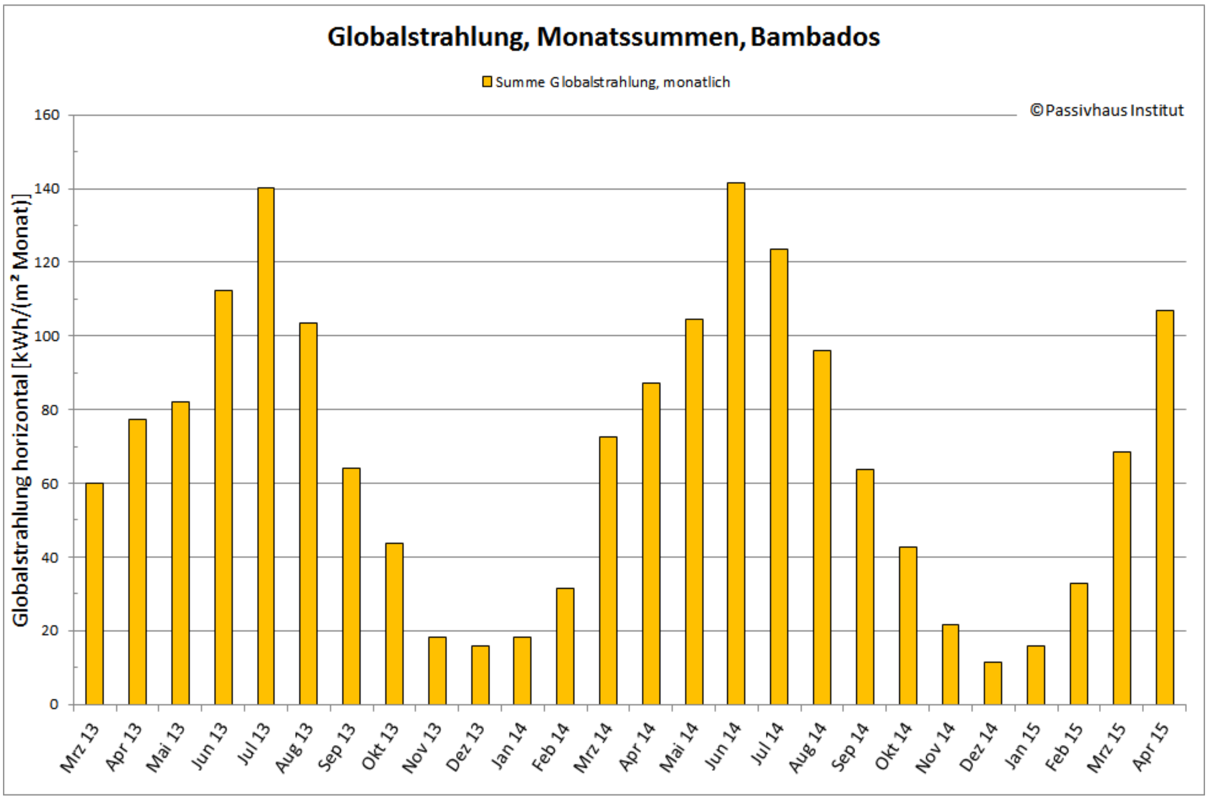


Figure 48: Measured monthly totals of the horizontal Global radiation for the whole Measurement period (March 2013 to April 2015)

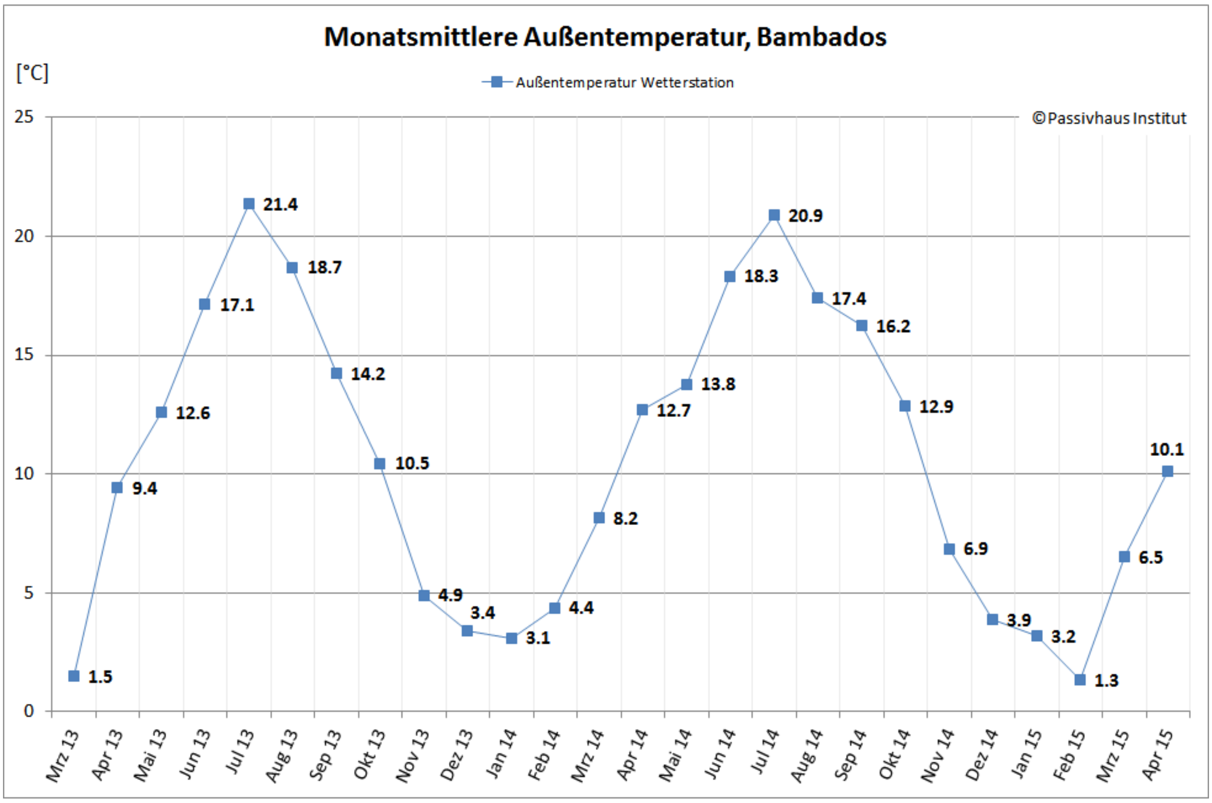


Figure 49: Measured monthly mean values of the outside temperature for the whole Measurement period (March 2013 to April 2015)

5.6 Indoor air conditions in swimming pools

The air conditions in the interior are largely evaluated using calibrated measurement data (see Chapter 3.1.2), which have been converted into hourly average values. Initially, effects from direct solar radiation on all relevant measuring points in the interior were examined and excluded. The following sections provide an overview of the course of temperatures, relative and absolute humidity in the swimming pools during the entire measurement period (March 2013 to April 2015). Periods in which a revision took place that is associated with a partial operation of the bath are always marked and are not used for evaluation purposes.

From the operator side, the setpoints for the relative air humidity in all hall areas are fixed at 58% in the exhaust air during the day. Outside of opening hours, the setpoints for the relative humidity are increased depending on the outside air temperature. The target temperatures underwent some adjustments over the course of time, some of which are clearly visible in the overall course. The section “Reference conditions” discusses which sensors have been selected for the specification of the representative air temperatures and humidity.

Floor plans with the marked positions of the measuring points can be found in the appendix.

5.6.1 Overview of the sports area

Figure 50 shows the course of the relevant air temperatures in the sports area over the entire measurement period. In the sports area, in addition to the sensors in the exhaust air of the two ventilation units, there are five wall sensors that are considered here. These are at heights of 1.5, 4, 6, and 10 m at different positions (see floor plans in the appendix). As expected, a temperature stratification (the higher the warmer) can be determined throughout. From February 2014, an optimization in ventilation control can be seen from the reduced range of exhaust air temperatures (for details, see section 5.7 "Ventilation hall"). Less outside air is brought in, which no longer lowers the hall temperatures so much, especially at night.

An unintentional rise in temperature to sometimes over 38 ° C in summer 2014 (approx. One month before the revision) can be clearly seen, which was due to a technical defect. A week earlier, the setpoint for the hall temperature was reduced from 30 ° C to 28 ° C for testing purposes. This was raised again to 30 ° C after the revision (September 2014).

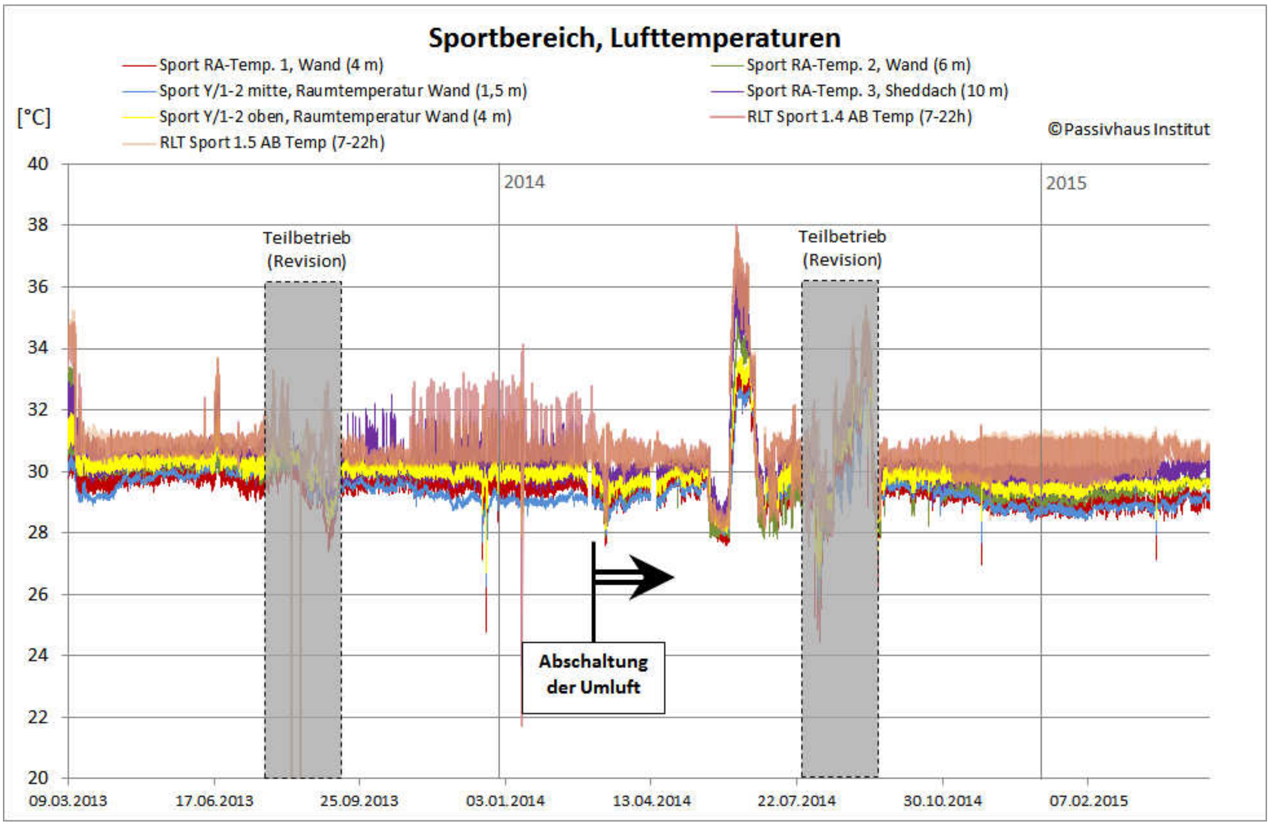


Figure 50: Course of air temperatures in sports area: Measurement data from Wall sensors in different heights and from exhaust air sensors in both Ventilation units throughout the measurement period.

A broad band of the relative humidity of all sensors is clearly visible in the overall display (Figure 51). A. is caused by the day-night change. It should be noted that the exhaust air sensors do not provide any values relevant to the hall when the ventilation units are at a standstill (see also Figure 57), which is why the measured values of the exhaust air sensors are only shown in the diagram between 7 a.m. and 10 p.m. With the final switching off of the recirculated air from February 2014, low relative air humidities are no longer ascertained apart from individual outliers or errors in the control system. Since at some higher positions in the sports hall area there is no optimal mixing due to the ventilation arrangement, the air humidity increases there in some cases. From October 30, 2014 it is striking that the air humidity is significantly increased at higher altitudes.

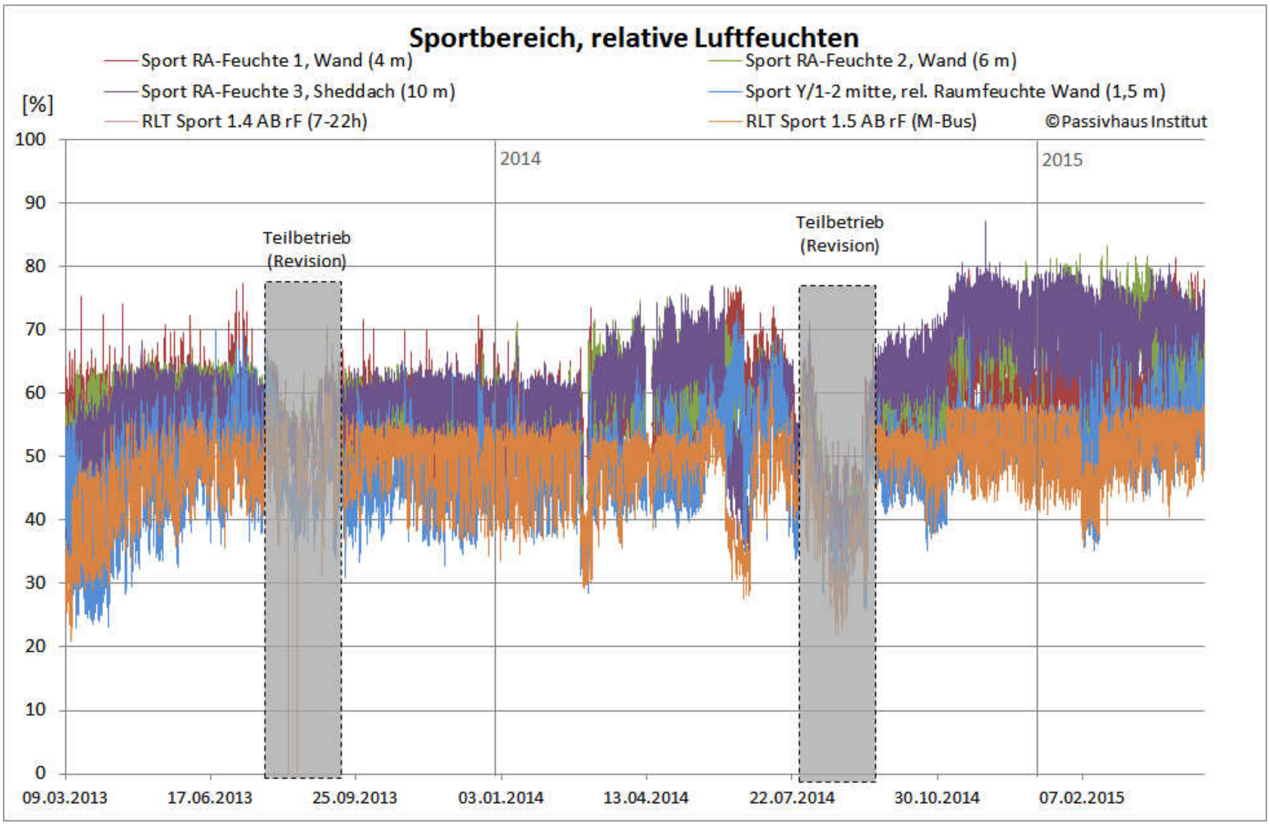


Figure 51: Course of the relative air humidity in the Sports area: Measured data from Wall sensors in different heights and from exhaust air sensors in both Ventilation units throughout the measurement period.

Figure 52 also shows the humidity values from the previous illustration as absolute values. After the revision in summer 2014 and various optimizations of the ventilation control, the relative humidity of the exhaust air from the ventilation units is in a band of ± 8%. From this point in time, increased humidity levels are found in higher positions in the sports area. The value of the surface criterion of 23 g / kg according to [Schulz 2009] can be used for classification. This represents the limit to the absence of condensation on the mullion-transom constructions that were available on the market at the time. A humidity of over 23 g / kg is not reached during normal operation. The value was exceeded only briefly during the technical defect in the heating control in summer 2014 (approx. One month before the revision).

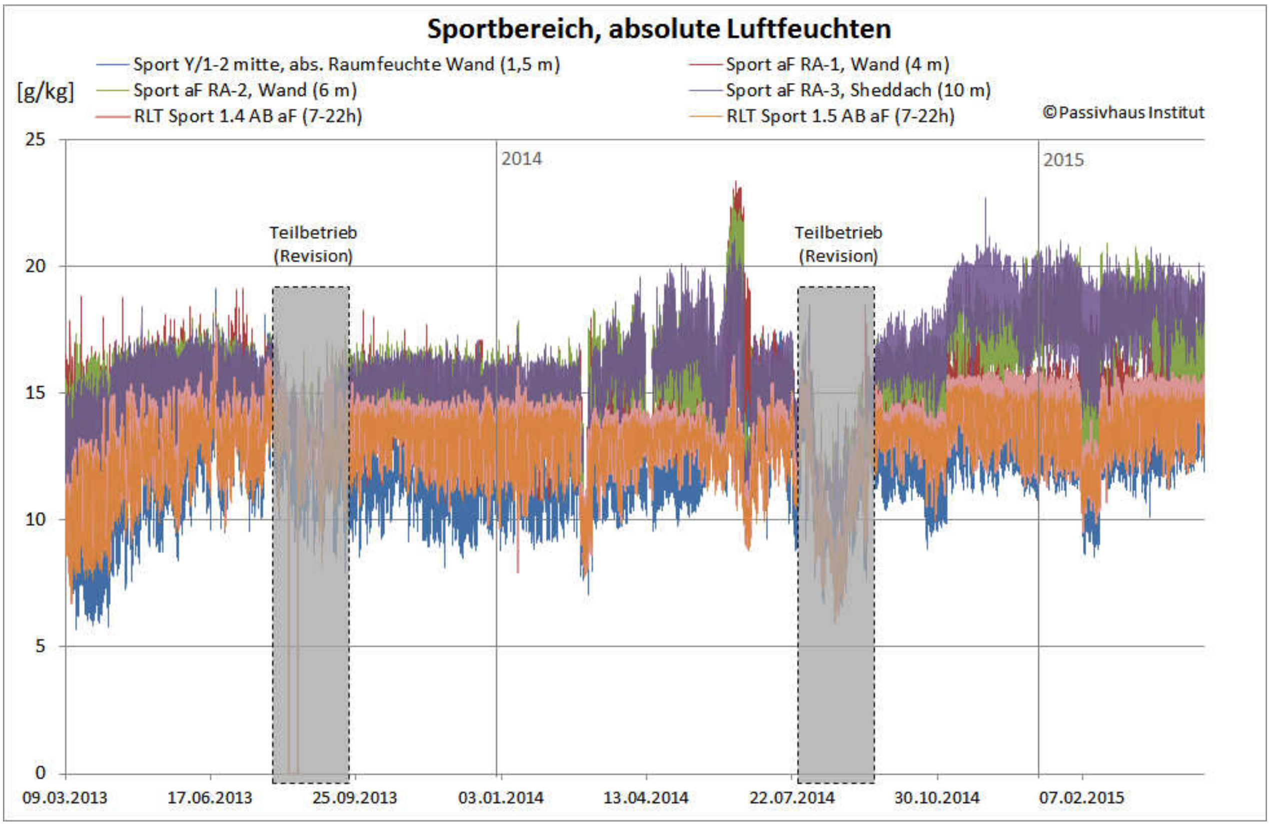


Figure 52: Course of the absolute air humidity in the Sports area: Measured data from Wall sensors in different heights and from exhaust air sensors in both Ventilation units throughout the measurement period.

5.6.2 Overview of the leisure area

Also in the leisure area, in addition to the exhaust air sensors in the ventilation units, there are wall sensors at heights of 1.5, 4, 6 and 10 m at various positions (see floor plans in the appendix). There were several changes in the air temperature setpoint during the measurement period. At the request of the bathers, this was last raised to 34 ° C (recognizable in Figure 53). The wall sensors of the measuring points MN / 7 are located below a staircase or within a jump and also close to water attractions and close to the door to the sports area, whose measured values are therefore only suitable for rough orientation, but not representative of the room conditions. Overall, a temperature band of ± 1.5 K to a maximum of ± 2 K around the respective setpoint is shown. It should be noted

Atypically, the leisure area was operated with an almost constant pool water temperature of an average of 32 ° C during the entire measurement period with air temperature setpoints from 30 to 32 ° C with a pool water temperature that was usually higher than the air temperature. From the
11/30/2014 this situation was reversed - with a change in the setpoint of the room temperature to 34 ° C with constant pool water temperatures. As a result, the
Air stratification with e in a wider temperature range than in the previous time period m.

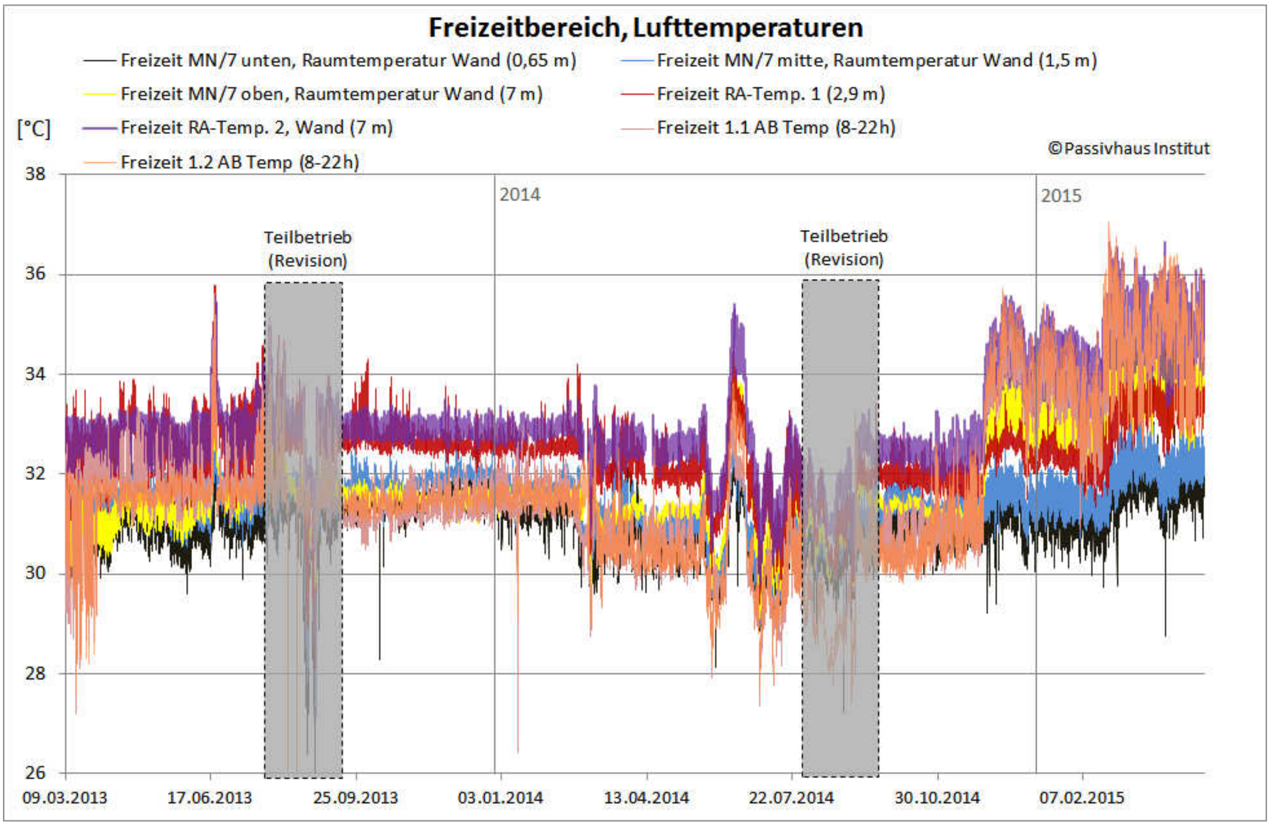


Figure 53: Course of air temperatures in the free time Range: Measured data from Wall sensors in different heights and from exhaust air sensors in both Ventilation units throughout the measurement period.

From November 30, 2014, the previously described change in air stratification can also be seen in the humidity values (see Figure 54 and Figure 55). At the measuring point MN / 7 in 1.5 m high, higher humidity levels are found than in higher altitudes (exhaust air intake and measuring point at 7 m high).

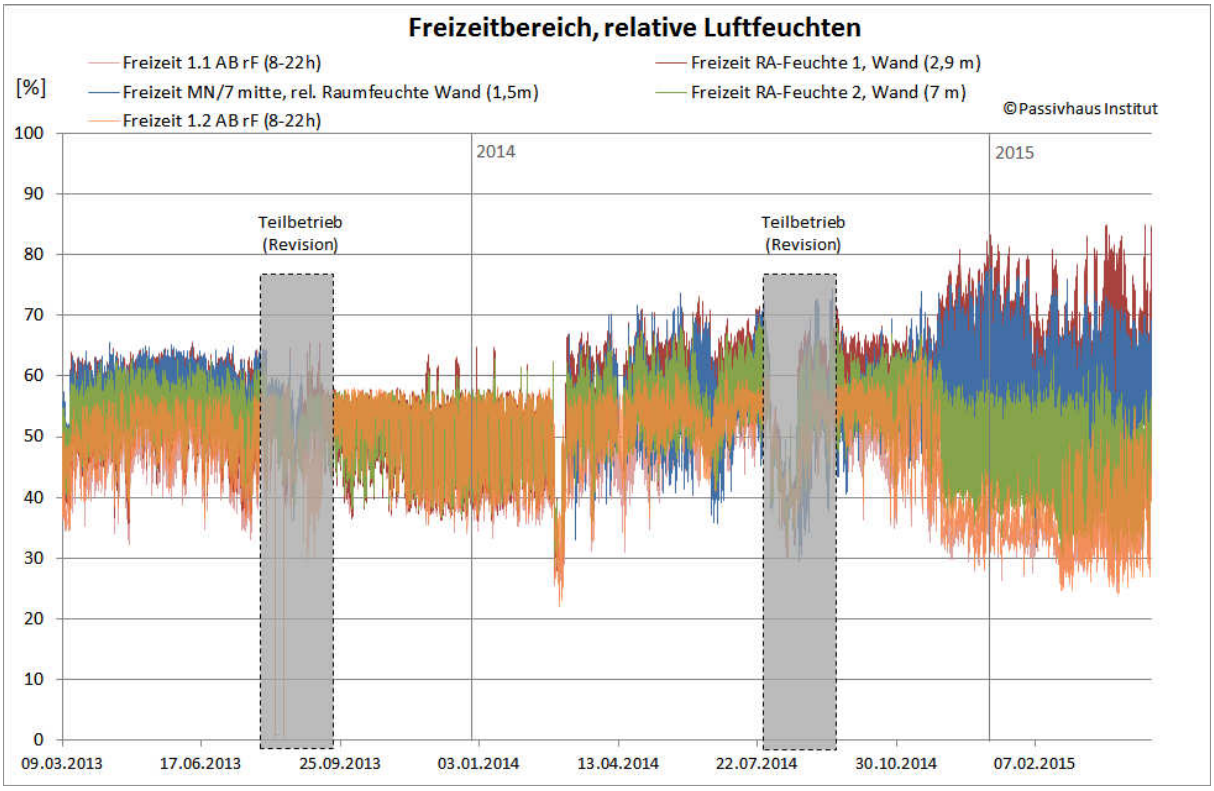


Figure 54: Course of the relative air humidity in the Leisure area: Measured data from Wall sensors in different heights and from exhaust air sensors in both Ventilation units throughout the measurement period.

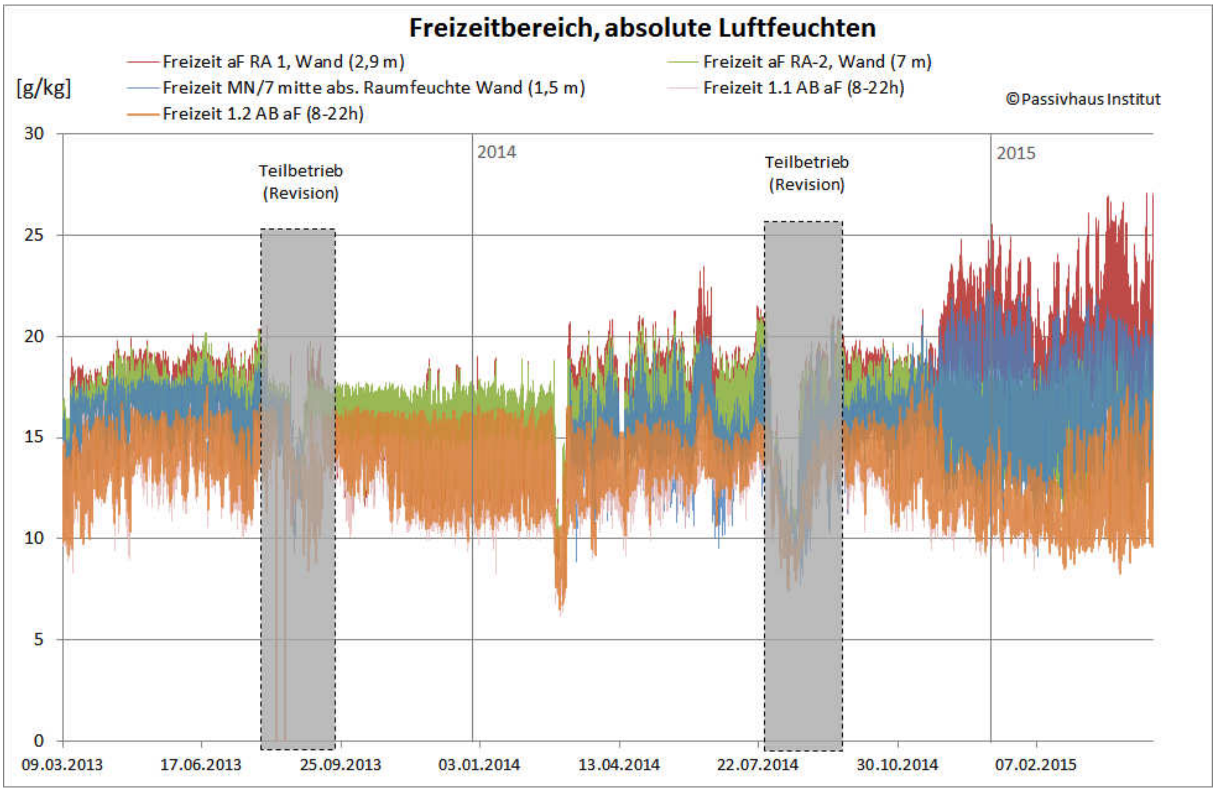


Figure 55: Course of the absolute air humidity in the Leisure area: Measured data are shown of wall sensors at different heights and of OJ air sensors in both Ventilation units throughout the measurement period.

5.6.3 Overview of teaching area

The teaching area consists of two halls, each with a swimming pool. Each hall has a wall sensor at a height of 1.5 m (teaching pool 1: TU / 11 and teaching pool 2: XY / 7, see floor plan in the appendix). The air supply for both parts is provided by a common ventilation unit. Various target temperatures were realized over the entire measurement period, which, as shown in Figure 56, are maintained by the measured air temperatures with the exception of individual outliers with a band of ± 1.5 K. Since the ventilation unit is partially switched off at night, the measured values of the exhaust air sensor are not relevant for statements about the hall conditions during this time. This is shown as an example in Figure 57. Because of this, only exhaust air values between 8 a.m. and 10 p.m. are used for display and evaluation.

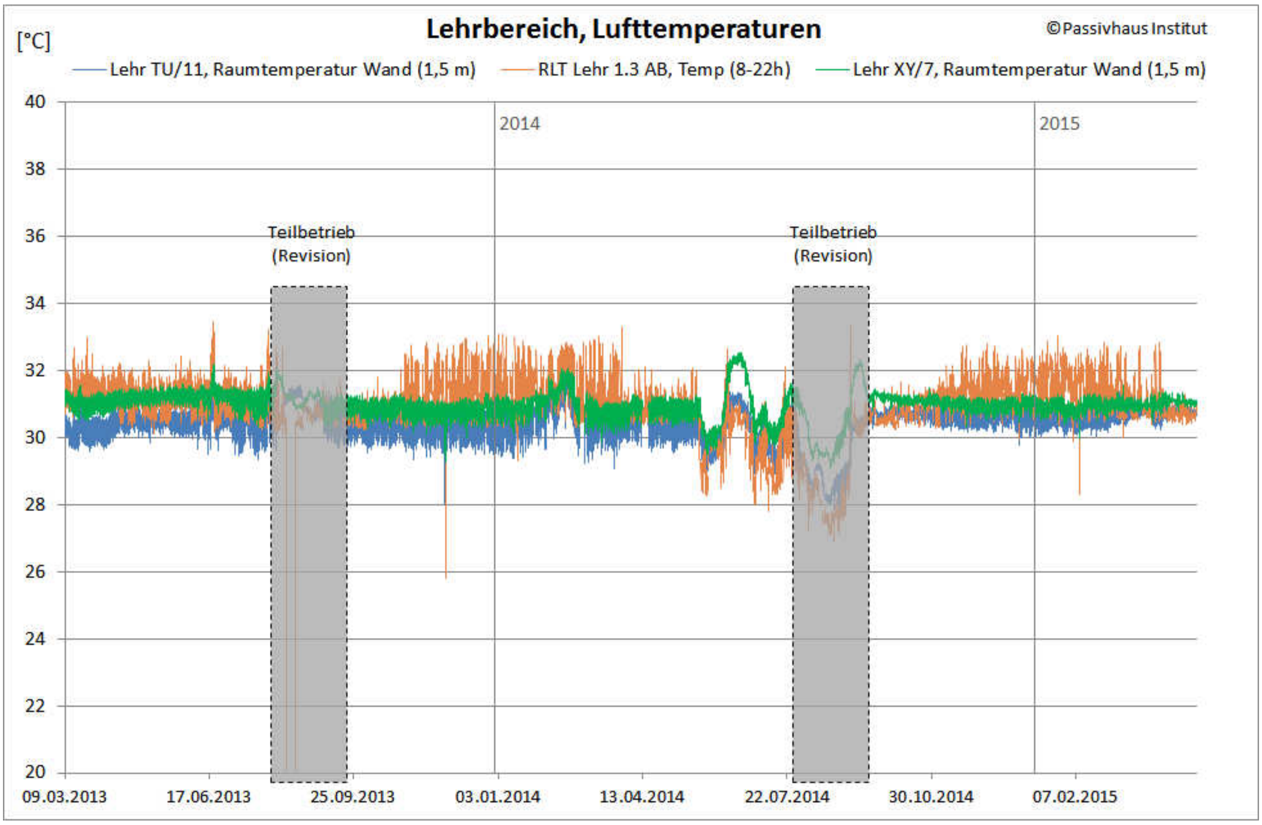


Figure 56: Course of air temperatures in the app ereich: Measured data of the Wall sensors at teaching pools 1 & 2 and exhaust air sors within the Ventilation unit in the entire measurement period.

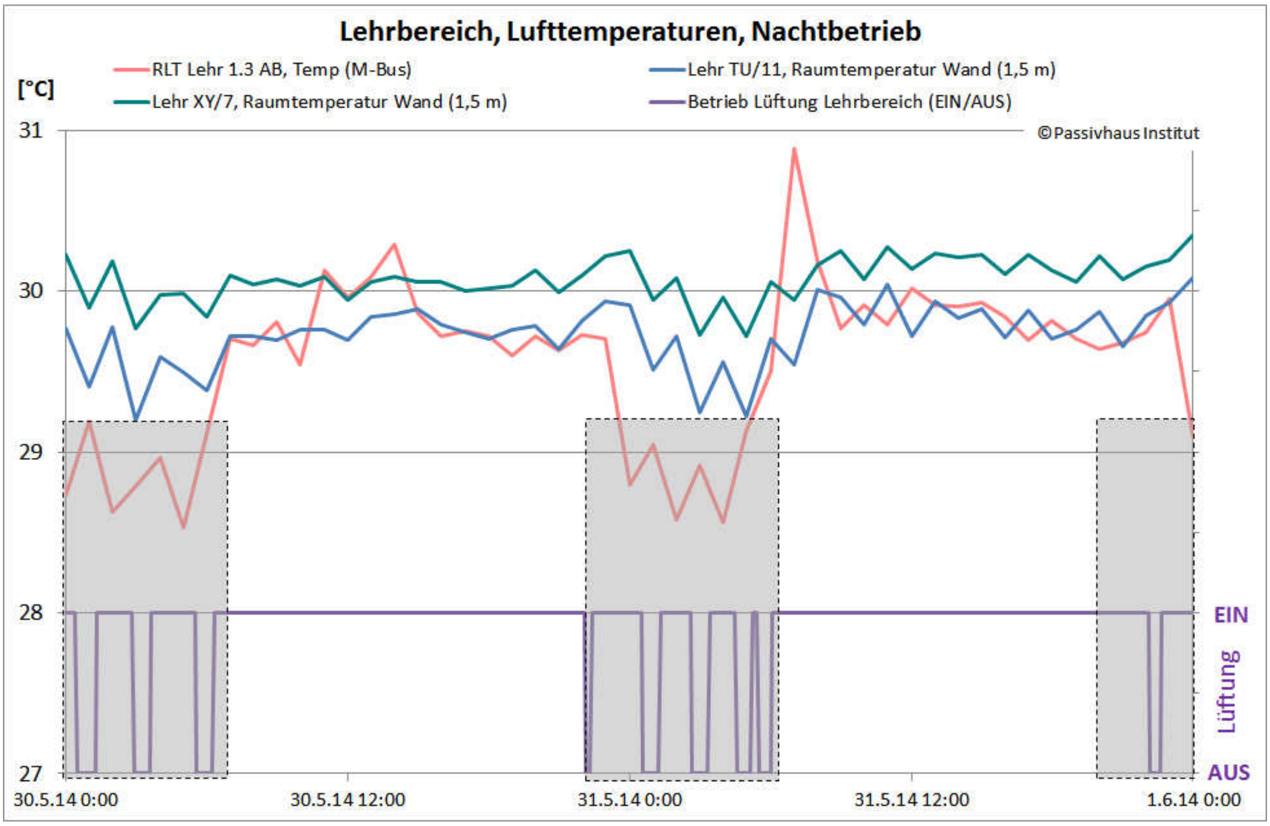


Figure 57: Course of air temperatures in the app ereich: Hourly averages of the Wall sensors at teaching pools 1 & 2 and exhaust air sors within the Ventilation unit for an exemplary period of on 48 hours. Marked in gray are the periods in which the exhaust air sensor is due the temporary shutdown of the Ventilation device (purple) for the evaluation irrele vante provides measured values.

There is a clear seasonal trend in the relative and absolute humidity in the pool area (see Figure 58 and Figure 59). This is due to the fact that, for air hygiene reasons, a minimum air change must always take place in swimming pools, which is associated with 15% of the design volume flow. This specification has priority over all other setpoint specifications. This means, for example, that the ventilation unit operates in both halls of the training pool area

always at least one Outside air volume flow of approx. 3700 m³ / h - regardless of whether the air conditions make dehumidification necessary or not. This means that in winter the hall humidity drops significantly below the setpoint if a higher volume flow is used in dry outside air than the respective dehumidification requirement provides.

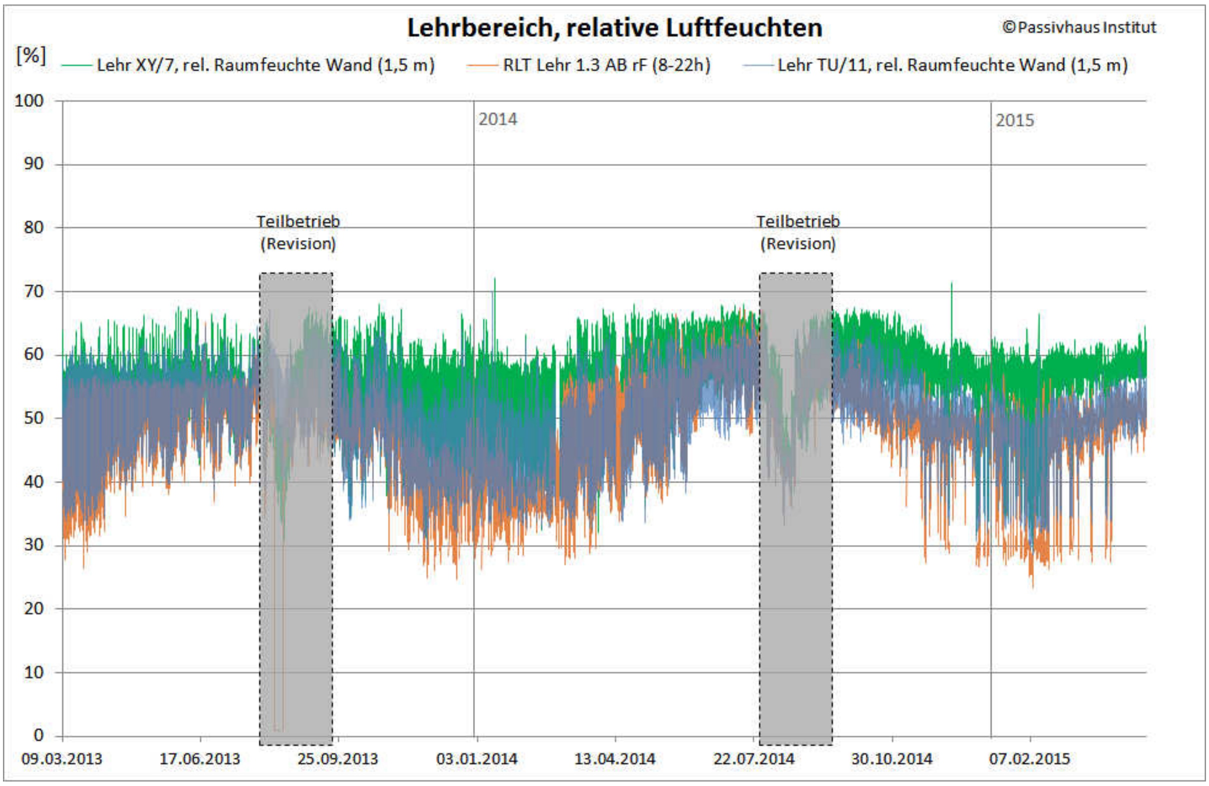


Figure 58: Course of the relative air humidity in the Teaching area: Measured data of the Wall sensors in teaching pools 1 & 2 and the exhaust air sensor within the ventilation unit throughout the measurement period.

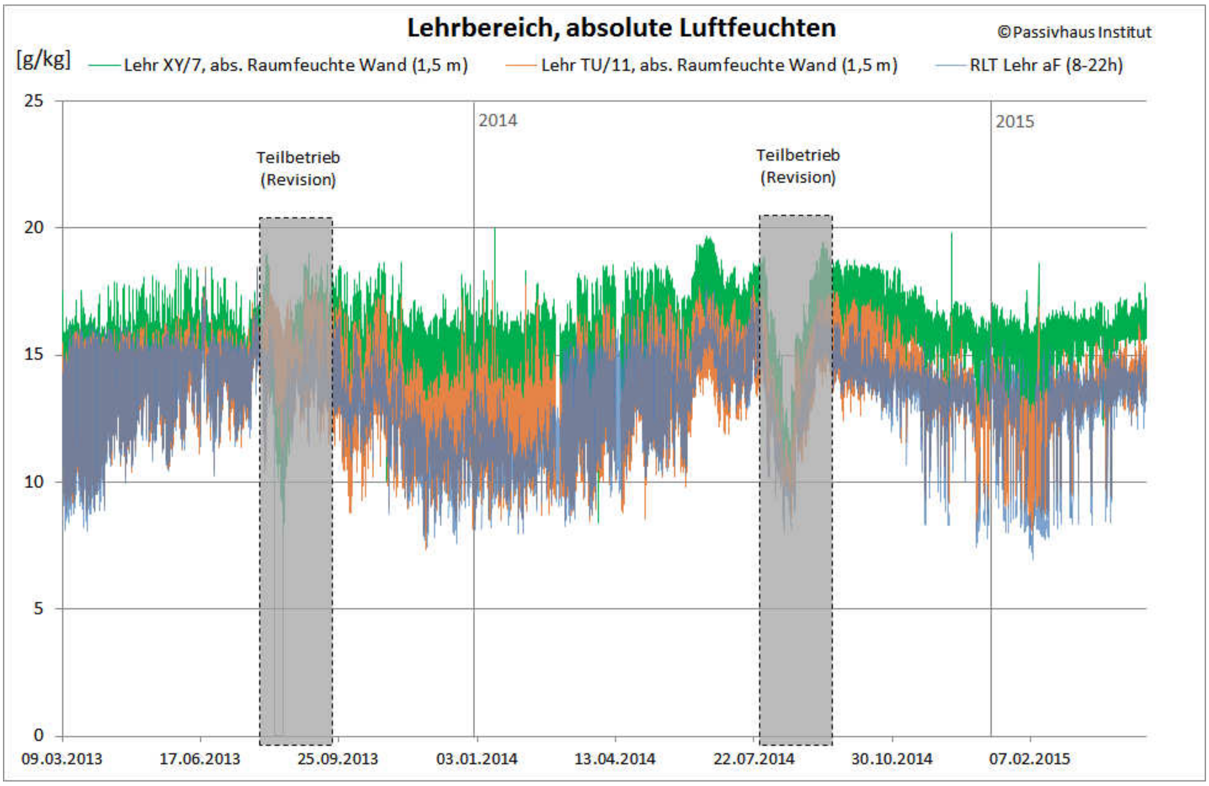


Figure 59: Course of the absolute air humidity in the Teaching area: Measured data of the Wall sensors in teaching pools 1 & 2 and the exhaust air sensor within the ventilation unit throughout the measurement period.

5.6.4 Reference sensors for hall conditions

Since the air conditions in the swimming areas can vary considerably depending on the position in the room due to possible stratification and flow influences, the question arises as to the determination of reference measuring points for temperature and humidity. Various additional temporary measurements were carried out for this purpose.

In the first of these measurements, on November 21, 2013, a comprehensive measurement network was set up at the respective heights of the permanent measuring points (1.5 m from the floor slab) using 17 temperature / humidity data loggers (see also 3.1 Temperature and humidity measurements) for approx. Four hours in the area Leisure and sports installed. Six data loggers were distributed in the sports area - one for direct renewed comparison with the permanent measuring point. The eleven other loggers were arranged in the leisure area - one for direct comparison with the permanent measuring point. Two more were placed in the area of the upper floor to check possible stratification. The measured values for temperatures and relative humidities resulting from the test were converted into absolute humidities and compared with the measured data of the permanent measuring points (on the walls and in the exhaust air). The measurement showed a good agreement with the permanent measuring points for the temperatures in both areas.

For the rear part of the sports area (axis XY), the moisture values corresponded to those of the permanent measuring point (XY / 1-2 center, wall sensor at a height of 1.5 m). At the four other measuring points in the sports area, the moisture values were significantly higher, which indicates that the rear part of the sports area is better supplied with supply air than the front. In the leisure area, the humidity values were all in a thin band within their measuring accuracy, which speaks for a uniform stratification and flow through the hall air.

In a further experiment, the stratification of temperatures and humidity at different heights at different locations in the sports and leisure area was examined over two days using 20 data loggers for temperature and relative humidity. The stratification of the air humidity is largely as expected. The evaluation shows that there is more evaporation during the day through activities in the pools than at night. It was also found that the permanently installed individual permanent measuring points (sports area Y / 1-2 and leisure area MN / 7) on the walls do not adequately reflect the climatic conditions of the halls.

especially the Permanent measuring point in the leisure area (MN / 7 center) is significantly influenced by the nearby bubble beds. Therefore, an unchecked specification of the average room humidity solely from the measurement data of these permanent measuring points is not sufficient.

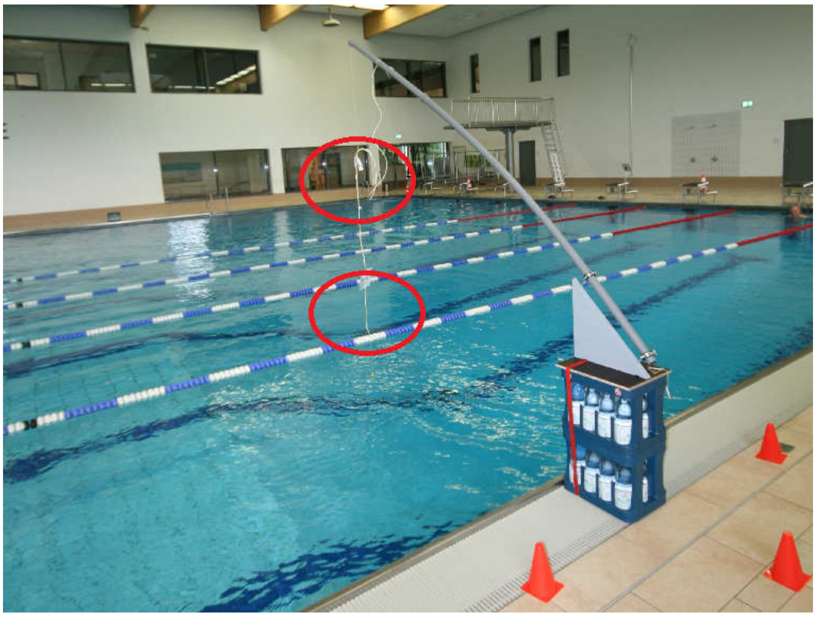


Figure 60: Measurement setup with two sensors for air temperature and humidity (red markings) at different heights above the sports pool in the B ambados

It is assumed that the temperatures and humidities of the respective exhaust air represent a mixed value of the indoor air conditions. However, since the ventilation units are not in continuous operation, but there are also wanted nightly downtimes, other measured values must be used during this.

By means of graphic and arithmetic comparisons of all existing temperature and humidity values and taking into account the two temporary measurements described, the following measurement data are used as reference values for the swimming areas:

Reference sports area

For the sports area, the mean values of the measured values of the two exhaust air sensors are used during operation of the ventilation system and the mean values of the measured values of the three RA wall sensors outside the company are used as reference values.

Reference leisure area

For the leisure area, analogous to the sports area, the mean values of the measured values of the two exhaust air sensors are assumed during operation of the ventilation system and the mean values of the measured values of the two RA wall sensors outside the company are taken as reference values.

Reference pool area

The measured values of the wall sensor at position EGTU / 11 are assumed as reference values for the area of the two teaching pools. During operation of the ventilation system, this has very good coverage with the measured values from the exhaust air.

5.6.5 Comfort

The comfort of the users of the bathroom has priority over energy savings. In [Schulz 2009], the effects on comfort were theoretically examined in accordance with the generally recognized procedure in accordance with DIN EN 7730 and ASHRAE2005. In practice, it has been shown that the individual perception of indoor air conditions can be quite different and depend on many different factors that cannot be determined theoretically. In general, a clear distinction must be made between dry and wet people. The experience in Bambados confirms that dry bathers (eg swimming trainers) prefer dry air, while dry bathers also find higher humidity levels pleasant in the leisure area. Since the criteria for comfort only need to be observed during the day (when swimming),

Recommendations for comfort

- Setpoints for air temperature and humidity during opening times in swimming pools should be tried out in practice and selected according to user requirements.
- Positions of wall sensors that are to be used for control purposes should be chosen with care. In addition, the quality of the sensors and their calibration must be valued and their condition checked regularly.
- It makes sense to structurally separate areas of different uses (sports area, leisure area, relaxation area etc.) with regard to temperature and humidity.
- For leisure or adventure areas, a "tropical climate" with increased humidity can be desirable.
- It is not only for reasons of energy saving that the proportion of recirculated air in the ventilation units should be reduced as much as possible, as this also avoids possible drafts.

5.6.6 Building protection

With the high component quality, high internal surface temperatures are achieved all year round. This means that higher levels of humidity can be achieved in passive house indoor pools than in bathrooms with poorer cover. The air change can thus be reduced, which directly results in reduced power consumption for the ventilation units and heating energy consumption for the indoor air. Indirectly, this means lower evaporation rates and thus also lower heating energy consumption for reheating the pool water. An increase in the humidity in the hall can lead to high moisture levels or condensation on the thermal bridges of building envelopes in standard bathrooms.

The calibrated window surface sensors (glass edge) consistently showed measured values that were at least 3 K above the respective dew point of the hall air even at cold outside temperatures from -8 ° C to -12 ° C. At the time with the lowest measured outside temperature in the measurement period, the hall conditions (air temperature and humidity) result in a dew point of
16.0 ° C, while the lowest measured window surface temperature is over 19° C (see Figure 61). This means that condensate formation at measuring points X / 1-2 in the sports area, / 11 in the leisure area and W / 10 in the teaching area can be ruled out during the entire measurement period.

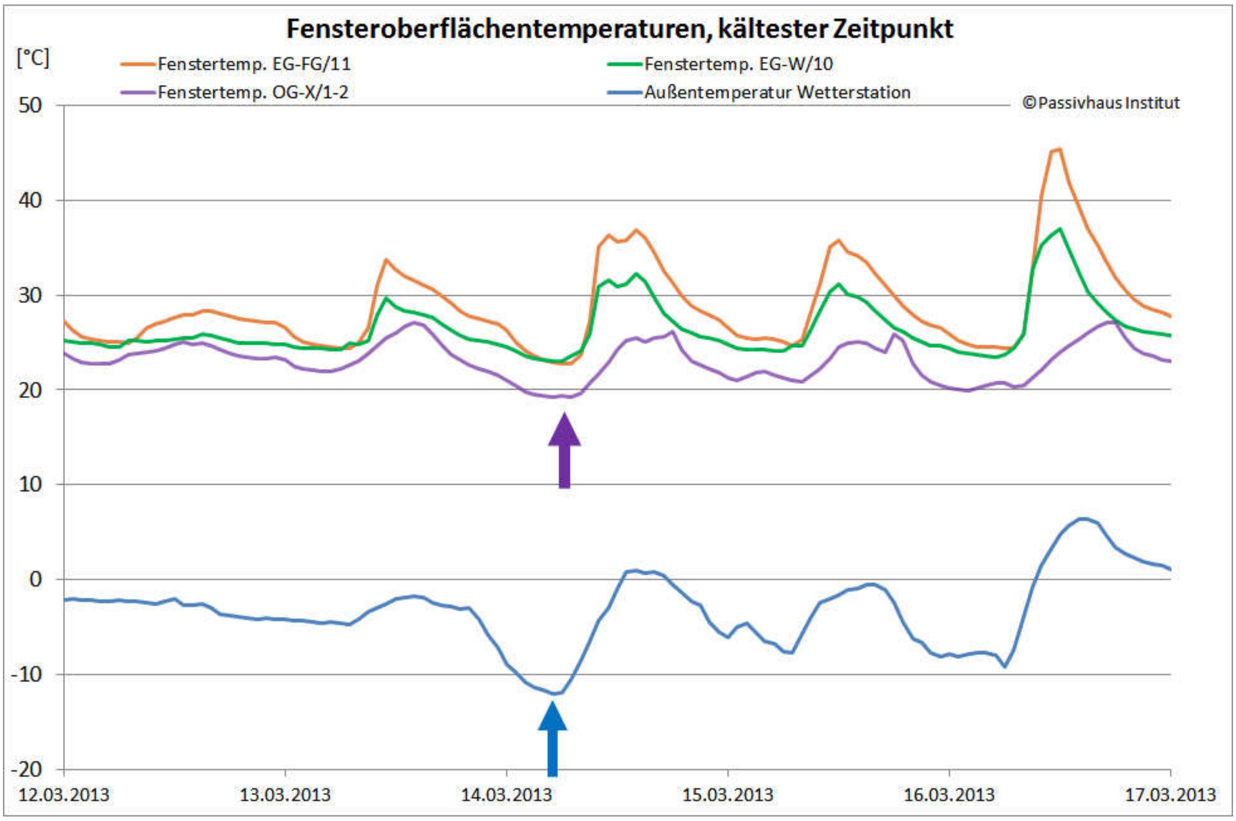


Figure 61: Window surface temperatures with Au outside air temperature at the coldest time in the entire measurement time. With an outside air temper at -12.1 ° C (blue) a minimum temperature of 19.2 ° C (purple) on one Window surface in the Sports area measured. (The high peaks of the windows surface temperatures are caused by solar radiation.)

The Bambados is inspected annually by an expert to check that there is no damage to the building, as well as regular maintenance by all relevant specialist companies.

recommendations

In the Bambados, the passive house building envelope contributes significantly to building protection. Regardless of whether it is an indoor swimming pool based on the passive house concept or not, the following recommendations can be made under the relevant air conditions (humidity, temperature and chemical composition):

- For orientation purposes, temperature and humidity sensors with high measuring accuracies (T: ± 0.1 K; RH: ± 1% in the relevant areas) should also be used in the vicinity of critical points of the building envelope may be installed. These should be calibrated and their measured values checked regularly for plausibility.

- Exhaust air sensors and sensors that reflect the air conditions for bathers and for Ventilation control serve and therefore crucial for the real ones Indoor air conditions, should have high measuring accuracy, be calibrated and checked regularly.

- It is conceivable that in the future corrosion sensors, which can also be installed in inaccessible places, will be a reliable indicator of the absence of structural damage.

- Regular inspections of the component status in the inventory by independent experts must be carried out in any case.

5.6.7 Air quality: trihalomethane concentrations n

The Bambados is operated with a ventilation strategy that has been changed compared to standard indoor pools. The most important point here is the reduction or the complete elimination of the air circulation in the halls. In order to control the indoor air quality, the PHI had the measurement of the concentration of trihalomethanes (THM) in the indoor air at nine different measuring points. The measurements were carried out by an employee of the Chemical Laboratory Graser (CLG) on February 6th, 2014 and accompanied by an employee of the PHI. For this purpose, the air at each of the measuring points was sucked 20 cm above the water surfaces of the pools for 20 minutes at a volume flow of 1 l / min onto activated carbon and subsequently analyzed in the laboratory. At the

11.03.2014 the measurement was repeated with changed ventilation settings (without circulating air) and otherwise the same conditions (same measuring points, same measuring method and same sampler) [CLG 2014].

In contrast to the pool water concentration (as yet) there are no standard or norm values for THM in the air, reference can only be made to literature values. The THM values shown as the result are standard values of the sum of the four individual parameters measured (trichloromethane, bromodichloromethane, dibromochloromethane and tribromomethane), weighted converted to the compound trichloromethane.

According to publications by the Federal Environment Agency (1994) and Eichelsdörfer (1996), the mean for 70 measurements of the THM concentration in indoor pool air at a height of 20 cm above the water surface is 36 µg / m³ (minimum 7.3 µg / m³ and maximum 219 µg / m³) [GSF 1997]. Studies by the Baden-Württemberg State Health Office in recent years have shown 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]. The following graphics each show the volume flows of the ventilation devices (supply and outside air) with the THM measured values and the air temperatures temporarily measured by the sampler, relative humidity and the respective number of bathers within a radius of approx. 10 m.

Simultaneously with the air measurements, the commissioned laboratory also took and analyzed samples of the pool water. The THM concentrations found in the water were approximately the same between 9 and 14 µg / l in all measurements. A floor plan with the positions of the measuring points can be found in the appendix.

Figure 62: Measurement of trihalomethanes 20 cm above the water surface of the Leisure pool, air intake on activated carbon

Indoor air teaching pool

The results of the examinations of the indoor air in the two training pools on the two measurement days are shown in Figure 63 and Figure 64. There is one measuring point for each pool (MS7: pool 1; MS8: pool 2). The blue lines indicate the period of the THM measurements and the level of the THM concentrations determined (refer to the right y-axis).

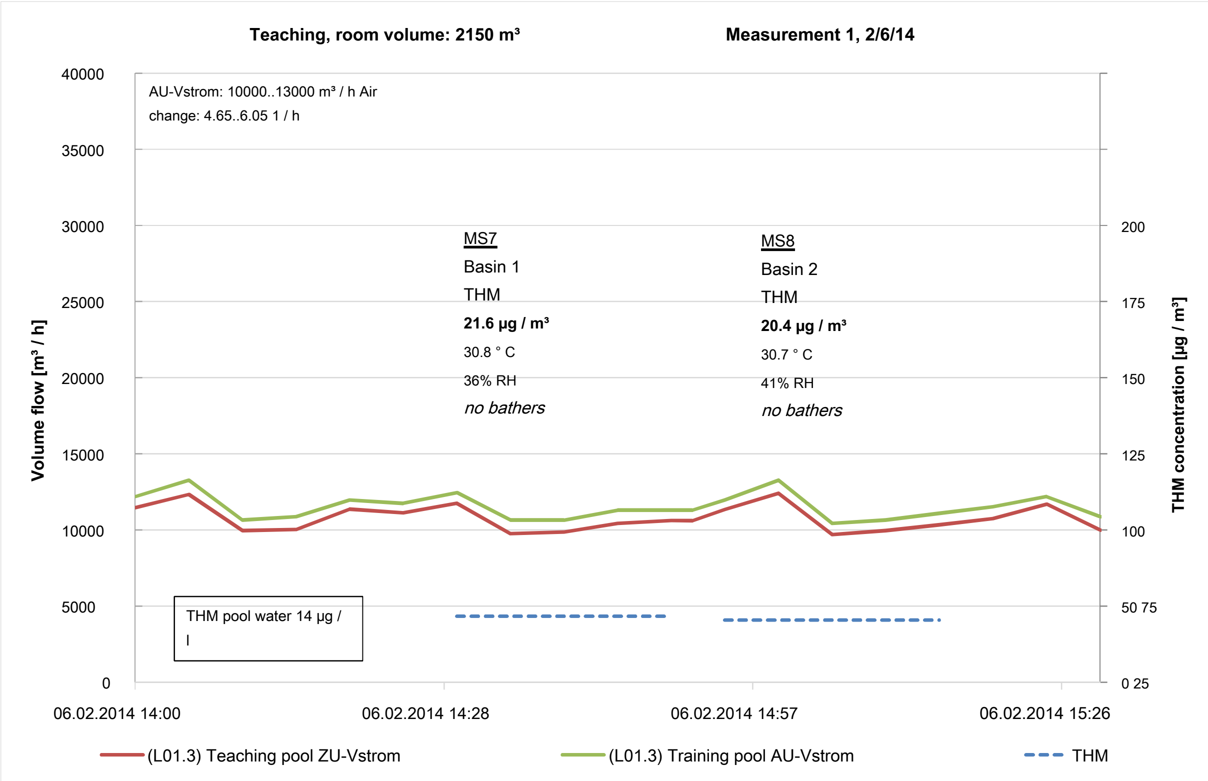


Figure 63: Measured values for basin 1 and 2 for volume flows and THM of the first measurement (06.02.14), measuring points 7 and 8

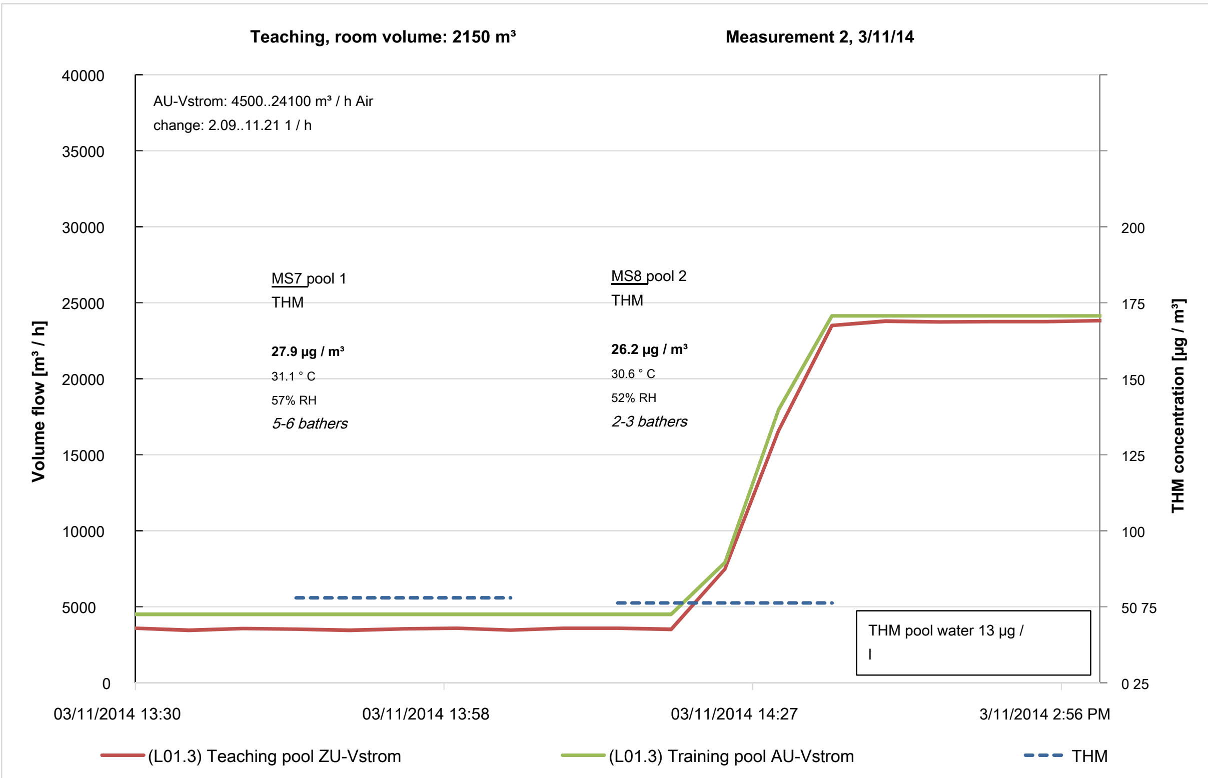


Figure 64: Measured values for basin 1 and 2 for volume flows and THM of the second measurement (11.03.14), measuring points 7 and 8

The THM measured values of the two teaching pools are between 20.4 and 27.9 µg / m³ compared to the average values from the literature on both days in a low range. The values of the second day of measurement are slightly above those of the first. It cannot be deduced from the available samples whether the cause is due to the temporarily lower volume flow and / or the number of bathers. There was no forced air circulation on both days.

Indoor air leisure pool

The results of the examinations of the indoor air of the leisure pool on the two measurement days are shown in Figure 65 and Figure 66 (first measurement, February 6th, 2014) and Figure 67 (second measurement, March 11th, 2014). Three measuring points (MS1, MS2 and MS9) were set up in the hall of the leisure pool.

The blue lines indicate the period of the THM measurements and the amount of the THM concentrations determined (refer to the right y-axis).

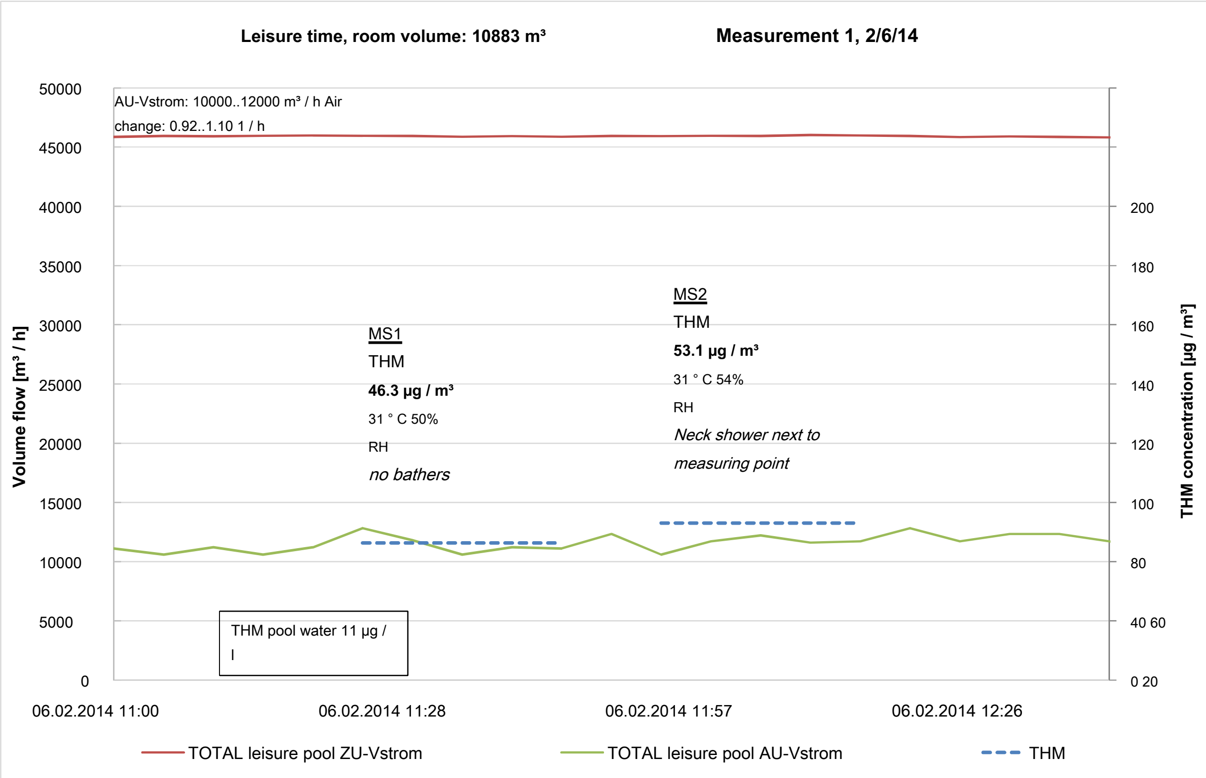


Figure 65: Measured values of leisure pools for volume currents and THM of the first measurement (06.02.14), Measuring points 1 and 2

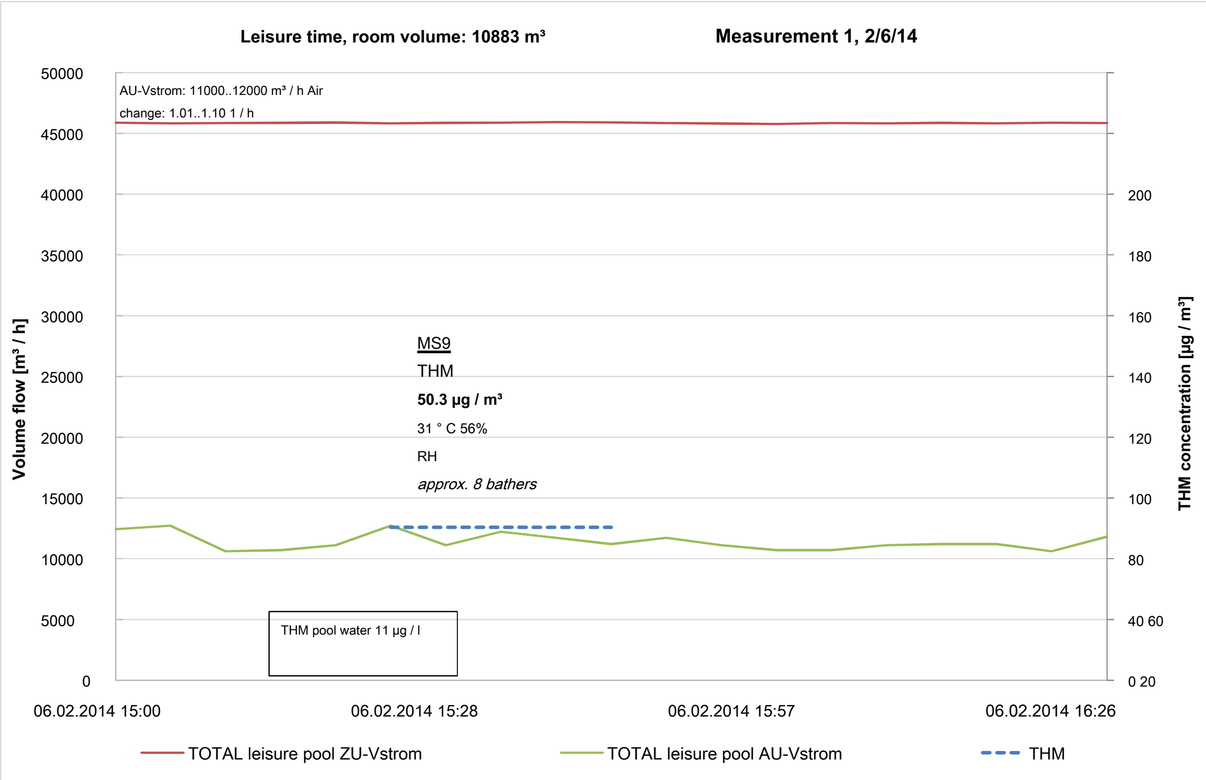


Figure 66: Measured values of leisure pools for volume currents and THM of the first measurement (06.02.14), Measuring point 9

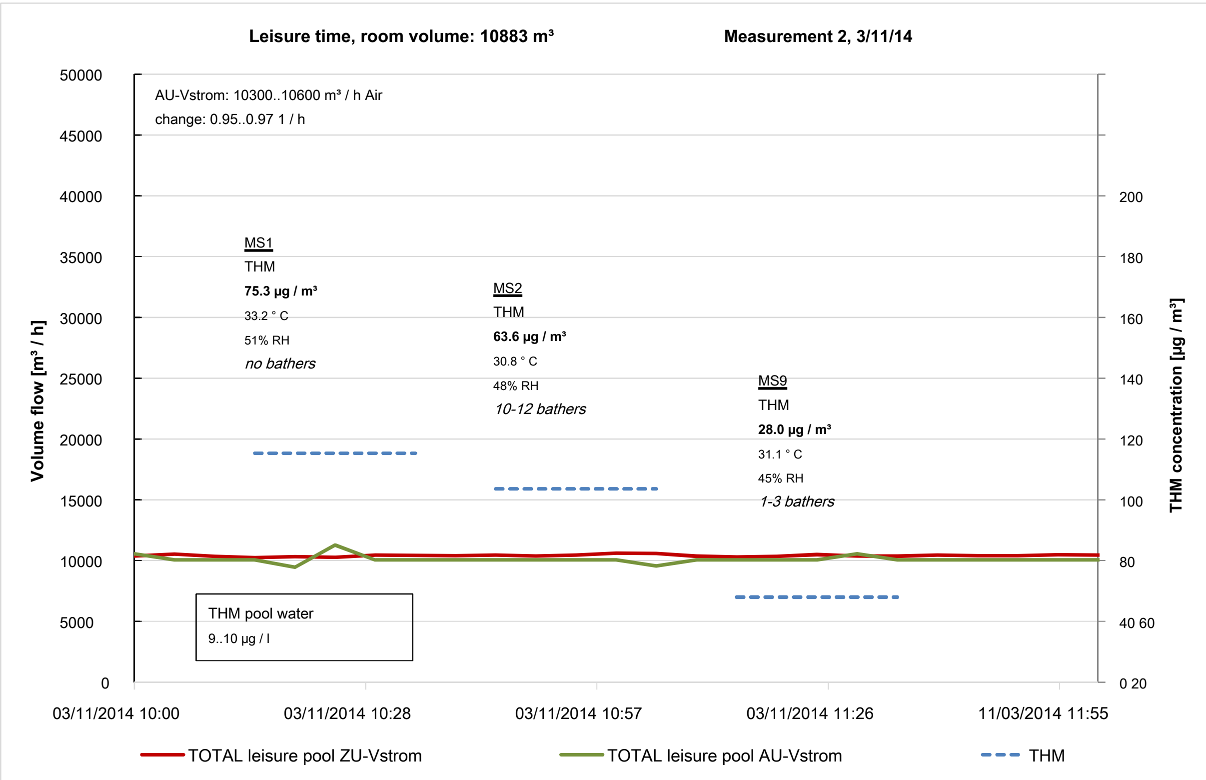


Figure 67: Measured values of the leisure pool for volume currents and THM of the second measurement (11.03.14), Measuring points 1, 2 and 9

For the first measurement (06.02.14), the THM measured values of the leisure pool lie immediately around the average of the Baden-Württemberg State Health Office of approx. 51 µg / m³. In the second measurement (11.03.14), somewhat higher values were found for measuring points MS1 and MS2 at the leisure pool. In contrast, a lower value was measured for measuring point 9.

Compared to the first measurement, the circulating air portion is omitted in the second measurement (supply air volume flow: 10,000 instead of 46,000 m³ / h). Since the THM values of the second measurement are clearly the lowest for MS9 despite the unchanged outside air volume flow, the reduced circulating air cannot be the reason for the higher values for MS1 and MS2. Further clarification of the causes (number of people, activity, circulating air and outside air volume flow) are necessary in order to analyze the relationships more precisely.

Indoor air sports pool

Four measuring points (MS3, MS4, MS5 and MS6) were set up at the sports pool with the 50-meter lanes to examine the indoor air. The results of the examinations of the indoor air of the sports pool on the two measurement days are shown in Figure 68 (first measurement, 06.02.14) and Figure 69 (second measurement, 11.03.14). The blue lines indicate the time period of the measurements and the level of the determined THM concentrations (secondary y-axis).

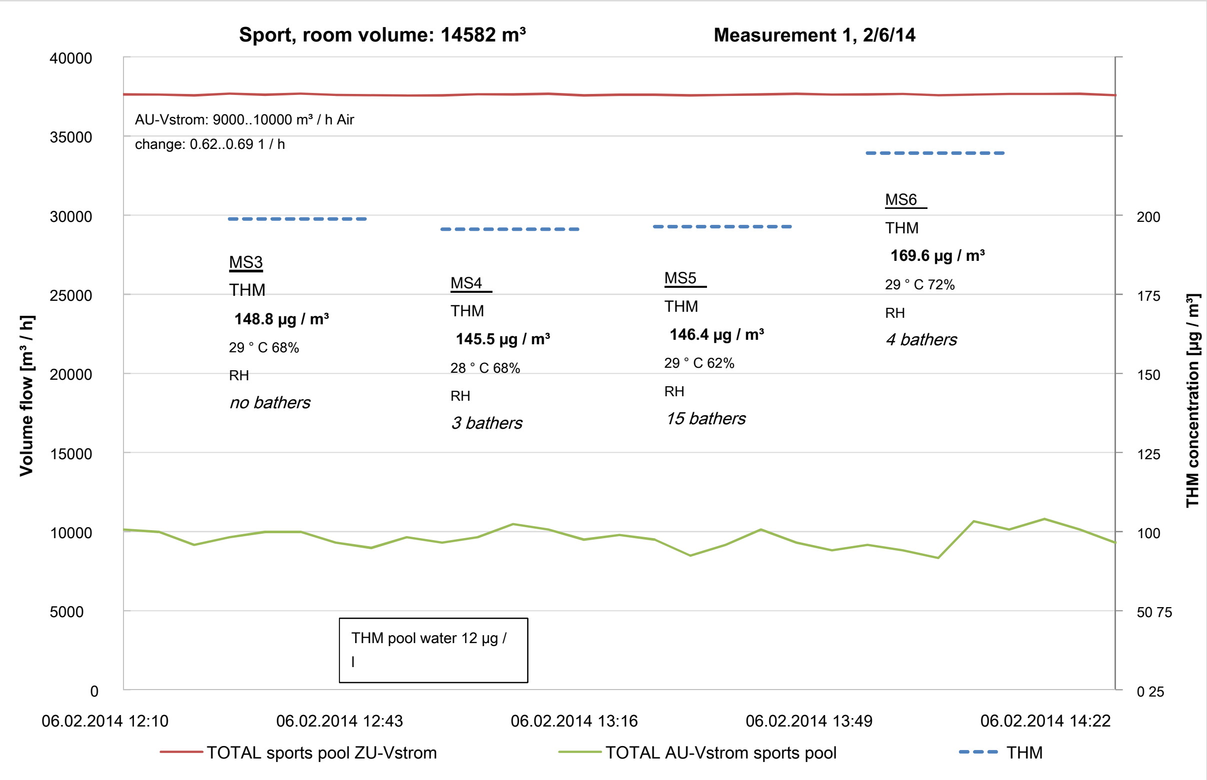


Figure 68: Measured values for sports pools for volume flows and THM of the first measurement (06.02.14), Measuring points 3, 4, 5 and 6

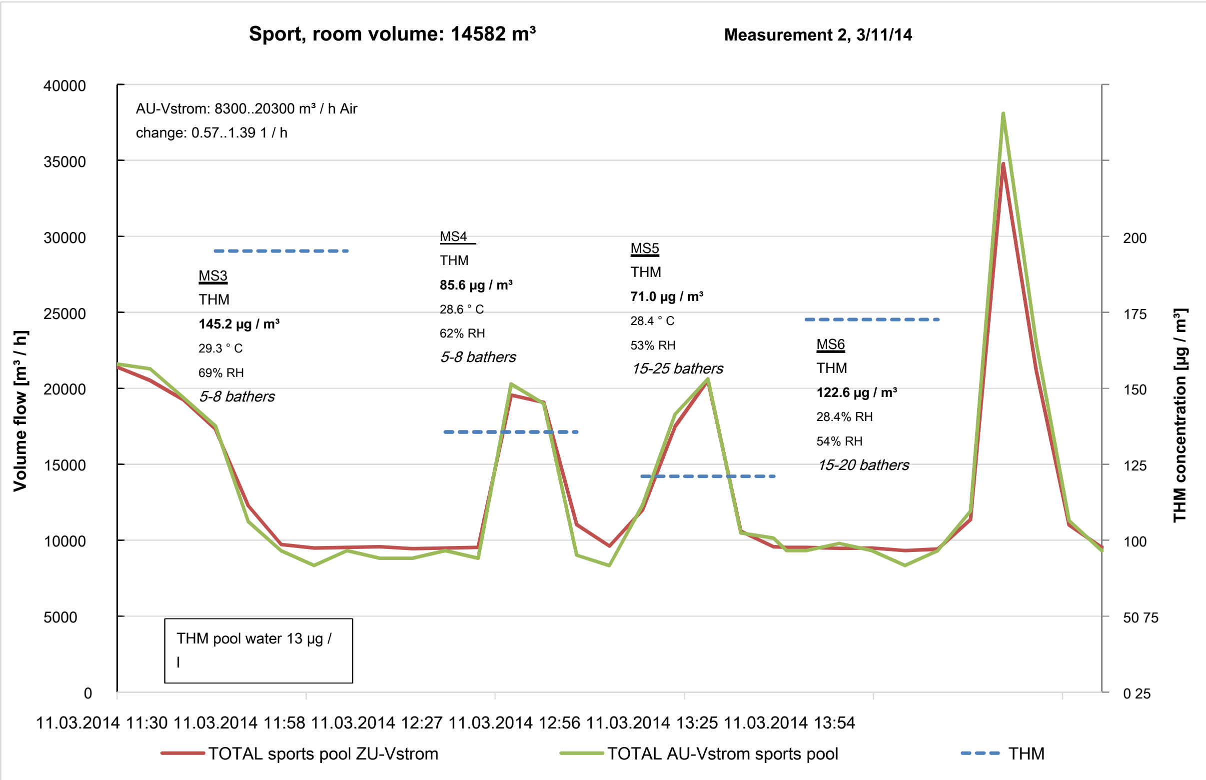


Figure 69: Measured values of the sports pool for volume flows and THM of the second measurement (03/11/14), Measuring points 3, 4, 5 and 6

The THM measured values in the sports pool reach comparatively high values, regardless of the amount of recirculated air in the supply air (approx. 37,500 m³ / h on the first day of the measurement, see (Figure 68)). The initially obvious assumption that the values of the second measuring day at measuring points 4 and 5 are lower because the outside and circulating air volume flow has been temporarily increased is due to the high value at the measuring point 3 (there is an increased volume flow before and during the first half of the THM measurement) not confirmed. Otherwise, this should have the effect of reducing the THM measured value. In this case, the present orientation measurement is not sufficient to be able to conclude the causes.

However, it must be assumed that the introduction and extraction of air on the same level on the hall ceiling or the introduction of the supply air through the existing swirl outlets (low-impulse) are reasons for poor hall flow. This assumption is also supported by the analysis of smoke tests by Mr. Kaluza (Fa. Inco) [Kaluza 2014]. The simultaneous installation and extraction on the ceiling could be optimized by installing the exhaust air valves in the lower part of the hall.

Summary: THM concentration

Overall, the sample-like THM measurements of the hall air in three of the four halls of the Bambado show low to average THM concentrations in relation to the comparative values from the literature. In contrast, the measured values are increased in the sports sector; the circulating air volume flow on the first day of measurement does not improve this. The reason for the higher THM values is the unfavorable position of the air intake and extraction (both on the ceiling) or the low-impulse

Air supply suspected. To remedy this, there is a proposal for the relatively easy-to-implement relocation of the exhaust air intake to the lower part of the hall.

The exact correlations and causes of the level of the THM concentrations in the indoor air in relation to the THM concentration in the pool water, the ambient and outside air proportions, the number of bathers and the activity of the bathers cannot be determined with the help of this orientating study. It turns out, however, that the reduction in the circulating air volume flow does not seem to have a negative influence on the THM concentration in the air.

The analysis values are summarized in the following table as an overview of all THM measurements on both examination days:

Table 8: **Trihalomethane concentrations of the Hal lenluft on two measuring days**

THM concentration [µg / m³]	Day 1 (06.02.2014)	Day 2 (11.03.2014)
Educational pool		
MS 7	21.6 without air circulation	27.9 without air circulation
MS 8	20.4 "	26.2 "
Leisure pool		
MS 1	46.3 with air circulation	75.3 without air circulation
MS 2	53.1 "	63.6 "
MS 9	50.3 "	28.0 "
Sports pool		
MS 3	148.8 with circulating air	145.2 without air circulation
MS 4	145.5 "	85.6 "
MS 5	146.4 "	71.0 "
MS 6	169.6 "	122.6 "

5.7 Ventilation hall

The task of ventilation in a swimming pool is to dehumidify and ensure good air quality. In addition, the supply air is used to heat the hall using a heating register in the supply air. Based on the basic investigation [Schulz 2009], the following concept was started in the planning phase.

5.7.1 Concept

The devices were designed according to the maximum volume flow according to [VDI 2089] (referred to here as "VDI 100%"). During operation, the outside air volume flow required for dehumidification should be used during the day, but at least 15% of the maximum volume flow (see [VDI 2089]). An additional circulating air flow can be dispensed with due to the thermally high-quality building envelope. The ventilation units are to be switched off at night, while the level of humidity in the hall is monitored by sensors in the room. If necessary, the ventilation units are switched on for dehumidification. Before operation, the air in the room is exchanged and if necessary the slight drop in temperature during the night is compensated for. Since higher humidity results in lower energy consumption, the humidity at night, as far as possible in terms of building physics. During the day, the level of moisture must primarily depend on the comfort of the user. In contrast to the usual driving style according to [VDI 2089] with constant supply air volume flow (outside and recirculating air volume flow), this varies in the Bambados. For this reason, the introduction of air into the hall (and thus the flow of room air) should be ensured by blocking supply air valves by means of flaps, even with a low volume flow.

When the Bambados was put into operation, the ventilation systems did not run according to this concept, but partly with standard programs from the device manufacturer. Unfortunately, the desired regulation was only implemented gradually in the ventilation unit program over a long period of time. With this in mind, the graphs and numerical values in this report should be considered.

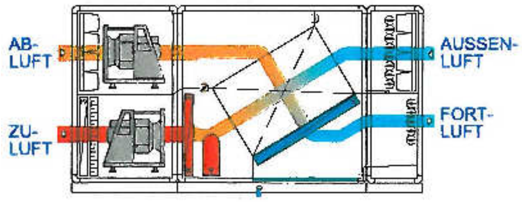
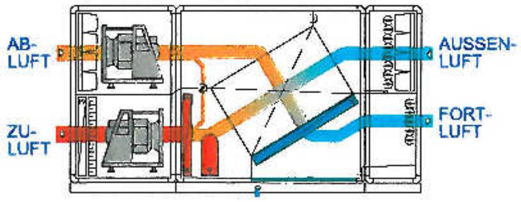
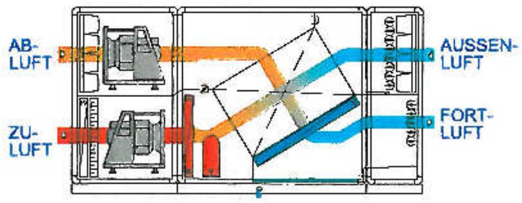
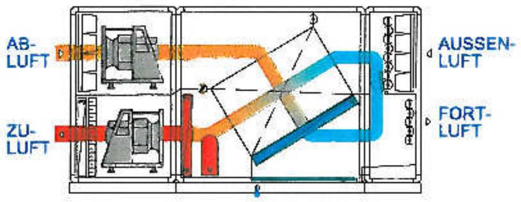
Daytime operation		
a		Pure outdoor air operation: • Dehumidifying: Exhaust air becomes by drier outside air replaced. • Energy recovery through heat exchangers and heat pumps • If necessary, supply air is reheated.
a '		If the volume flow of the supply air is not sufficient to heat the hall, "heating" recirculated air is also used (recirculated air does not go through the heat exchanger).
Nac htbetrieb a		
		If there is a need for dehumidification, pure outside air operation is carried out as in day operation.
b		If the outside temperatures are very cold, "dehumidification" can be used as an alternative: • Dehumidification by heat pump (WP) • Heat recovery through a heat pump

Figure 70: Operating modes of the hall ventilation units te (pictures by Menerga, edited by Passive House Institute) In practice has been shown , that only one mode of operation (a) is required as long as the heat pumps are not in bed are rubbed.

5.7.2 Overview of operating modes

The following three diagrams show an overview of the operating modes of the ventilation units for the hall over a longer period of time. As expected, a correlation between the outside volume flow and the absolute humidity of the outside air can be seen in all devices. The seasonal fluctuations are more pronounced in the sports and teaching area than in the leisure area.

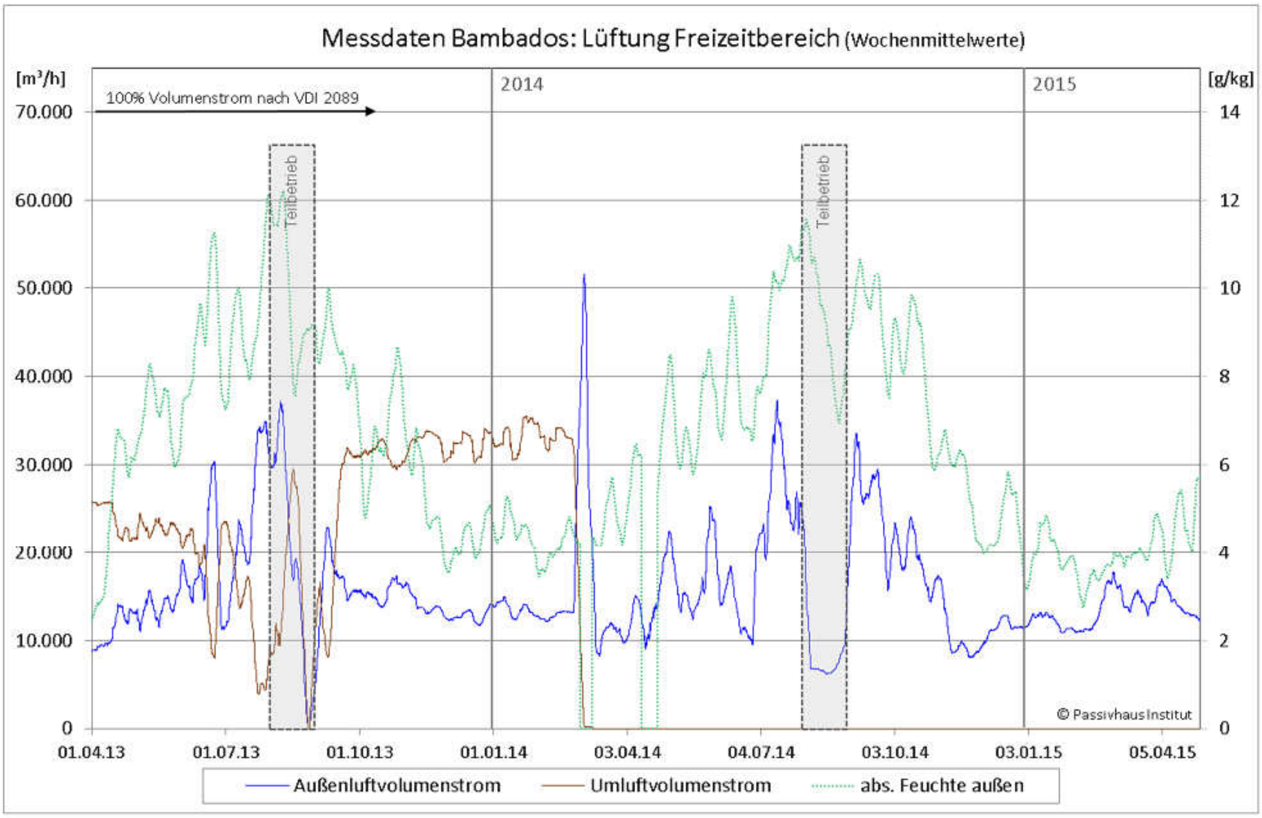


Figure 71: Overview: Operating mode ventilation unit te free time (shown are in the Hourly interval the moving weekly averages)

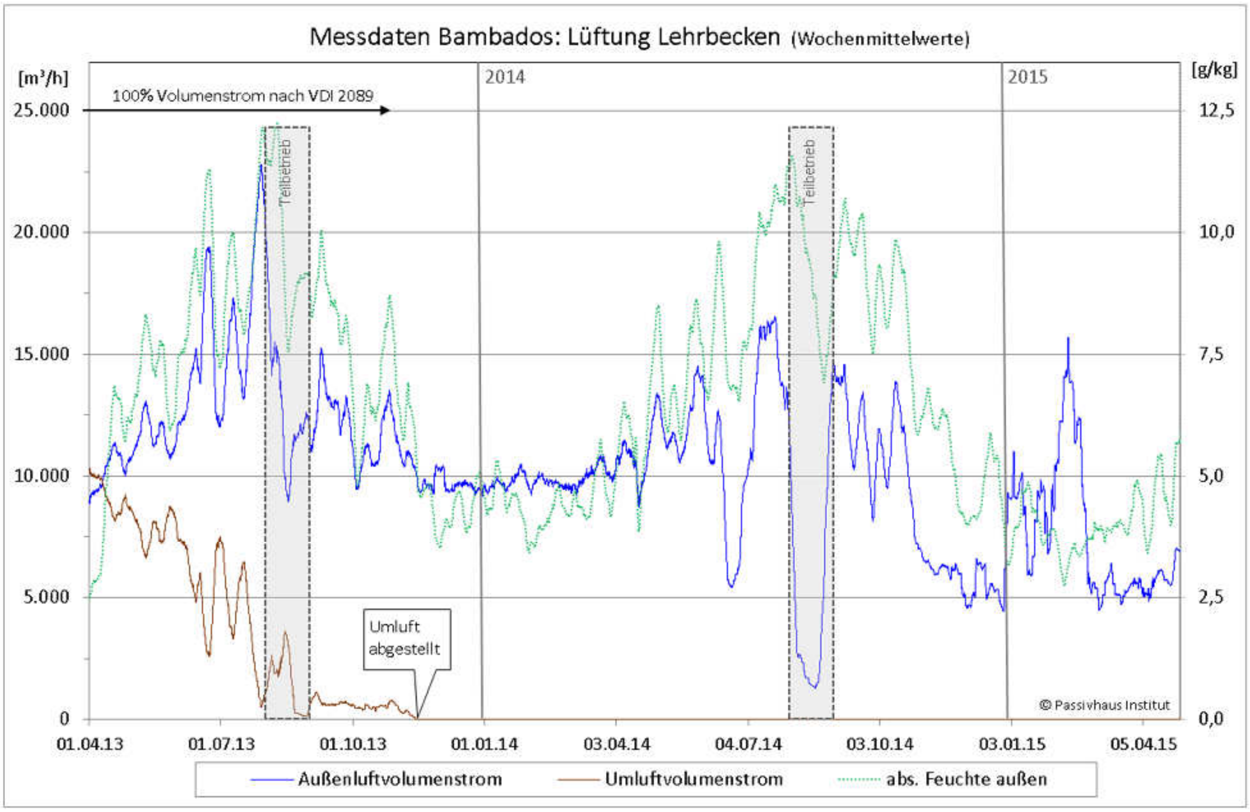


Figure 72: Overview: Ventilation unit operating mode te teaching pool (shown are in the Hourly interval the moving weekly averages)

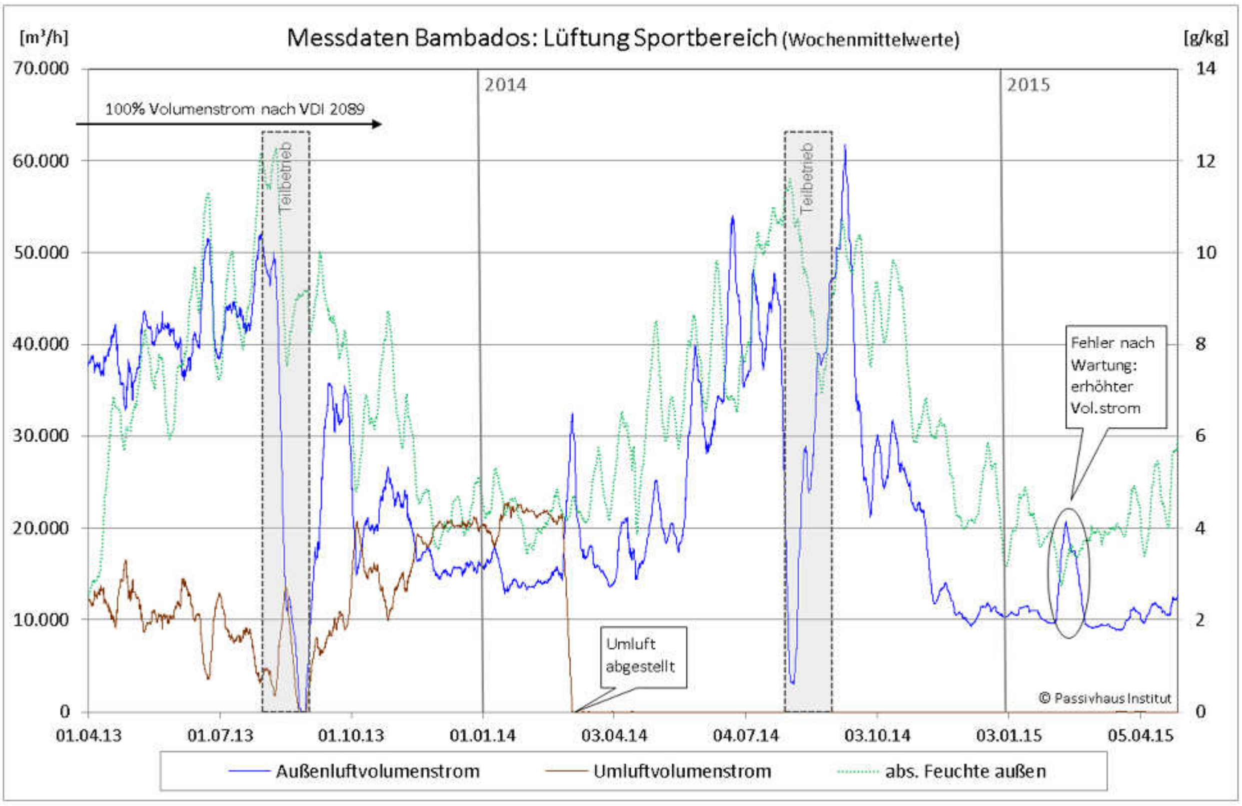


Figure 73: Overview: Operating mode ventilation unit te sport + slides (are shown in the Hourly interval the moving weekly averages)

The hall is dehumidified by replacing damp exhaust air with dry outside air. This means that the volume flow shown in blue dehumidifies and at the same time ensures fresh outside air, while the circulating air volume flow (brown) does not contribute to these two tasks. In figure 71 in winter 2013/2014 it can be seen particularly clearly that a high circulating air volume flow must be conveyed by the fans of the ventilation units. This circulating air volume flow has no use, but doubles the supply air volume flow during this period, ie the electricity costs are more than twice as high. As can be seen in the diagrams, the devices could be gradually switched over to operation without recirculation, which is also clearly noticeable in terms of power consumption.

(Supplement to the previous diagrams: The ventilation units are technically equipped in such a way that they can drive a recirculating air component past the heat exchanger ("recirculating air heating", brown curve) and a recirculating air component via the heat exchanger and the evaporator ("recirculating air dehumidification"). " Circulating air dehumidification is included in the blue curve (outside air), but it only takes up a small proportion.

5.7.3 Volume flow and power consumption

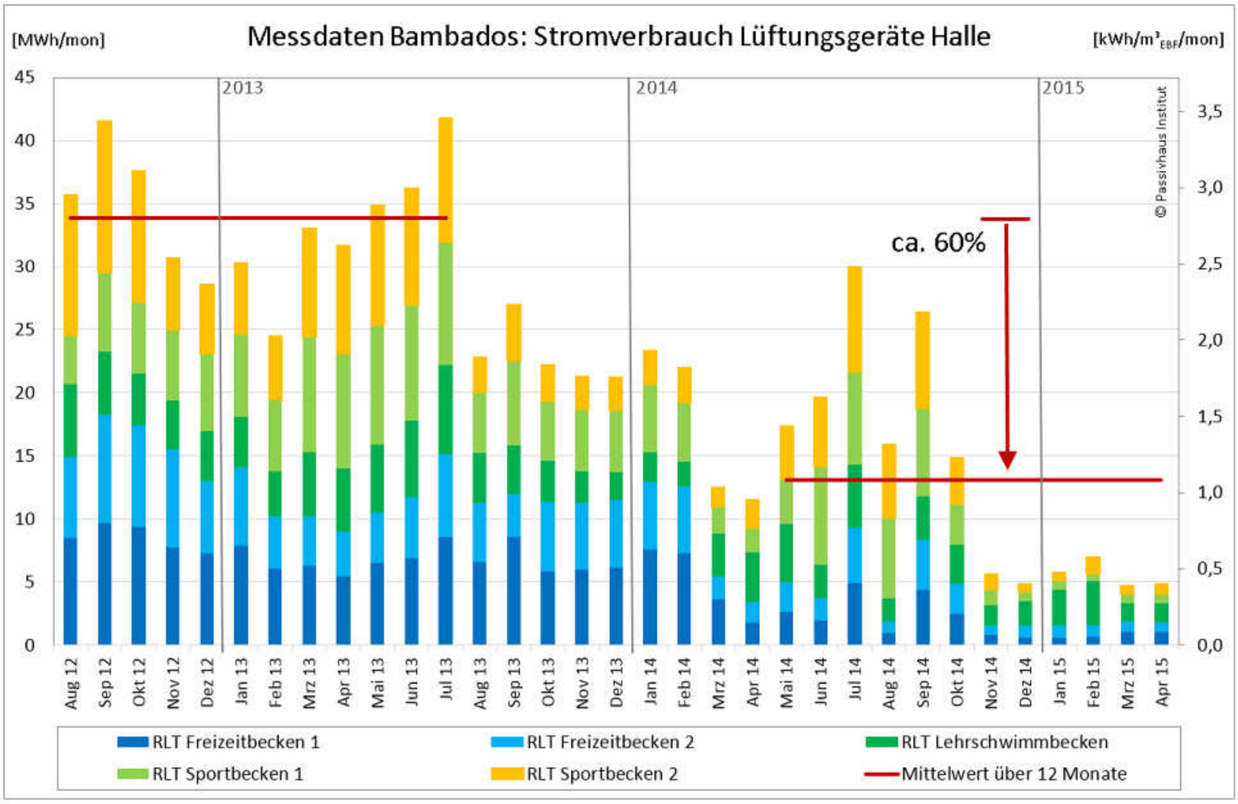


Figure 74: Power consumption of the ventilation units for the swimming pool area. By Optimizing the control during operation significantly reduced power consumption. (The average are shown in red monthly values averaged in each case over twelve months.)

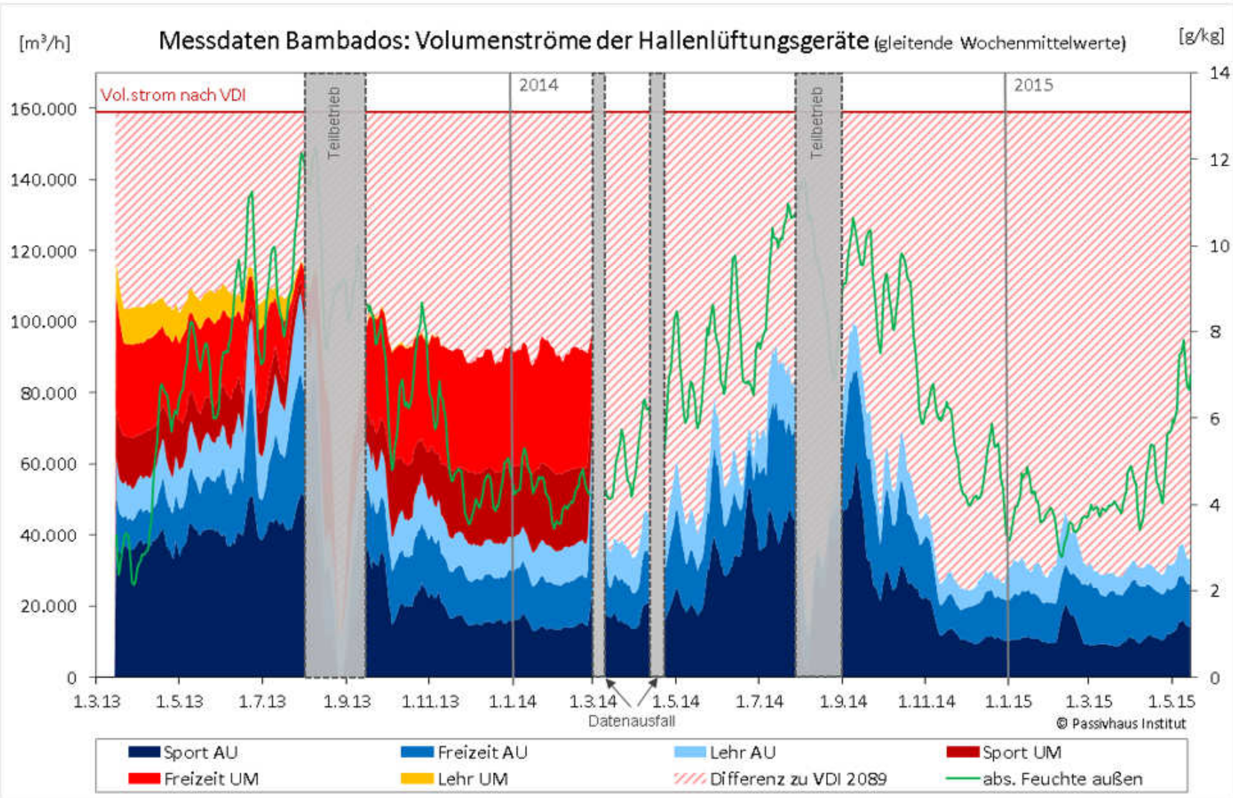


Figure 75: Volume flows of all hall units (AU = Outside air, UM = recirculating air)

Figure 74 shows a significant decrease in electricity consumption for indoor ventilation. This was achieved by optimizing the ventilation control. The most relevant changes were night operation (ventilation units switched off, but with humidity monitoring) and operation without circulating air volume flow. Figure 75 shows how the volume flow of the hall units could be reduced. The annual electricity consumption for indoor ventilation was thus reduced by over 60% in the period shown (consumption: August 2012 to July 2013: approx. 400 MWh; May 2014 to April 2015 approx. 150 MWh).

The average air changes (day and night operation together) were for the period 1.5.2014 to 1.5.2015 evaluated:

- Hall leisure / parent-child pool: 1.5 times air change
- Indoor sports pool and slide area: 1.3 times air change
- Hall teaching pool: 4.0 times air change

The differences in the air exchange result among other things from the different room heights. The leisure and sports halls are more than twice as high as the teaching swimming area. Figure 75 also shows in gray which volume flow would have to be promoted in an operating mode according to [VDI 2089].

5.7.4 "Heating" circulating air

In the planning phase, it was assumed that there were certain hours in which recirculated air had to be used in order to bring the necessary heating output into the hall (see operating mode a 'in Figure 70). The monitoring shows that this was not necessary in all hall areas. This is shown as an example using the training pool ventilation unit in Figure 76. At the beginning of the measuring time is the "circulating air heating" flap due to Standard settings of the device are often open. After the mode of operation was adapted to the planned concept (including without recirculating air) from autumn 2013, there is no further requirement that additional recirculating air is required to cover the heating load.

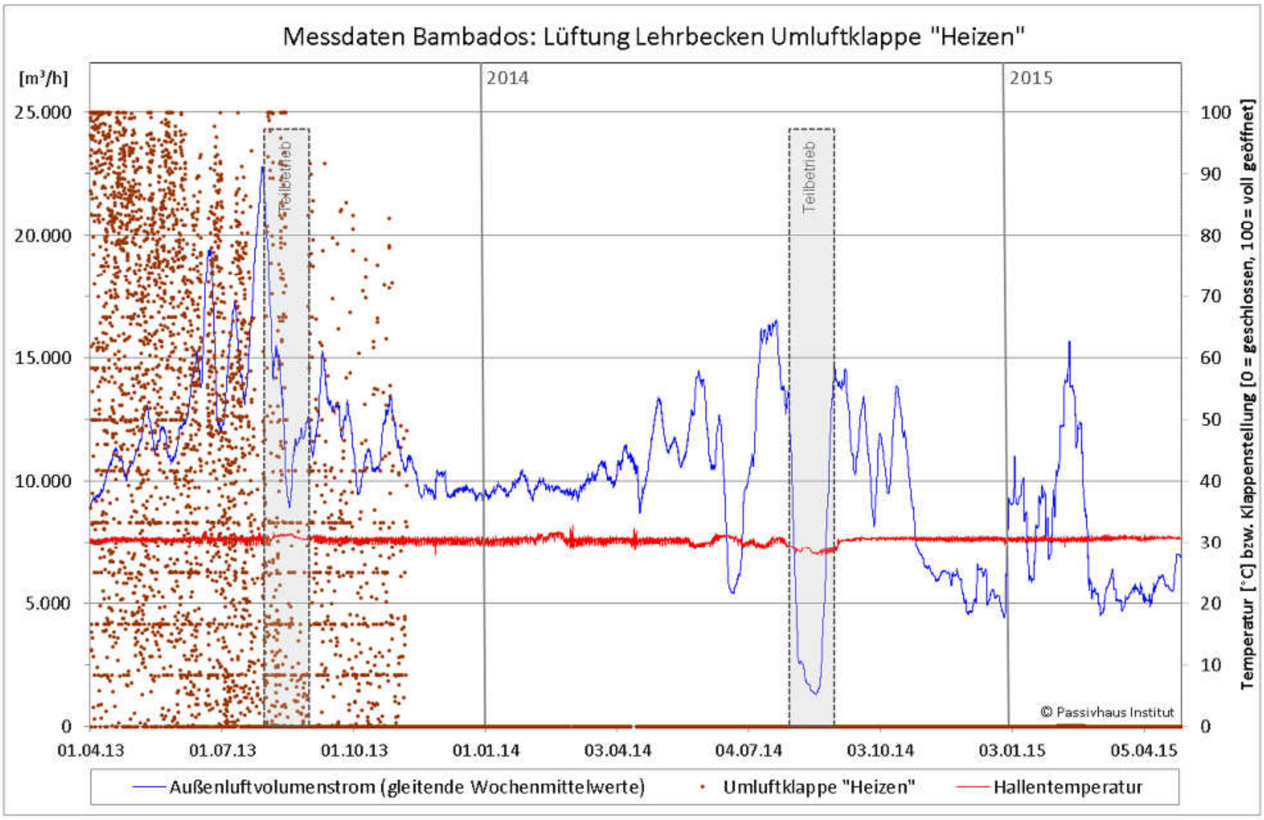


Figure 76: Ventilation device for the teaching pool: From H erbst 2013 the device runs upwards described concept and it turns out that none additional air circulation required is to be able to cover the required heating output (the "heating" air recirculation flap remains always closed).

5.7.5 Evaporation and dehumidification

The dehumidification performance is of interest because it allows conclusions to be drawn about the moisture input into the hall (mainly through evaporation). With the help of sensors in the ventilation units, the dehumidification performance can be calculated as follows:

Dehumidification performance [kg / h] • •

With

: Water content in the exhaust air : Exhaust air volume flow

: Water content in the supply air : Supply air volume flow

The following diagrams show the dehumidification performance over a longer period together with the indoor air conditions in the hall and the ventilation volume flows.

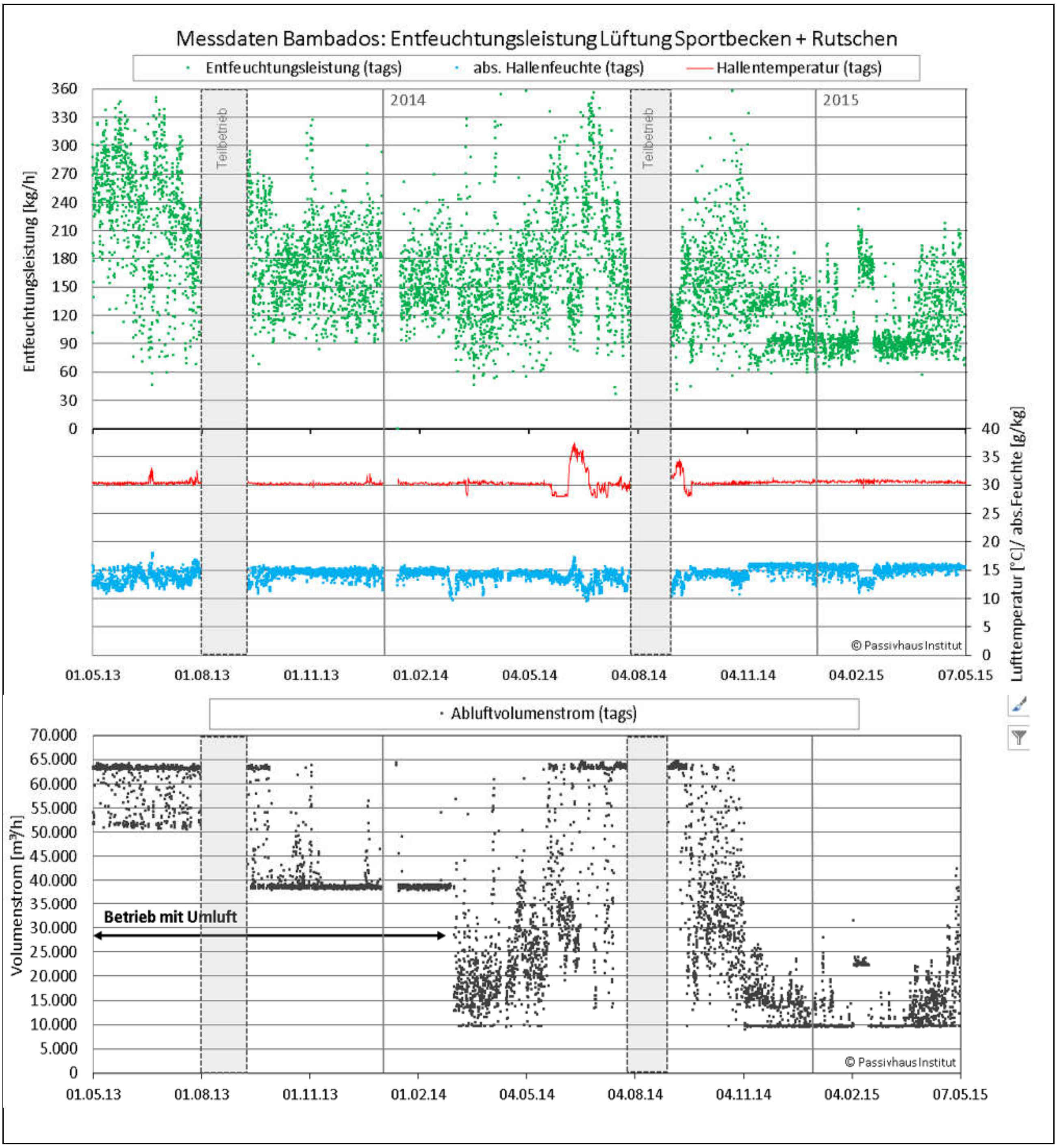


Figure 77: Dehumidification using Spo ventilation units rt + slides (tags: from 9 a.m. to 9 p.m.)

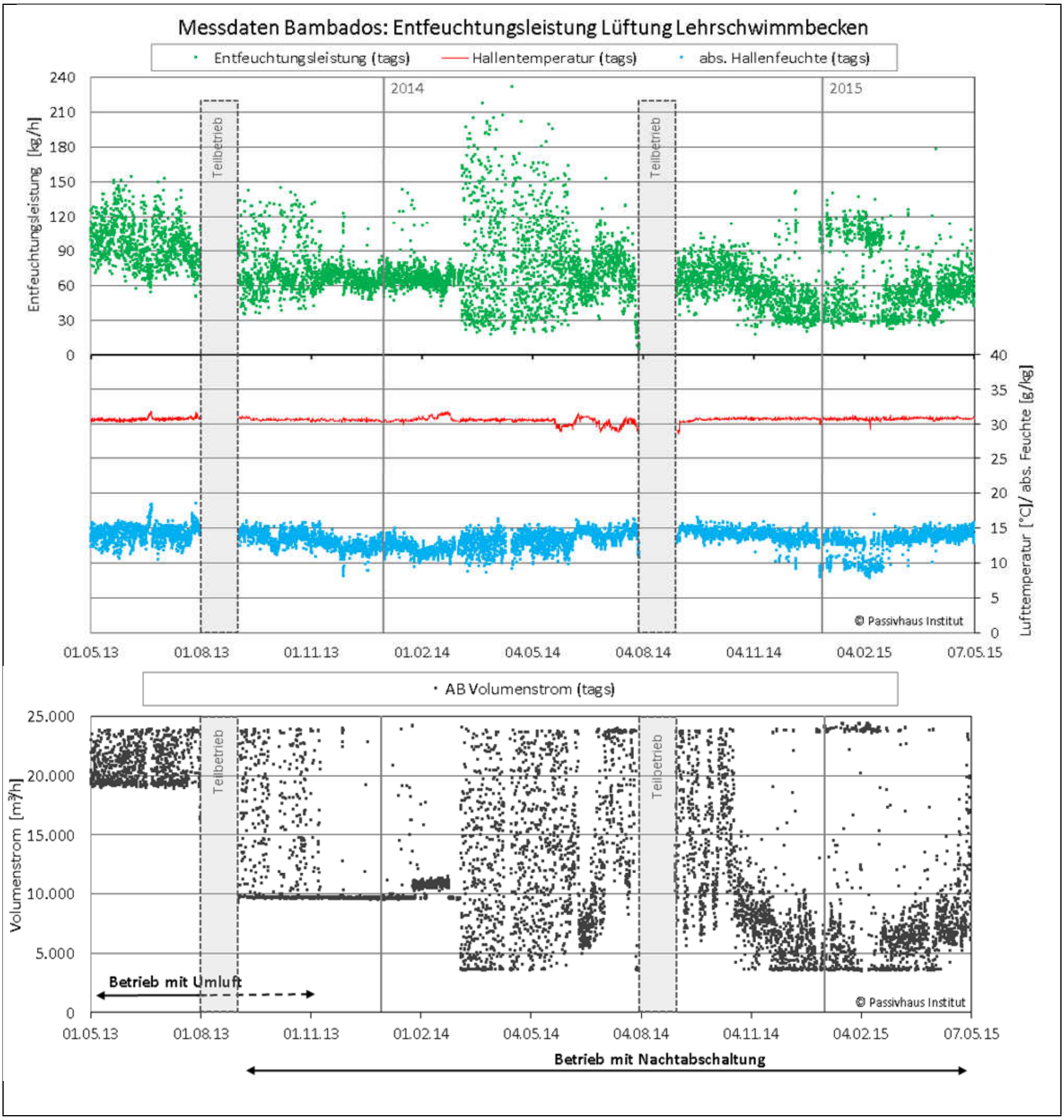


Figure 78: Dehumidification using the ventilation unit Lehr swimming pool (tags: from 9 a.m. to 9 p.m.)

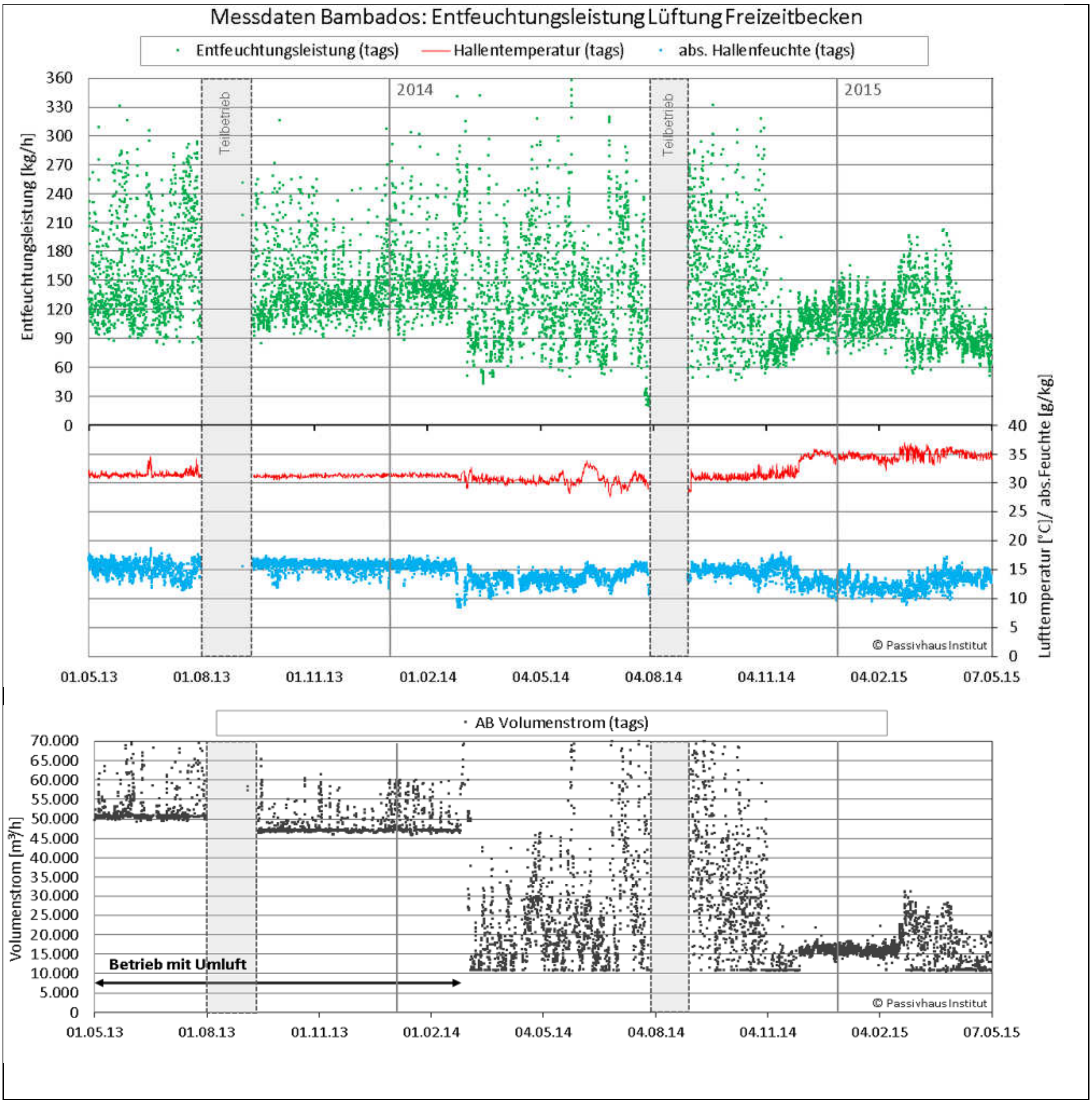


Figure 79: Dehumidification with ventilation units Fre **i time (during the day: from 9 a.m. to 9 p.m.)**

In phases in which the dehumidification performance of the ventilation units does not lead to a change in the humidity in the hall, the dehumidification performance roughly corresponds to evaporation (from the pool and on the passageways or by people). If you evaluate the dehumidification over a longer period in which the hall humidity is ultimately not higher than at the beginning, an average evaporation rate and thus an average water transfer coefficient can be calculated using the average dehumidification performance β can be estimated. Since the exhaust air sensors in the ventilation units can only be used for evaluation during their operation, the calculation is based exclusively on daily values. Nevertheless, the order of magnitude of evaporation can be shown during the day. This can be helpful when calculating the energy balance or operating costs.

The following table compares the planning values from [VDI 2089] with practical values (values for operating hours (9 am to 9 pm), excluding summer break in August; period: leisure time: September 12, 2013 to April 30, 2015; teaching area: 1.9.13 to 30.4.15; sports area: 9.9.13 to 14.2.15)

Table 9: Planning and Readings from Water transfer coefficients and Dehumidification performance (daily values: 9 a.m. - 9 p.m.)

Hall area	β according to [VDI 2089]	β (measured)	Dehumidification performance attractions (measured)
Leisure and parent-child pools	40 + Attractions	about 10	approx. 0.32 kg / h / m²WF *
Instructional pool	40	approx. 14	approx. 0.26 kg / h / m²WF
Sports pool and slides	28 + Slides	approx. 15	approx.0.15 kg / h / m²WF *

*) The dehumidification performance is based on the water surface (WF), but also contains dehumidification due to increased evaporation due to attractions or slides. Figure 80 shows a shorter period of the sport and slide area. Due to an error after maintenance, the volume flow of a ventilation unit remained increased for a few days. As a result, the absolute humidity in the hall dropped, which increased the evaporation and dehumidification requirements. This can be clearly seen in the diagram. While the heating requirement for indoor air increases significantly during this period (see Figure 15), there is no effect in the heating requirement of the pool. This may be due to the generally very low heating requirements of the pool. The heat consumption for heating the hall increases in this period to about double (from approx. 800 kWh / d to approx.

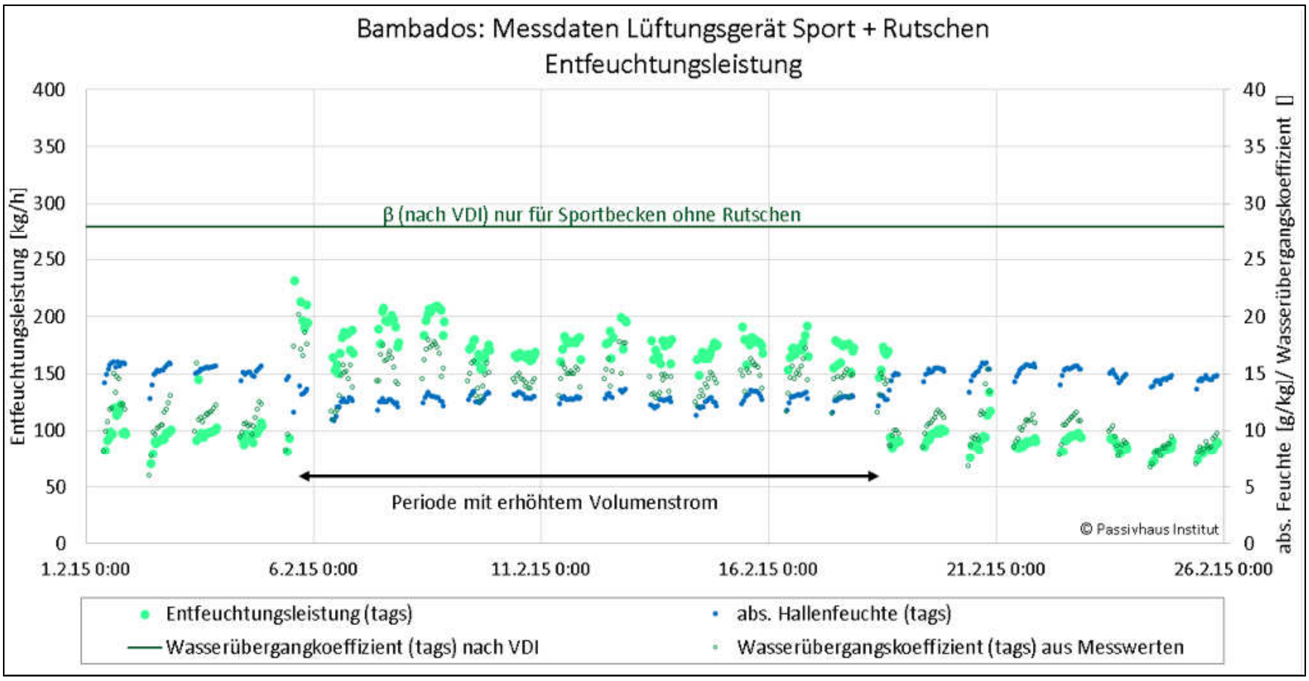


Figure 80: Sports ventilation unit: volume flow (error after maintenance) the dehumidification or evaporation increases (Darg only the values are set between 9 a.m. and 9 p.m.)

5.7.6 Design of ventilation units

If the average evaporation and dehumidification performance so much lower is than that Design planning according to [VDI 2089], the question arises whether even smaller ventilation units can be selected for future projects. If you look at the measurement data in detail, it can be seen that peak volume flows (individual peaks, but also several days) were often driven in summer, ie the devices ran with nominal volume flow. There are three reasons for this:

- The [VDI 2089] stipulates that the ventilation units only have to provide the necessary dehumidification performance up to a maximum outside air humidity of 9 g / kg. Due to the low evaporation, the humidity setpoint can be maintained in the Bambados even in times of higher outside air humidity (over several weeks) (see Figure 81).

- The measurement data indicate that peak volume flows are partially driven due to an (unnecessary?) Cooling requirement. In our opinion, the cooling request was programmed with too small a difference to the heating request. Attempts at which internal temperatures cooling is desired by the staff or guests or whether cooling is even necessary can only be carried out together with the programmers of the device manufacturer. Further investigations would be desirable here.

- The control parameters implemented in the programming are set so quickly that very strongly fluctuating volume flows and thus also peak volume flows will. Here, the operation could be further optimized with the help of more sluggish control parameters.

An immediate recommendation for smaller devices cannot be drawn from the previous measurement results. However, there is the possibility with further research in the future to be able to dimension the ventilation devices for swimming pools somewhat smaller.

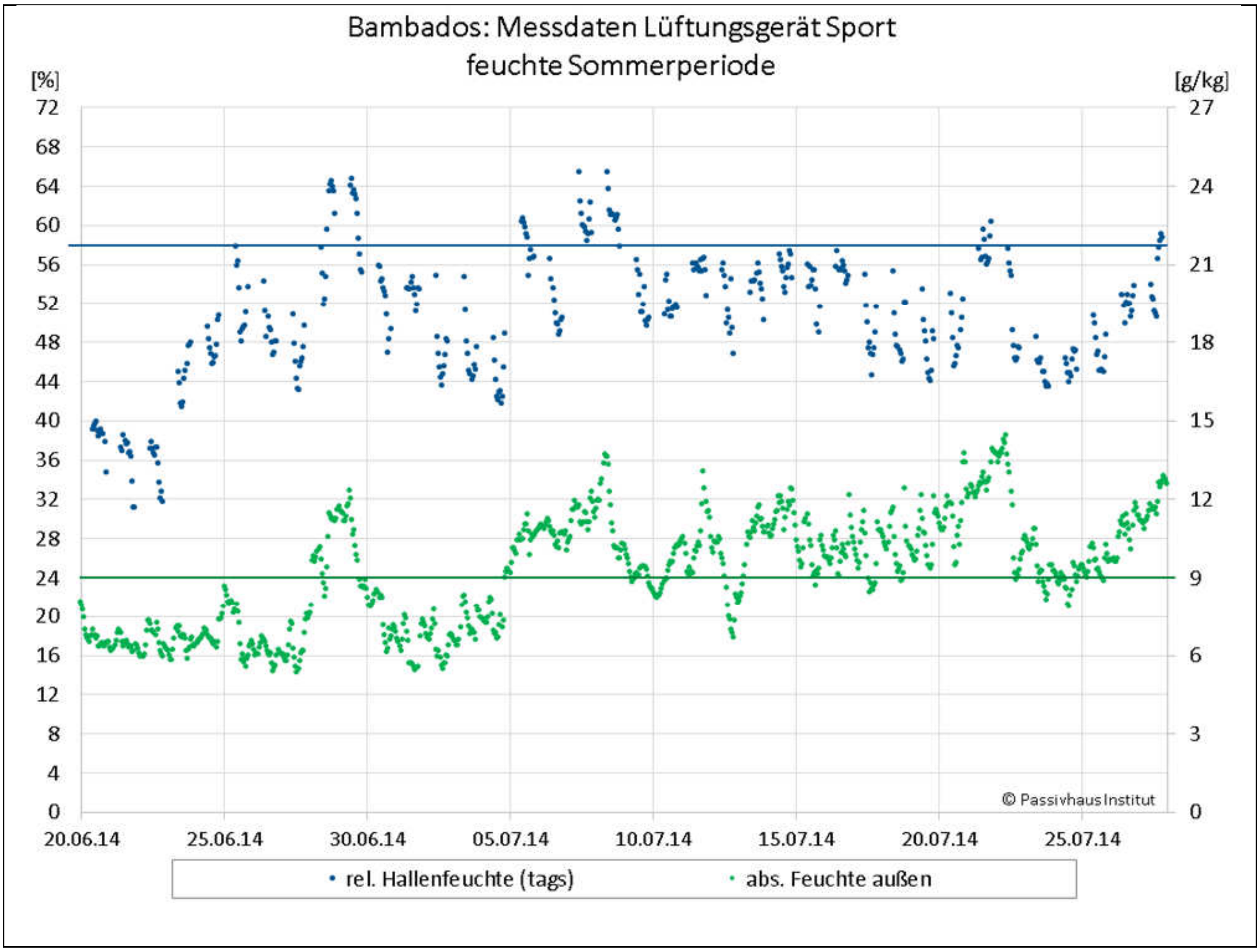


Figure 81: Sport ventilation unit: even in the fire right summer period (over 9 g / kg abs. humidity outside) the setpoint of 58% relat iver humidity in the hall be respected.

5.7.7 Night operation

According to the concept, the ventilation units should be switched off at night as long as the hall air is dry enough. An interesting aspect of the monitoring was to see how often dehumidification is necessary at night. The result is that the three different ventilation areas behave very differently.

In the area of the training pools with low room heights, the ventilation unit starts up regularly, briefly and with a high volume flow. This shows that there is a certain need for dehumidification, but not continuously during the night and in all seasons. An optimization in the form of slower controllers would be desirable so that the volume flow fluctuates less, but with lower volume flow is operated over a longer period of time. However, this was not implemented by the device manufacturer.

In the leisure pool area, the device usually switches off at night and is requested due to a need for dehumidification at different night times. The ventilation unit then runs with a minimum volume flow until the air humidity has dropped accordingly.

In the sports pool area, on the other hand, the device usually runs at night and the humidity in the hall even increases. In order to understand this process, a series of tests was carried out in March 2015. The measurement results are shown in Figure 82.

- Reference night (16./17.3.15): Regular operation: Sport ventilation unit runs at night and the hall humidity rises to the limit. The leisure ventilation unit switches off temporarily. The ventilation unit changing / showering is off except for a short interval switch to check the humidity.

- 1st night (March 17/18, 2015): The leisure ventilation unit was operated all night as a test, so that there is less humidity there. As a result, the humidity in the sports area is lower than the nights before and a lower volume flow is driven due to the lower dehumidification requirement.

- 2nd night (March 18/19, 2015): Both the leisure ventilation unit and the ventilation unit for the changing rooms / showers were operated throughout the night as a test. This night, too, a lower humidity and a lower volume flow can be seen in the sports area. However, no change to the 1st night, which would suggest a dependency on the changing / showering zone.

The experiment has shown that the Sport ventilation unit presumably also dehumidifies the indoor air in the leisure area during regular night operation, although the doors between the two areas (sports / slides for leisure) are closed.

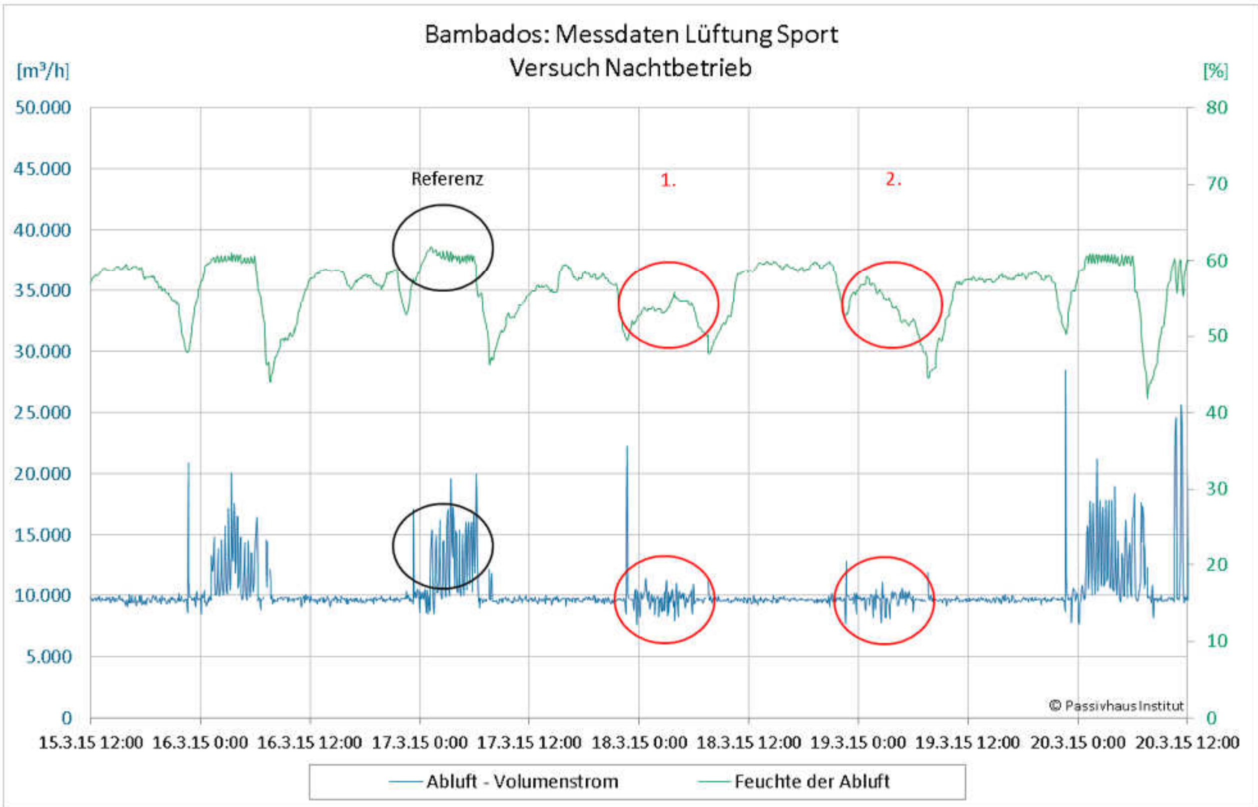


Figure 82: Sport ventilation unit: attempt to detach independence with the zone leisure and Changing rooms / showers

5.7.8 Heat pumps

There is a lot of energy in the exhaust air from the halls, as the temperature and moisture content are high. In order to recover this sensitive and latent energy, ventilation devices with a "passive" heat exchanger were used on the one hand and exhaust air heat pumps on the other hand in the ventilation devices for the swimming pools. Energy is extracted from the exhaust air in the first step in the heat exchanger and in the second step by the heat pump's evaporator. It has been shown in operation that there is very little need for dehumidification. This is advantageous because it can save energy. The consequence, however, is that the installed heat pumps are too large. You need a minimum volume flow of 30% based on the nominal volume flow. Since the volume flow is lower during most of the year, the heat pumps cannot run. It would be counterproductive to increase the volume flow in order to use the heat pumps. For the period from August 2013 to May 2015, the measurement data of the ventilation units without the operation of the heat pumps were evaluated. With increasing outside air humidity, the heat pumps were switched on from mid-May. It quickly becomes apparent that even in summer the heat pumps in the Bambados cannot be used profitably. There are three reasons for this:

- The low dehumidification requirement leads to low volume flows. Even in summer with higher outside humidity, the volume flow is often below 30%.
- In summer, especially in sports, there is not always a need for heating.

- The regulation of ventilation devices (volume flow rates) fluctuates very strongly, especially in the leisure and teaching areas. An optimization of the regulation would make sense. For future projects, heat pumps should be dimensioned for lower volume flows. It should also be noted that heat pumps compete with other energy sources. A cogeneration plant is operated in the Bambados, which had to be switched off in the summer months because the heat consumption of the entire bathroom is so low.

5.7.9 Recommendations for indoor ventilation

- Run varying outside air volume flow according to dehumidification requirements.
- No circulating air flow.
- Good air flow (further research needs): In Bambados that could be Air flow in the sports area can be optimized by installing exhaust grilles in the ascending shafts so that the exhaust air is not discharged from the ceiling but in the lower area of the hall. [Kaluza 2014]
- Summer: Set the limit for increased volume flow for "cooling" as high as possible.
- Test air humidity and temperatures during operation to get the best.
- If a CHP is planned, its optimization potential should be exhausted before considering the operation of heat pumps.

5.8 Ventilation sub zones

The basic pillar of the passive house concept is to ensure the hygienic air change required via a ventilation unit with highly efficient heat recovery (heat recovery> 75%). Except for dehumidification, there is no reason to introduce higher air changes than hygienically necessary in a passive house. The design volume flows according to the current standards are relatively high in comparison. Demand-based control (with regard to hygiene and humidity) can also significantly reduce heating energy and electricity requirements in the adjoining rooms of an indoor pool. Due to the good building envelope, the temperatures only drop if the heating is interrupted

slowly. Therefore, the ventilation units can largely are operated intermittently, ie they are switched off at night and in the morning the rooms are flushed with fresh air in a pre-purge phase.

Table 10: Ventilation units in the sub-zones with ventilation flow rates and control concept

No.	Ventilation unit	Nominal volume flow [m³ / h]	Min. Volume flow [m³ / h] [% of nominal]		regulation
2.1	Changing rooms / showering on the ground floor	16,000	9,600	60% after	relative humidity
4.2	Changing / showering upstairs (sauna)	9,500	5,700	60% after	relative humidity
2.2	Foyer / administration	10,000	3,752	38% after	constant pressure; in the foyer after CO_2; Personal showers after humidity; Rest constant; (using supply air flaps)
2.3	Storage / technology	4,880	1,500	31% by	temperature
3.1 / 3.2	Kitchen / ancillary	10,600	2,580	24%	according to the volume flow of the Kitchen hood
4.1	Sauna EG / OG	13,650	9,500	70%	constant volume flow

5.8.1 Showering / changing

For the area of showers and changing rooms there are two ventilation units, one for the ground floor and the other for the upper floor. The supply air is introduced into the changing rooms on both floors. From there it flows over overflow elements and under doors into the rooms with showers and toilets and is discharged there via exhaust air valves. This double use of the volume flow reduces ventilation losses and electricity consumption. Since the use of the changing room correlates with that of the showers, the volume flow can be regulated together. A Minimum volume flow of 60% of the design volume flow ensures continuous air exchange. In addition, depending on the humidity in the showers, the volume flow is increased. For this regulation, humidity sensors were installed in the two exhaust air ducts of the ventilation units, which gives a guideline for the room humidity. A seasonal fluctuation was expected due to higher outside air humidity in the summer half-year (i.e. higher volume flows in summer). The ventilation units are switched off at night. In order to nevertheless monitor the humidity at night, the device is briefly switched on once an hour and the value of the humidity sensor in the duct is checked (see Figure 83).

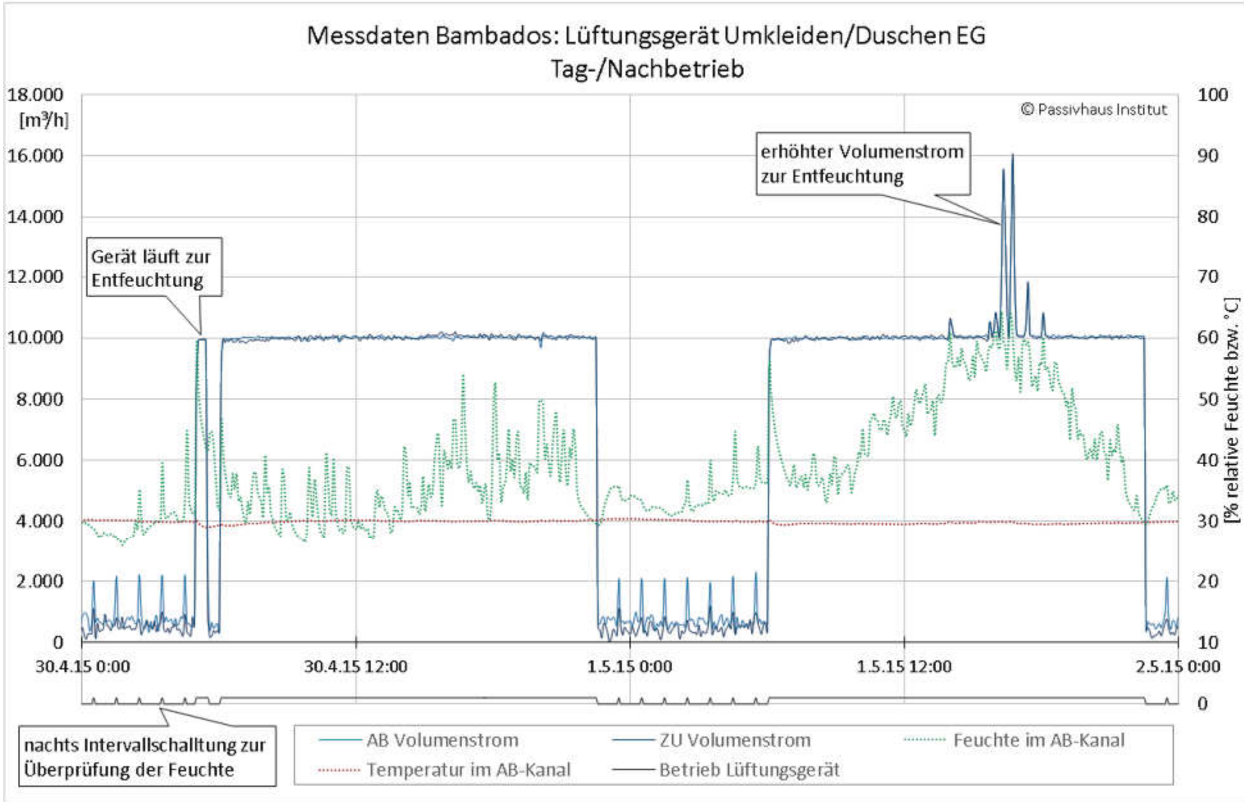


Figure 83: Ventilation unit changing room EG: day and Night operation. Are shown more measured Supply and exhaust air volume flow and the air temperature and humidity in the exhaust air duct.

Dehumidification

Practice shows that the dehumidification requirement is almost all year round below the dehumidification due to the selected minimum volume flow.

For the ventilation unit that supplies the changing rooms and showers for the swimming pool area (on the ground floor), an exact evaluation of the volume flow could be made over two season periods (1.4.2013 to 1.4.2015). As Figure 84 shows, a volume flow increase is only requested and driven very rarely and only in summer. The measurement results show that 99% of the selected minimum volume flow is used during the day and only 1% of the day hours with an increased volume flow. The device runs for 8% of the night, otherwise it is switched off. Overall, the volume flow could be reduced by more than half compared to the planning of 16,000 m³ / h (planning value without passive house advice).

The operating mode of the ventilation unit for the sauna room cloaks (on the upper floor) could not be evaluated in such detail because the regulation of the unit did not run for a correspondingly long time in the planned operation.

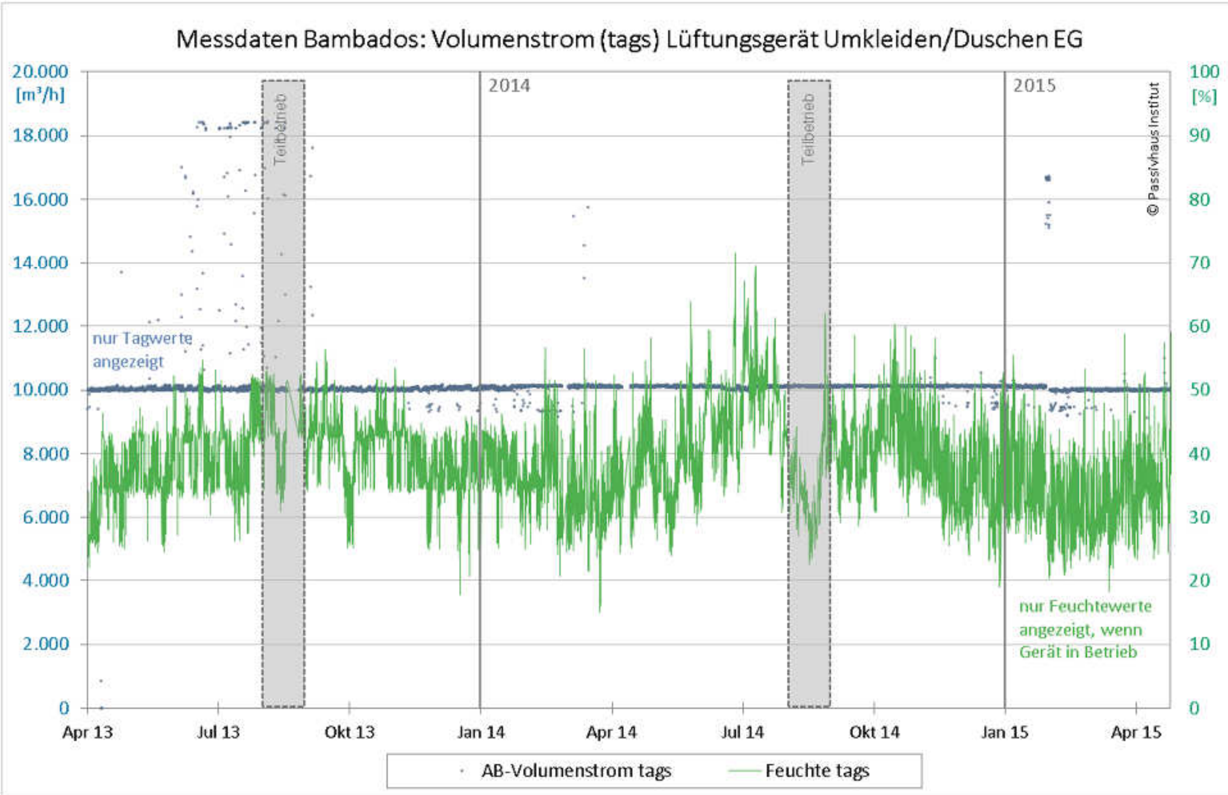


Figure 84: Overview of ventilation unit changing room EG: The device runs almost continuously minimum volume flow and the relative humidity is mostly lower than 50%.

Volume flow comparison

To compare the air exchange depending on the use, the relevant values are entered in the following table.

Table 11: Comparison of air changes depending on usage (Guideline, planning and measured values)

Area	after [KOK 2002]	Determination by the planning office	Regulation as required: Readings
Changing rooms	15 - 20 m³ / h per m²	6-7 times LW	EG: approx.2.1 times LW OG: approx.3.5 times LW *)
to shower	220m³ / h per shower, max. 30 times LW	30 times LW	Ground floor: approx.9.3 times LW OG: approx.8.2 times LW
Toilets	100m³ / h per toilet, max. 15-fold lW	15-fold LW	
LW = air change *) This LW is less meaningful than the LW on the ground floor, since the upper floor not only includes changing rooms, but also stairwells and toilets.			

It is clearly recognizable that the specified planning values are very far on the safe side. Operation according to these requires unnecessarily high operating costs (electricity for the operation of the ventilation unit and additional heating energy requirements due to higher ventilation losses). In the Bambados it could be shown that with a minimum volume flow of 60% the relative air humidity is around 40% RH. Furthermore, the operators and guests are satisfied with the air quality in the changing rooms and showers. The only criticism initially was the temperature in the changing rooms on the ground floor, which was eliminated by increasing the temperature setpoint. Due to the indoor air connection to the foyer, energy is continuously released to the foyer, which is why more heating is required in the changing rooms.

In contrast, the changing rooms run

Upper floor, which are closed to the foyer, with the original target temperature. Summer night cooling was often requested for the changing room OG first. Practice has shown, however, that there is no cooling requirement for the zones of both devices. For this reason, night cooling on the BMS was deactivated.

Recommendations ventilation showers and changing rooms

- Neither reheating register nor active overflow between changing rooms and showers are necessary.
- Reduce the volume flow (see above) and regulate it according to actual requirements (e.g. via a moisture sensor in the duct).
- Since the dehumidification requirement is low, it would be interesting to examine in more detail how large the hygienic air requirement is. If the minimum volume flow could be reduced even further, the heating energy and electricity consumption would decrease.
- In the operational optimization, the ventilation interval could be adjusted at night, for example only every two hours. Alternatively, the use of moisture sensors in critical exhaust air rooms for moisture monitoring could be considered in future projects.

5.8.2 Foyer / administration

The foyer / administration ventilation unit supplies office space on the one hand and the large foyer on the other. While there is usually no need-based ventilation for office rooms, the fresh air requirement is subject to great fluctuations due to changing numbers of visitors in the foyer. It could be assumed that there will never be as many people in the foyer as the planners have planned for the volume flow design. For this reason, a CO_2-

Sensor installed in the foyer. This sensor controls flaps so that either two or eight supply air valves supply the foyer. The ventilation unit regulates the volume flow by means of a pressure control, so that the volume flow can adapt to the actual demand in two stages. When using CO_2- It is important that sensors are calibrated regularly. This ventilation unit also supplies personal showers that have very short periods of use. These rooms were equipped with hygrostatic valves to adjust the volume flow to the needs.

The device is switched off at night. The recommendations of a thermal separation from the sauna zone and a demarcation (wall, glazing or similar) from the changing room were not implemented, which led to an (increased) need for night cooling in summer.

Volume flow

In operation, the above assumptions were confirmed and it can be seen that the CO_2- The value is always so low (below 1,000 ppm, mostly below 600 ppm) that there is no need to run an increased volume flow. Figure 85 shows the operation of the ventilation unit foyer / administration. This is characterized by a long phase of operational optimization. In the optimized state (January 2015 to May 2015), the volume flow during the day is approx. 4,000 m³ / h, of which approx. 2,000 m³ / h are in the foyer. According to the KOK guideline [KOK 2002], the planning office

6,300 m³ / h suggested (5 m³ / h per m³ room). The volume flow actually driven can be evaluated in various ways:

- With a fresh air requirement of 20 - 30 m³ / h per person, the volume flow would be sufficient for 67-100 people. The majority of people will only stay around the foyer for a short time and not continuously. For this reason, the volume flow would be sufficient even for a larger number of people.

- The volume flow driven corresponds to a 1.3-fold air change in the foyer. Compared to a 0.3-fold air change to remove pollutants from building materials, furniture and cleaning agents, basic ventilation is ensured.

- All other rooms except the foyer, which are supplied by this ventilation unit, have an average air exchange of 2.3 h^{-1}. These rooms have very different functions (office, corridor, ELT room, changing room, etc.) and therefore also very different air changes. Viewed overall, there is also a sufficiently hygienic air change (far higher than 0.3 h^{-1}).

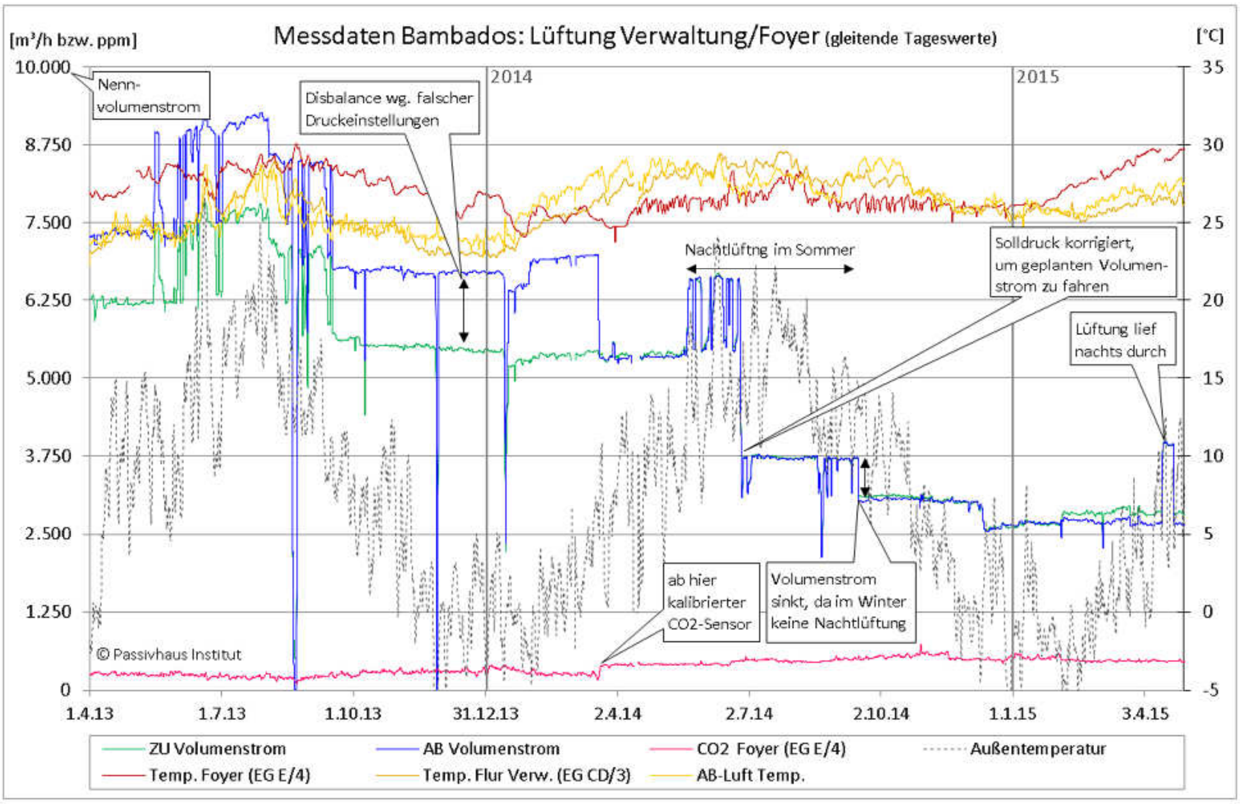


Figure 85: Overview of ventilation unit foyer / administration ung: by optimizing operations Volume flow can be significantly reduced.

Figure 86 clearly shows the great influence that operational optimization has on operating costs. Consumption was reduced from approx. 100 kWh electricity per day to approx. 20 kWh. In addition to this saving, the heat consumption is reduced because the ventilation losses are reduced by lower volume flows. Better commissioning would be even cheaper and desirable, so that operational optimization can be carried out in a shorter time.

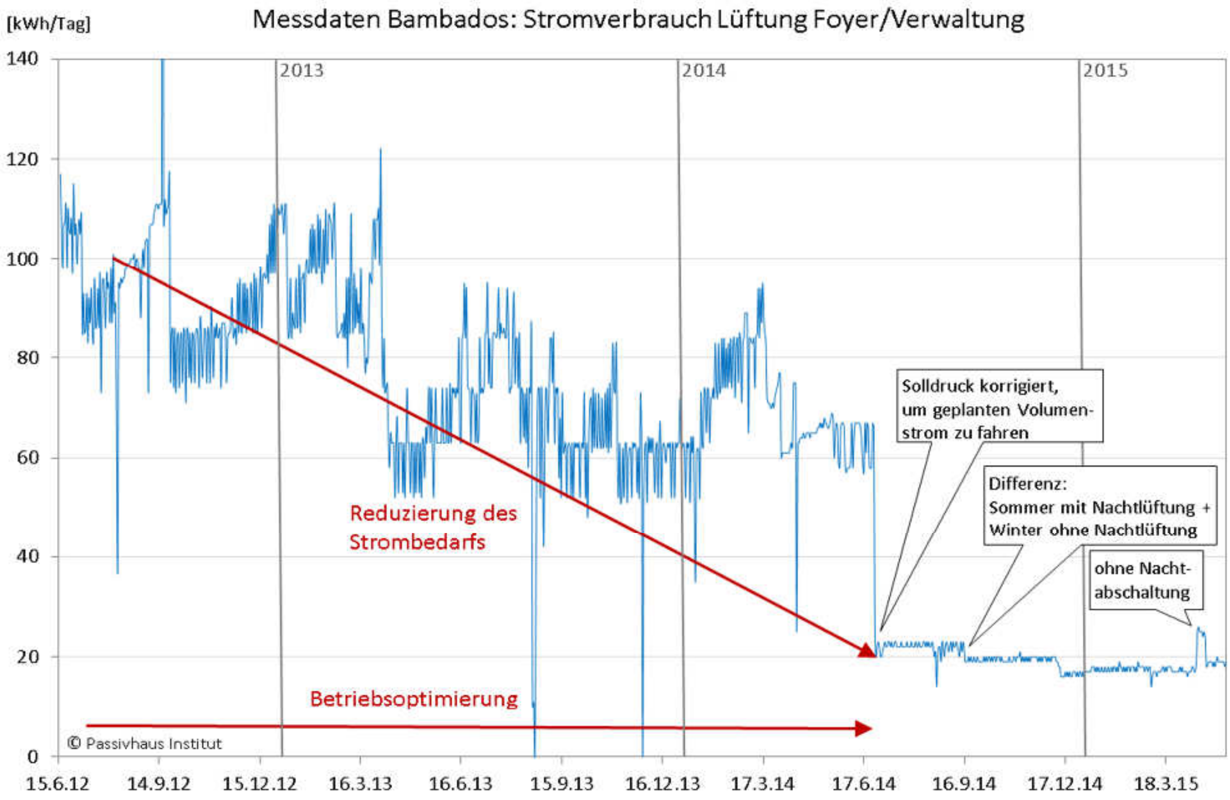


Figure 86: Power consumption of the ventilation unit Foyer / Ve management

Night operation

As in other non-residential buildings, the ventilation system is operated intermittently. This means that no hygienic air changes are required outside of the operating hours and the ventilation unit is switched off. The foyer and administration are warmed from the adjacent warmer zones. This creates a cooling requirement. In addition to passive night cooling via windows and skylights, cooling is also carried out via the ventilation unit. At night, the ventilation unit is switched on in a temperature-controlled manner in summer and operated with a summer bypass (air flow not via heat exchanger). For night cooling via the ventilation unit, the electricity requirement is about 3 to 4 kWh per night.

Recommendations ventilation foyer and changing rooms

The goals of needs-based ventilation and thus low operating costs have been met. Better regulation of the different temperatures would be desirable. The course for future bathrooms should already be set in the architectural planning. The following recommendations can be derived from the experience in Bambados.

Office:

- Thermal separation to warm building zones (here: sauna)
- Personal air change (20 to 30 m³ / h per person) as in passive house office buildings

- Passive night ventilation for cooling (windows, flaps, skylights)

Foyer:

- No indoor air connection with the changing rooms, because lower temperatures are desired by the staff than by the bathers in the changing rooms.
- Volume flow according to CO_{2}- Regulate the content of the indoor air
- or constant flow at low level; this could simplify the regulation considerably and make CO more susceptible $_{2}$- Sensors would not be necessary.

Staff changing rooms / showers:

- Due to the desired temperature, it would be cheaper to supply the personnel changing rooms and showers with the ventilation unit changing rooms / showers.
- The hygrostatic valves used could not be evaluated more precisely.

5.8.3 Storage / technology

The device for "storage and technology" supplies several side rooms in the basement. Worth mentioning on the one hand are chemical stores, whose fresh air requirements are defined according to regulations, and on the other hand electrical rooms with internal heat sources. In the planning phase, the precise internal heat gains from the technology (server, ELA, etc.) could not be exactly determined by the electrical planner. Unfortunately, most projects lack experience. If these values could be determined more precisely in the planning phase, a suitable and efficient cooling concept could be planned. In the Bambados, the monitoring shows higher internal heat loads in the electrical rooms or especially in the ELA room than initially assumed.

It is cooled by ventilation with a summer bypass and by increasing the volume flow for the entire device. The electricity requirement could be reduced somewhat by primarily cooling with summer bypass by optimizing the control. Nevertheless, a further optimization of the regulation would be desirable. The aim is to further shorten the run times with a high volume flow. At the moment there are also considerations to retrofit a cooling system instead of running with an increased volume flow.

5.8.4 Kitchen

The kitchen rooms are ventilated or ventilated on the one hand by a ventilation unit with heat recovery and on the other hand by three exhaust hoods. The amount of supply air is adjusted depending on the stage switching of the exhaust hoods. Ie the ventilation unit runs out of balance, which is undesirable,

as this significantly increases the degree of heat supply worsened. A

Possibility of optimization, which was recommended by the PHI during the planning phase, would be to operate the induction hoods with outside air that was not preheated as supply air. Then about 5,000 to 7,000 m³ / h less air would have to be heated, with the same comfort in the kitchen. The ventilation unit is operated intermittently, ie it is switched off at night.

5.8.5 Sauna

The "Sauna" ventilation unit introduces fresh air into the sauna rooms or relaxation rooms. This flows into the sauna cabins below the doors and is extracted there as exhaust air. In contrast, the Passive House Institute recommended a ventilation separation of the sauna anteroom and the sauna cabins.

In the course of the ventilation installation, the rooms of the spa area (previously planned as an office) were connected to the sewer network of the "Sauna" ventilation unit. However, the target temperature of the sauna area differs from that of the separate spa area. In practice, this example shows how important it is to skillfully zonate and divide the rooms between different ventilation devices in order to maintain the desired room temperature on the one hand and to regulate the volume flow and operating times as required. The ventilation unit is operated intermittently, ie it is switched off at night.

Summer bypass

The simulations are confirmed in the evaluation: Unfortunately, part of the energy from the sauna cabins can only be released to the supply air via the heat exchanger, otherwise the supply air for the sauna area would become too warm. Ie own heat recovery for the sauna cabins could reduce ventilation losses.

In this project, the temperature is regulated by the summer bypass. In order to reduce ventilation losses, bypass operation (bypassing heat recovery) was significantly reduced in winter 2015 compared to winter 2014 (see Figure 87). This was achieved by a larger distance between the target temperature and the maximum temperature in the zone. The strong fluctuations in the volume flow in Figure 87 result from the night shutdown. The volume flow is largely constant during the day.

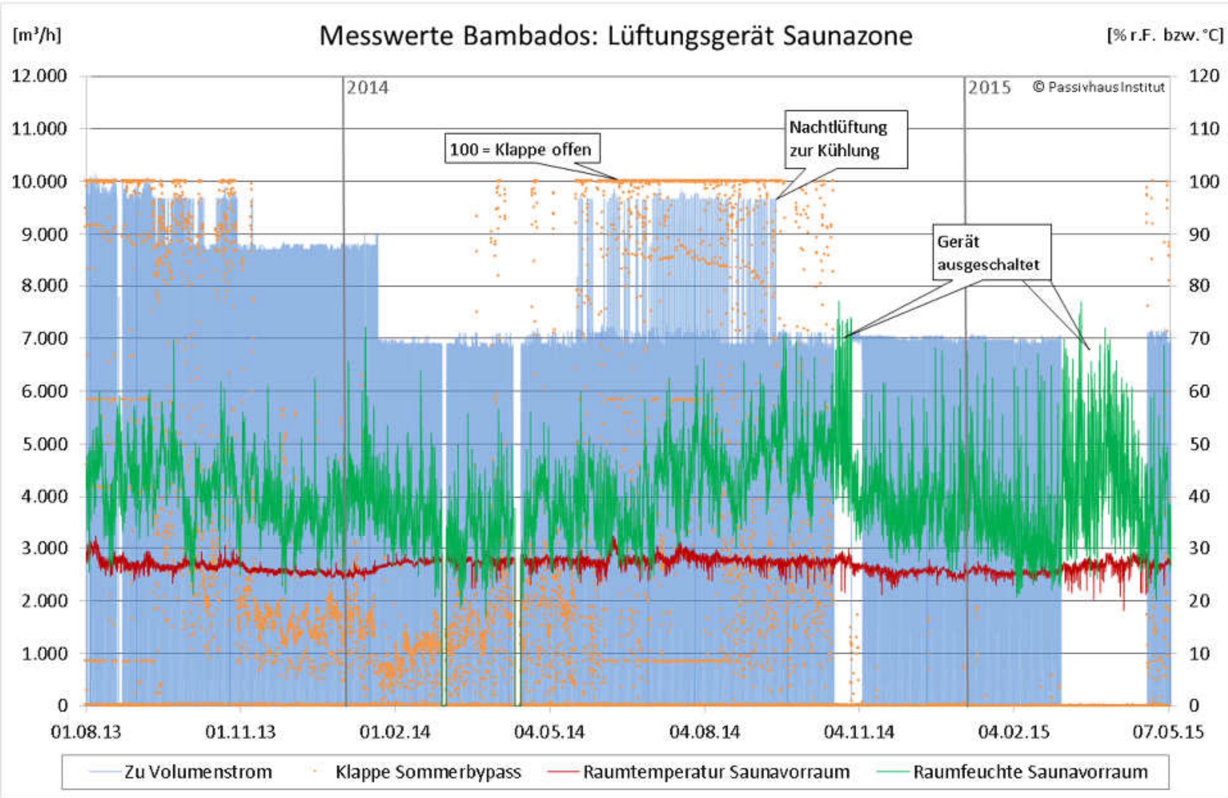


Figure 87: Sauna ventilation unit: using the Summer bypasses were possible in winter 2015 be significantly reduced.

Power consumption

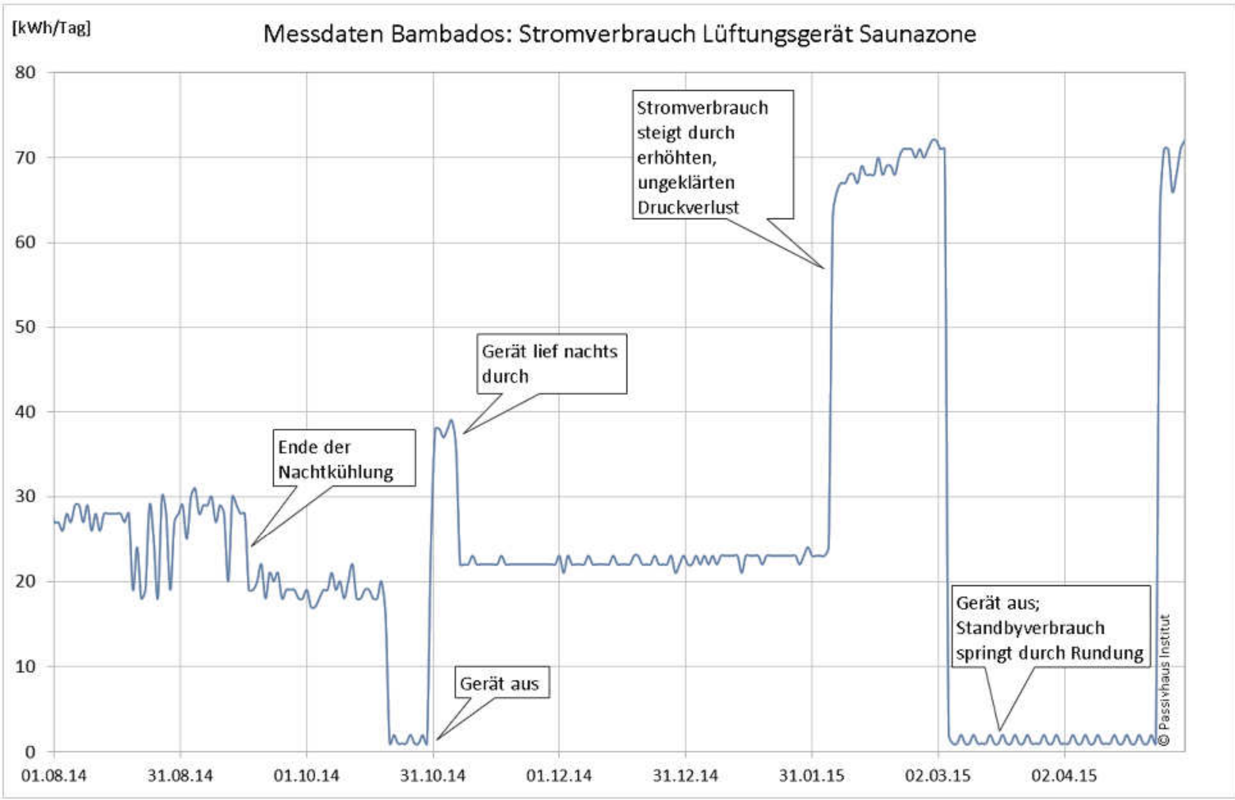


Figure 88: Sauna ventilation unit: power consumption b in different modes of operation

Figure 88 clearly shows the impact of different modes of operation (intentional or due to errors) on power consumption. A change in the volume flow also reduces the heating requirement due to lower ventilation losses in addition to the reduction in electricity consumption. The device was temporarily switched off, surprisingly without the operator and guests noticing. This fact shows that the dehumidification requirement is very low and leads to further considerations. Of course, the vestibules and relaxation rooms of the sauna should be ventilated for good air quality and to ensure dehumidification. In the sauna cabins, perhaps less air change would be enough.

Recommendations for ventilation in the sauna area

- if necessary, sauna cabins with separate ventilation unit
- or less air exchange (further research required)

5.9 Water heating

The heat is transferred from the energy center with the CHP and peak load boilers to the Bambados and there with a heating circuit distributed in the building and to the individual Distributed heat exchanger / heating register for pool water, domestic hot water and the ventilation devices. Warm water is mainly used for the showers, but also in smaller quantities for the kitchen and for cleaning. There are three systems for water heating (heat exchanger with storage):

- for showers in the sports area with 500 liter storage
- for showers in the sauna area and the kitchen with 500 liter storage
- for showers in the leisure area with two 500 liter tanks. Since the storage volume was too small at peak times, a 1,000 liter storage was upgraded. This means that the peak times can be covered much better.

Figure 89: Three thermally insulated hot water tanks in the technical basement of Bambado

5.10 Bath water technology

Various pools are provided in the Bambados (see table below). The main task of bathing water technology is to ensure the hygiene of the pool water. In addition, technology is installed for various attractions such as slides, bubble loungers, flow channels, etc.

Table 12: Pools with water areas, volumes and -temperatures in Bambados

pool	Pool area [m²]	Pelvic volume [m³]	Pool temperature (measured mean) [° C]
Leisure pool	354	436	32
Parent-child pool	55	14	32
Training pool 1	133	153	32
Training pool 2 (with lifting floor)	133	239	32
Sports pool (partly with lifting floor)	1,050	3,208	28
Slide pool	16	not specified	32
total	**1,743**	**4,290**	

5.10.1 Ultrafiltration

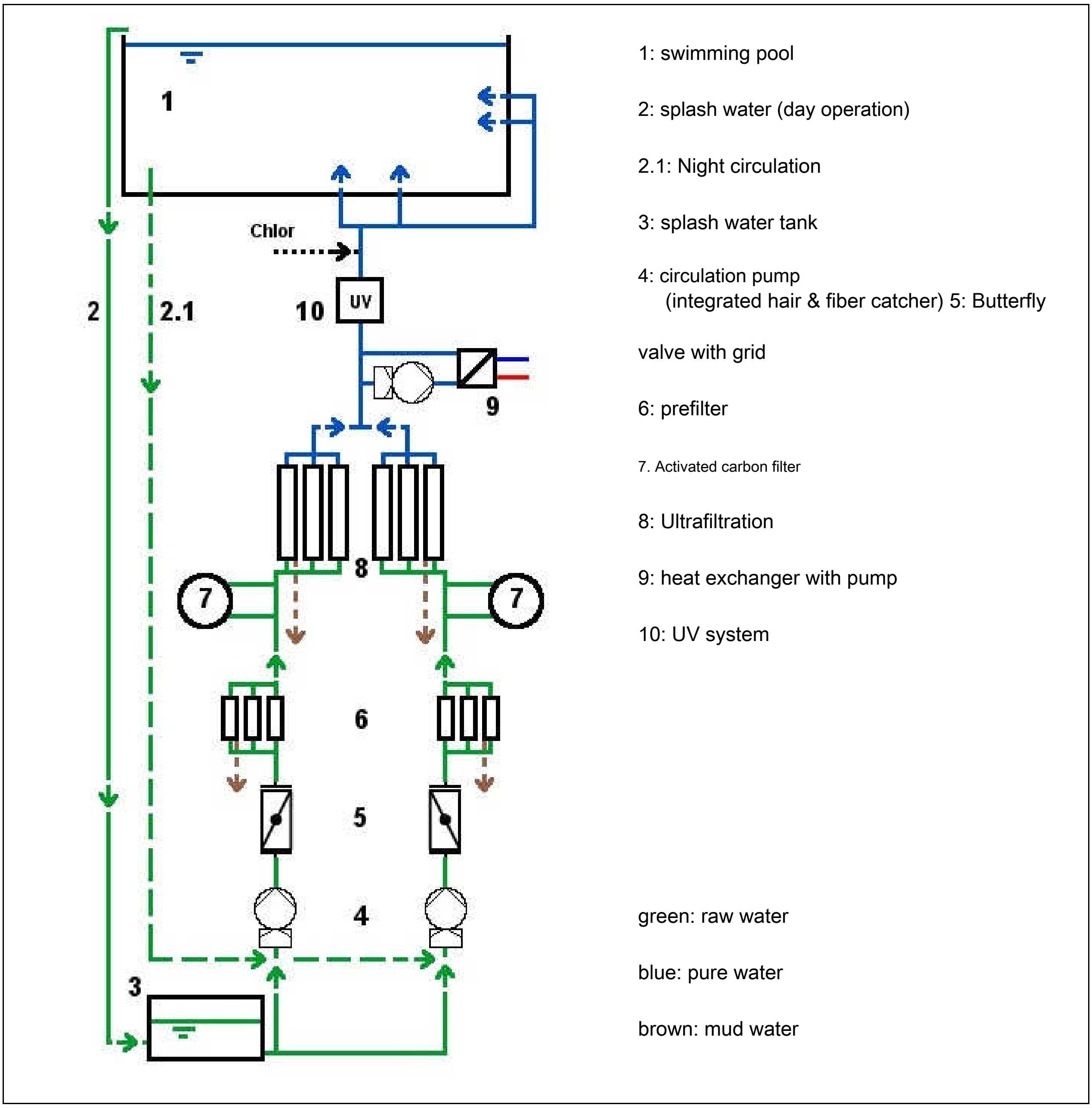


Figure 90: Scheme of bath water treatment in Bambados

When choosing the filtration, the operator decided on the ultrafiltration (UF) method, which was still young at the time of planning. Figure 90 shows the exact sequence of water treatment. Since there were initially problems with the values of the bound chlorine, activated carbon filters were retrofitted in mid-2012. Since then, the system has been running without any problems. Even with a high number of visitors, this process combination with the planned circulation volume flow (k-factor = 1) can ensure very good water quality in the Bambados. The advantage of ultrafiltration compared to multi-layer filters is that half of the circulation volume is planned. In practice, it has been shown that other baths had to increase the planned volume flow to ensure the water quality. In the Bambados, however, the low planning value was confirmed.

The client is satisfied with the system and there have been no UF module failures so far. In the future, chemical filter backwashing should nevertheless be carried out once a year so that the tubes of the UF do not become permanently clogged. This can be done inexpensively by a company with a mobile system. The installation of a bathing facility would not pay off.

The disadvantage of ultrafiltration is the high pressure loss of the filter modules. To take a closer look at this, the engineering company inco GmbH carried out an analysis of the pelvic circuits. The aim was to measure the actual state of the pressure losses as a whole, and the ultrafiltration in particular, and thus to show further potential for optimization.

5.10.2 Pressure measurement

On October 20, 2014 the engineering company inco GmbH carried out a measurement of the pressure curve of the pelvic circuits (Sport 1 + 2, Leisure 1 + 2) [Kaluza 20014]. In the special measuring method developed by the office itself, the pressure is measured in sections using a manometer and small holes in the pipes. The circulation circuits are each divided into two parallel circuits with their own pumps and filters. Figure 91 shows the measured values of the pressure in both circuits of the sports pool.

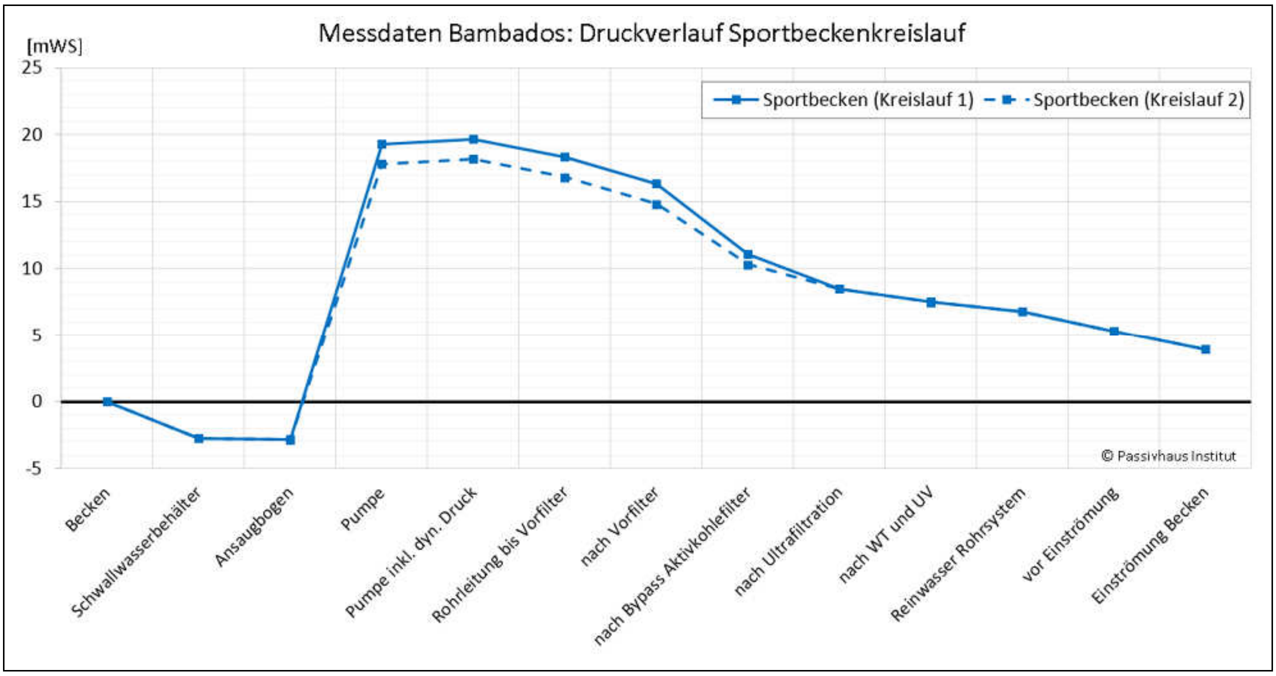


Figure 91: Sports pool circuit 1 + 2: section measurement of the pressure curve, shown in the unit mWS (meters of water column)

Compared to the information from the planning phase, the pressure loss of the ultrafiltration is lower, but the total pressure loss is significantly higher. In the sports pool circuit, the total pressure loss (delivery head of the pump) was specified by the swimming pool technology planning as 14 mWS (meters of water column), the measurement gives a value of 22 mWS. As expected, the ultrafiltration, with a pressure loss of 2.6 and 1.8 mWS for the two measured pool circuits, is higher than for sand filters, but only makes up a small percentage of the total

Pressure loss. It should be noted that the pressure loss of the filter depends on the degree of contamination.

The following hydraulic optimizations are possible and recommended for the pipe networks of the circulation circuits in Bambados (see also Figure 92):

- Larger pipe diameters (planning goal of the speed: v = 1-1.3 m / s) have a major influence on the pressure loss (pressure change with (1 / D) 4)
- In the Bambados, the retrofitted activated carbon filters are installed in the bypass in such a way that the main strands are throttled. Alternatively, both activated carbon filters could be operated in parallel in only one circuit.
- Operate a circuit permanently like the internal night circulation, this saves the height difference between the basin and surge water tank and at the same time discharges the particles below the water surface.
- The smallest possible difference in height between the pool and the splash water tank (position and level of the splash water tank)

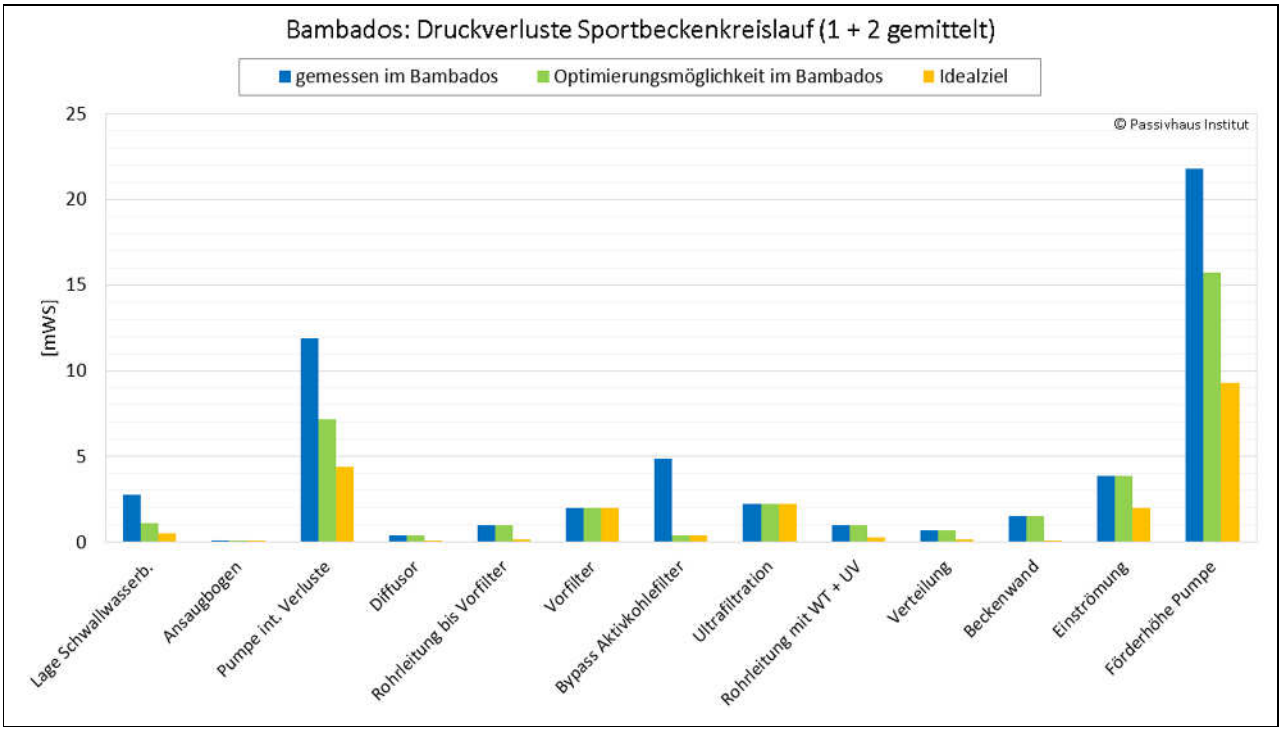


Figure 92: Sports pool circuit 1 + 2: averaged e measured pressure losses of the two Circuits as well as their optimization potential in Bam bados and pressure losses in a fictitious "ideal bath" [Kaluza 2014]

5.10.3 Pumps and electricity consumption

The power requirement is determined on the one hand by the pressure losses in the circuits and on the other hand by the properties of the pumps. During the consultation, great importance was attached to designing the pumps to be suitable for the operating point of the circulation. Because the pumps temporarily

further company u nkt, namely for filter backwashing, it may happen that ass the operating point of the circulation is shifted to a poorer efficiency range. For this reason, a booster pump was used in the circuits of the slides and the teaching pool in the Bambados, which is only switched on for filter backwashing. As a result, better efficiency could be achieved in circulation operation. The circulation pumps are selected in such a way that good efficiency is achieved even with the larger delivery heads. In Figure 93 (right)

is the pump characteristic of a sports pool circulation pump for the

Design point of planning shown.

If the pump is designed with the actual delivery head, the efficiency of the pump drops only slightly from 79.9% to 78.1%. The calculation results in an output of approx. 10 kW and a total efficiency (pump, motor and frequency converter) of 71.9%. This performance was confirmed by a temporary measurement over twelve days.

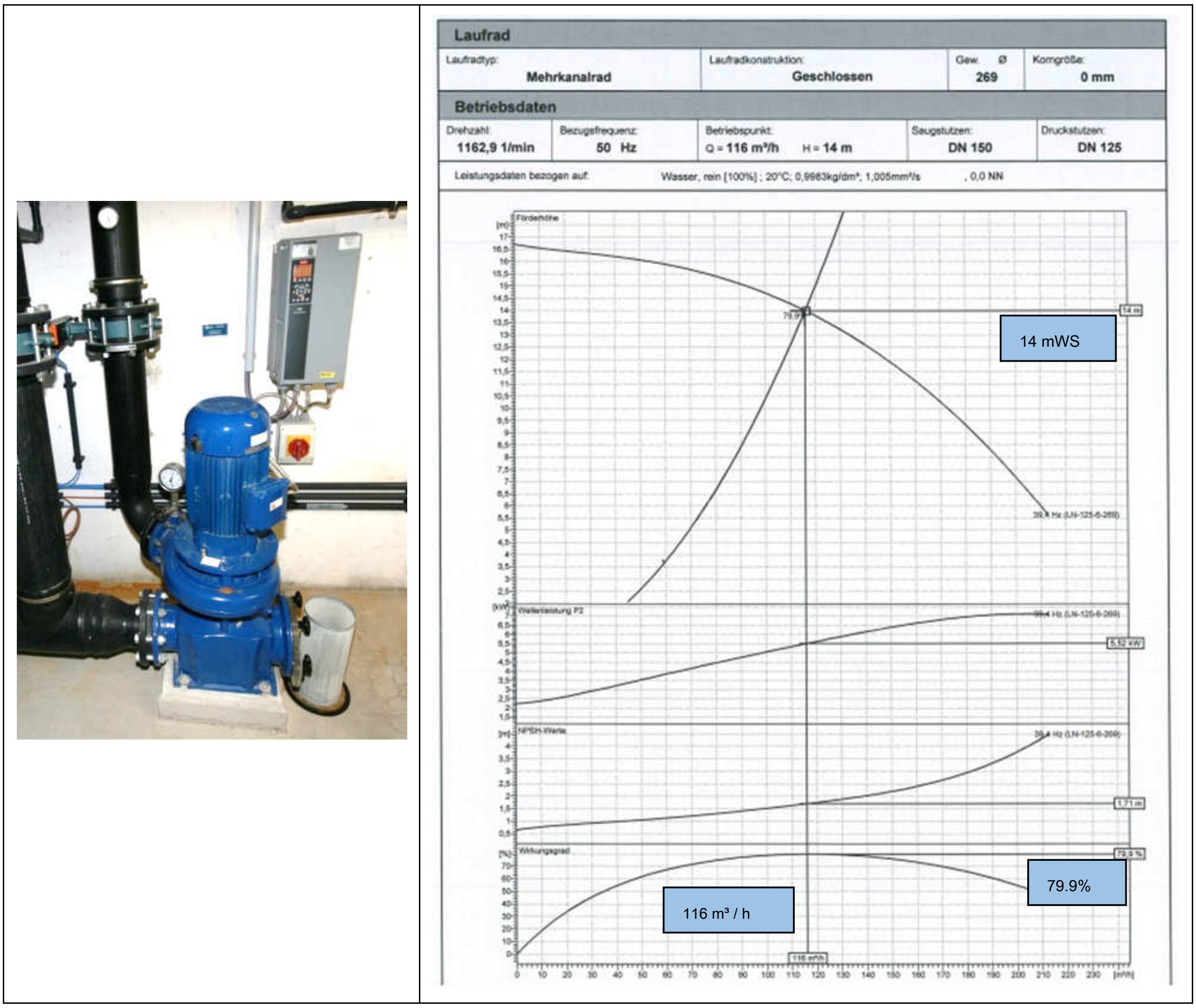


Figure 93: Sports pool: circulation pump Unibad 125-2 70 / 1504X-W2 with frequency converter (top right on the wall) and replacement filter basket (bottom right); Pump curve: 116 m³ / h, 14 mWS, 79.9% pump efficiency (design: Herborner)

The electricity requirements of bathing water technology are made up of the hygienically necessary water treatment that runs day and night and the technology that is required for attractions such as slides, bubble beds, etc. A rough one can be made on the basis of two temporary measurements

Estimate these shares. In day-to-day operation, the attractions take up about 30% of the electricity consumed by bathing water technology, and over 24 hours it is around 20%. The pumps for pool water circulation make up the largest part of the electricity consumption of hygienic bath water treatment. The output from the temporary measurement gives a value of 0.084 kW per cubic meter of water actually pumped for the sports pool circuit

1. However, this system must overcome a somewhat higher pressure loss due to ultrafiltration, but at the same time only convey half the volume flow compared to multi-layer filters. In order to be able to compare baths with each other despite different filtration processes, it makes sense to relate the electricity consumption to a uniform reference value. The calculated circulation volume flow is suitable for this at k = 0.5 m^3 (corresponds to the nominal load according to [DIN 19643]; k: resilience factor). For a pool of the same size and use, this value is always the same and independent of the filtration system or the volume flow. In the Bambados, there is a reference output of 0.042 kW per m³ / h for the sports pool circuit 1 (conventional circulation volume with k = 0.5 m^3). This is, so to speak, the result of a pipe network worth optimizing, a good pump and a low volume flow due to the good filtration performance of the ultrafiltration. The power consumption is comparable to the average values from the Lippe Bad Lünen. Other optimization options have already been identified there. [Peper / Grove-Smith 2013]

Hygienic water treatment is a core part of a swimming pool and must be ensured at all times. That is why the circulation circuits are kept in operation at night. During night operation, an internal circulation is carried out, ie the water level in the pool is lowered, the water is sucked out approx. 50 cm deeper from the pool and fed directly into the pre-filter. This avoids both the overflow channels and the splash water tank. The pressure loss in the circuit thus drops by 2.75 mWS. A partial load operation could achieve further electricity savings. However, the volume flow is so low due to the filter technology ultrafiltration that it is difficult to lower it even further without restricting the flow through the pool.

As a conclusion to the bath water technology, the following can be noted:

- The operator is very satisfied with the filtration system (UF + activated carbon) and the quality of the water quality.
- The internal night circulation has proven itself and is also rated as positive from a cleaning technology perspective.
- By optimizing the pressure losses in the pipe networks, the electricity consumption could be further reduced (for detailed recommendations see above).

6 Results and summary

6.1 Overall results

The main question is: How is the energy consumption of the Bambado compared to other bathrooms? A 1: 1 comparison can unfortunately not be carried out with total energy consumption, since the bathrooms have very different equipment (sauna, spa, attractions, etc.) and operating modes (opening times, temporarily heated outdoor pools, etc.). In addition, there is no statistically reliable consumption data available for other pools. As a guide, the total consumption values (heat, electricity, water) of the Bambado were compared with the corresponding consumption of approx. 37 leisure pools (44 annual consumption data in total) (mean, minimum and maximum). These data come mainly from [ÜÖBV] and additional data from 6 baths from [SBFBauten 2012].

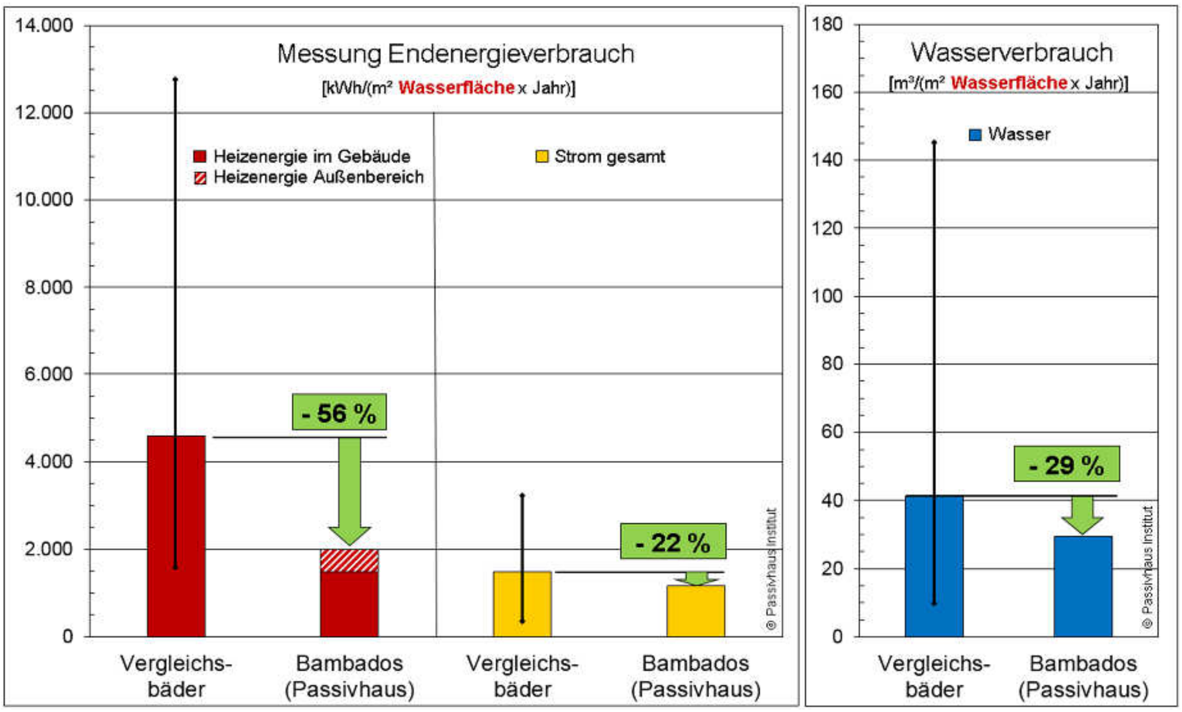


Figure 94: Comparison of the final energy and water verv consumption (per m² of water surface) other leisure pools. It should be noted that the consumption values can only be compared with one another to a limited extent, since the bathrooms about very different Equipment (Sauna, Spa, Attractions etc.) and modes of operation (Opening times, temporarily heated outdoor pools, etc.) feature.

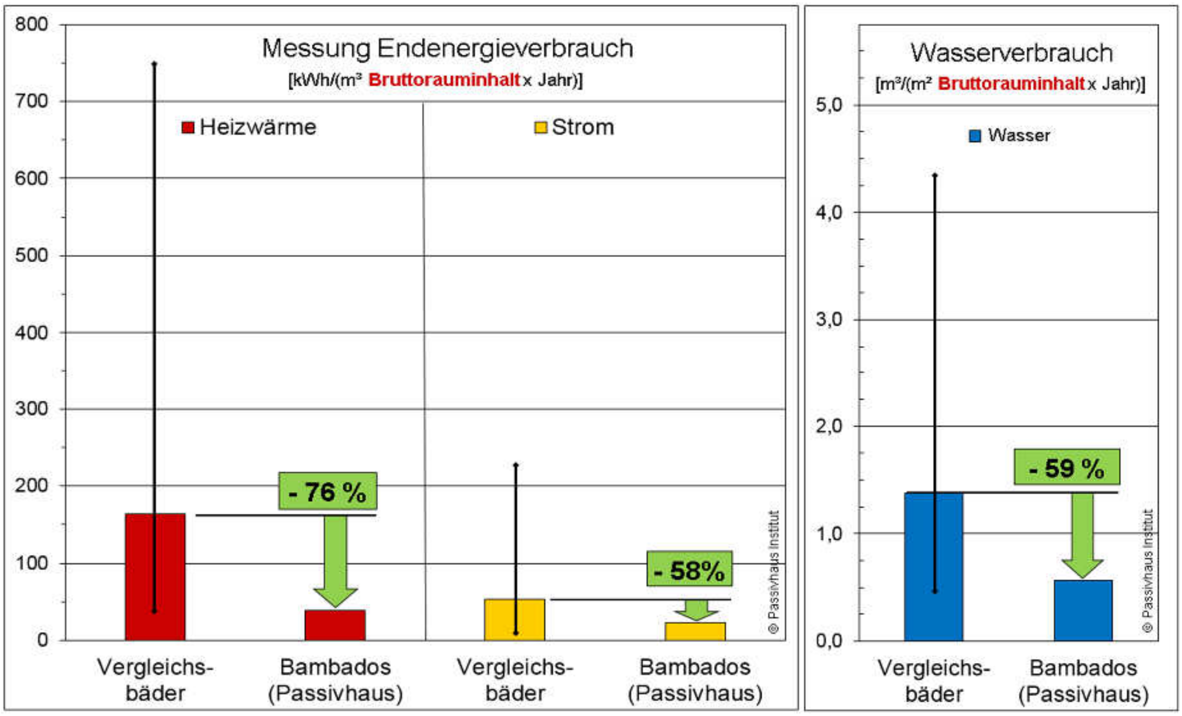


Figure 95: Comparison of the final energy and water verv consumption (per m³ gross volume) other leisure pools. It should be noted that the consumption values can only be compared with one another to a limited extent, since the bathrooms about very different Equipment (Sauna, Spa, Attractions etc.) and modes of operation (Opening times, temporarily heated outdoor pools, etc.) feature.

Figure 94 shows the comparison of energy consumption in relation to the water surface and Figure 95 in relation to the gross volume. In addition, the water consumption is also shown. It can be seen that the reference variable has a decisive influence on the comparison. Especially for leisure pools that offer other uses besides water areas such as saunas, gymnastics rooms, etc., the usual reference to the water surface is not expedient. If you want more than just a rough classification of consumption, it would be advisable to compare individual consumption data with different references. For example:

- Electricity consumption of bath water treatment per m³ circulation volume
- Power consumption of the slides per slide, per meter height
- Electricity consumption of the lighting per m² of energy reference area
- Heating energy consumption of the saunas per sauna space
- Heating energy consumption pool water per pool area or pool volume Even when evaluating these exact comparisons, uncertainties such as different pool temperatures and different opening times must be taken into account. In addition, it has been very difficult to get data in this level of detail because it is usually not recorded.

The monitoring results clearly show that the increase in efficiency in the area of heating energy and water consumption was successful, while in the area of electricity considerable energy was saved, but there is still great potential in efficient technologies.

When advising on the pilot project as a passive house indoor swimming pool, different levels of optimization could be achieved. The focus of the advice was on the building envelope, evaporation, swimming pool pumps and ventilation. The outside area was only dealt with marginally (this is not part of the passive house concept and accounts for approx. 25% of the measured heating energy and approx. 6% of the measured electricity consumption), the kitchen and the use by the tenant. There is further optimization potential for further projects in the area of swimming pool technology (for specific recommendations see Chapter 5.10), zoning and air routing.

6.2 Summary

For the construction of a new leisure pool in Bamberg, the client, Stadtwerke Bamberg, focused on energy efficiency in 2008 and therefore decided to build a passive house indoor pool. This became the passive house

Institute Darmstadt, the in advance one

[Schulz 2009] had commissioned a fundamental investigation into passive house indoor pools, with an energetic consultation during the planning process. In addition, monitoring was carried out due to funding from the EnOB. In indoor swimming pools, the focus is on operating costs due to the high energy consumption. Therefore, it makes sense to take advantage of the possibilities of energy efficiency and thus to enable the bathroom to be operated more cost-effectively and in the long term. The passive house institute's approach is based on an energy analysis of the given use (swimming in warm, clean water, etc.) in order to lead the building as a whole to high energy efficiency. New approaches were taken as a pilot project and the monitoring clearly shows that the overall concept and the measures taken were successful. In addition, it explains how further reductions in energy consumption are possible for the Bambados and for new indoor swimming pools in the future.

The Bambados is a leisure pool with sports, leisure, children's, outdoor and two teaching pools. In addition to attractions

in the hall area (slides, bubble loungers,

Gush showers etc.) it offers a sauna area inside and outside, a spa area and gastronomy.

The building envelope (walls, roofs, foundations, windows, connections etc.) was optimized in terms of energy using an energy balance (average U-value of the entire envelope: 0.164 W / (m²K)). A specially developed multi-zone PHPP (Passive House Planning Package) was used for energy balancing. Compared to a residential building, an indoor pool with an internal temperature of 32 ° C has a greater temperature difference to the outside air and a significantly longer heating period. The airtightness required in the passive house and its checking are irreplaceable for an indoor pool due to the room humidity to protect the building structure. In Bambados a very good n50 value of 0.07 h 1 (corresponds to q50 = 0.21 m / h).

The **Passive house building envelope** significantly reduces transmission losses and at the same time forms the basis for further energy efficiency measures for an indoor pool:

- possibility from higher Room humidity and in order to reduction the Evaporative heat losses and ventilation losses
- Ventilation units can be operated without recirculating air; it is not necessary to blow on the window facades **Air conditions in the swimming pools** were adapted at the request of the bathers and due to energetic optimization of the ventilation in the course of the operation. On the operator side, a relative humidity of 58% was specified as the target value. Outside the opening times, the setpoint for the relative humidity is increased depending on the outside air humidity, which is energetically advantageous

is. With the orientation measurement of the swimming pool air Trihalomethane was the concentration level independent of the air circulation. However, the measurement shows that a good air flow is essential.

The **Heating consumption** Bambados was able to be reduced by more than 50% compared to comparison baths (see also 6.1) This is made up of the energy required for heating the indoor air (39%), the pool water (41%), the hot water (16%) and the sauna cabins (5%) is required.

The reasons for the low heating consumption for air heating lie in the passive house building envelope and ventilation volume flows that meet the needs. It is heated via the supply air. Radiators are not necessary. Zones with a higher target temperature (swimming pool, changing rooms, showers) have a higher heating energy consumption than colder zones (administration, storage, technology). In order to enable good control of the colder zones (administration), an internal thermal separation is useful.

When it comes to heating energy consumption for the pools, it is striking that the "colder" sports pool (28 ° C) has a very low heating energy consumption compared to the warm pools (32 ° C). This is probably due to the low loss of pool water or the profits from the warm basement.

In addition to heating the pool water, hot water has to be heated mainly for the showers. Here the decisive influencing factor for the water and energy requirements is the flow rate of the shower heads. The energy required to heat a liter of water is approx. 60 - 70 Wh, the average shower time is approx. 3 minutes per person.

The **Power consumption** was significantly reduced in some areas, especially in the ventilation area. The largest proportion of the electricity consumption in Bambados is generated by bathing water technology, followed by lighting, ventilation and other consumers such as kitchens, spas, offices, etc. In the area of **Bathing water technology** measurements of the pressure losses were carried out on site in order to uncover further potential savings. The circulation pumps were selected to match the operating points. The measurement of the pressure losses shows that the design of the pipe networks offers potential for a reduction in electricity consumption by, among other things, lowering the pressure losses through low flow velocities (v = 1-1.3 m / s). With the addition of an activated carbon filter, the ultrafiltration plus UV system cleans the water well with the planned low circulation volume flow (50% in relation to multi-layer filters).

For the **lighting** In the halls, daylight can be used through large glazing areas in the facade and shed-like skylights in the roof. The electrical lighting is energy-efficient with T5 fluorescent tubes and LED lighting and is controlled by daylight in many areas. Optimizing the demand-controlled control (e.g. cleaning lights at night) offers potential for further savings in electrical energy.

The area of ventilation was both a focus of advice and operational optimization. In addition to good heat exchangers, regulation is of crucial importance. The outside air volume flow required for dehumidification is operated in the hall area, but at least 15% according to [VDI 2089]. The ventilation units are switched off at night, but the humidity is continuously monitored. In the sub-zones, the volume flows could be reduced by a total of 50% during the planning phase by designing volume flows and overflows that were tailored to the needs. After the operational optimization, this reduced value could be confirmed by measurement data. Example: Supply air is introduced into the changing rooms and discharged as exhaust air via the shower rooms. The required dehumidification performance is ensured by regulation based on relative humidity. The evaluation showed that the dehumidification requirement is so low that it is covered by the set basic air change. A demand-based volume flow in the entire building is so important because a reduction in the volume flow has multiple effects:

- Reduced ventilation losses lead to reduced heating consumption.
- Reduction of electricity consumption for ventilation
- lower pressure loss in the sewer network and ventilation unit; this increases the electricity efficiency of the ventilation unit and the electricity consumption also decreases
- Comfort: Drafts are avoided and in rooms with low moisture loads (e.g. offices) the risk of excessively dry air is reduced. An example of these effects can be seen in Figure 96: The power consumption of the hall ventilation has been reduced by 60% through the optimization of operations. In the same period, the total electricity consumption of the ventilation in the secondary zones was reduced by approx. 50%.

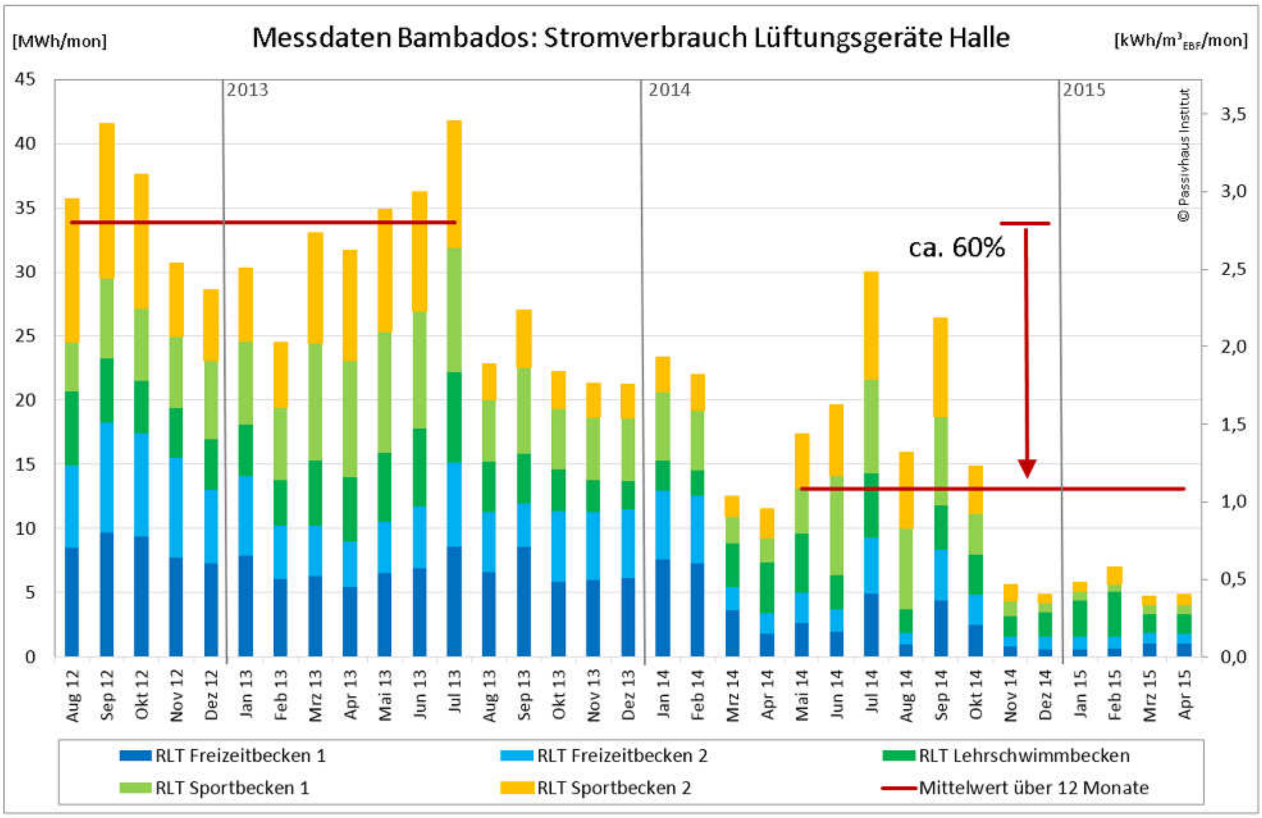


Figure 96: Reduction of electricity consumption through needs-based ventilation control in the Swimming pools. (Shown is the impact of Adjustment and Optimization of operations, in red the average Monthly values averaged in each case over a year)

During the monitoring it was shown that a **Settlement** respectively. **Operational optimization** is indispensable in an indoor pool, regardless of whether it is a passive house standard or another construction quality. The digital data acquisition with the help of a BMS enables the operator to get immediate feedback. In order for this data to be tracked, the operation to be optimized and to be monitored in the long term, it is essential that the operator is well informed about the technical regulations and energetic relationships.

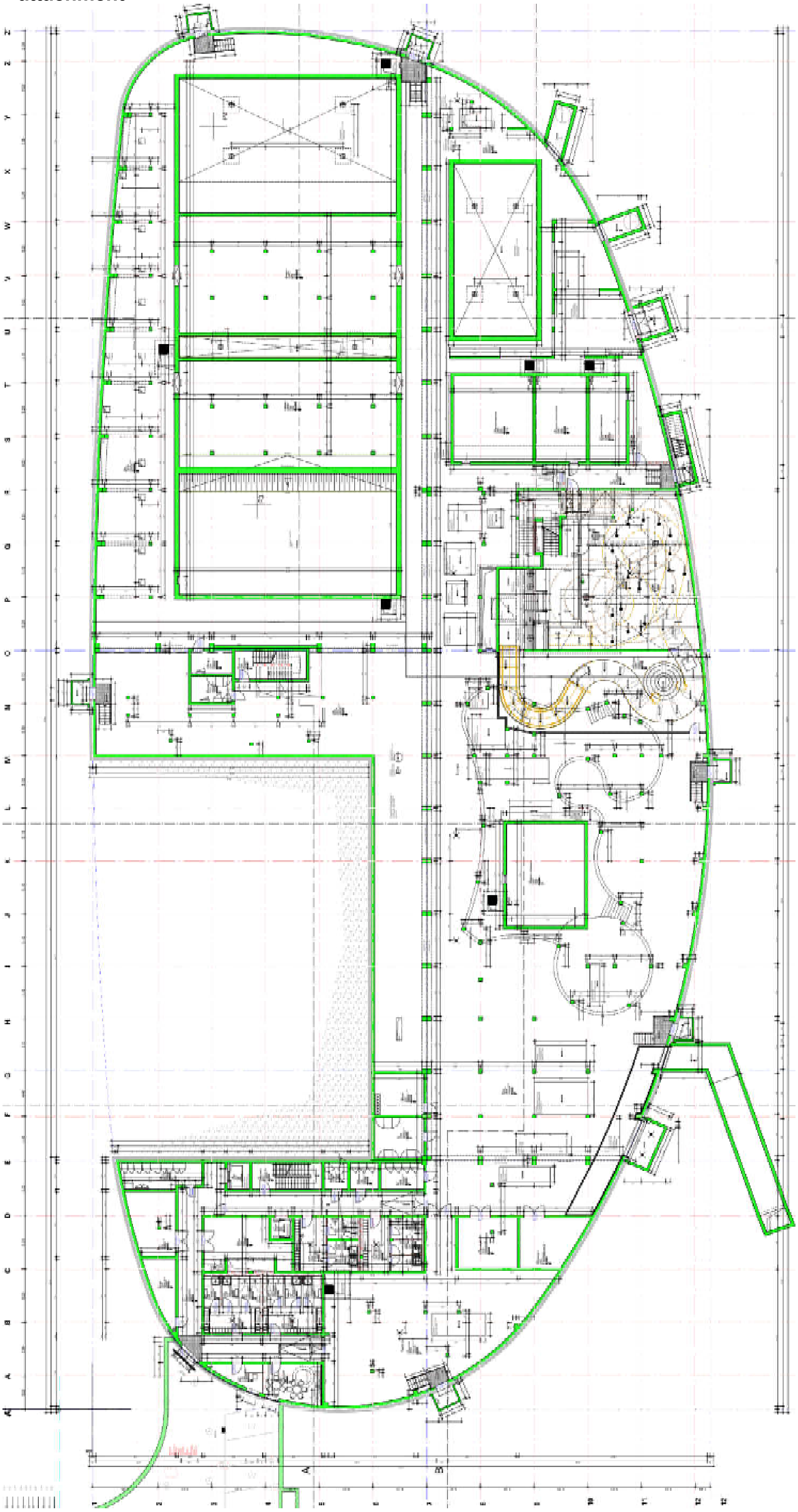
6.3 Further research needs

In the course of this evaluation it became clear that it would be helpful for the future successful implementation of energy-efficient bathrooms to examine the following points in more detail:

- Measures for the secure implementation of integral planning
- Measures for joint regulation and operational optimization (cooperation between planners, executing companies, energy advice and operators)
- Air flow in and flow through swimming pools
- Checking the possibility of using smaller ventilation devices (reduce peak volume flows, for example, by suitable control)
- Type and optimization of pressure compensation for splash water tanks
- Investigation of variants for the ventilation of sauna cabins
- Investigation of the use of various heat generators for heating
- Investigation of suitable reference values for the comparison of different bathrooms
- Reference and target values for individual areas

Stadtwerke Bamberg has guided many national and international groups through the Bambados since the bath was commissioned. This shows that energy efficiency in pool construction has met with keen interest. The findings documented in this report are intended to help implement the high potential for energy efficiency in future projects and bathroom renovations.

7 attachment



Floor plan basement

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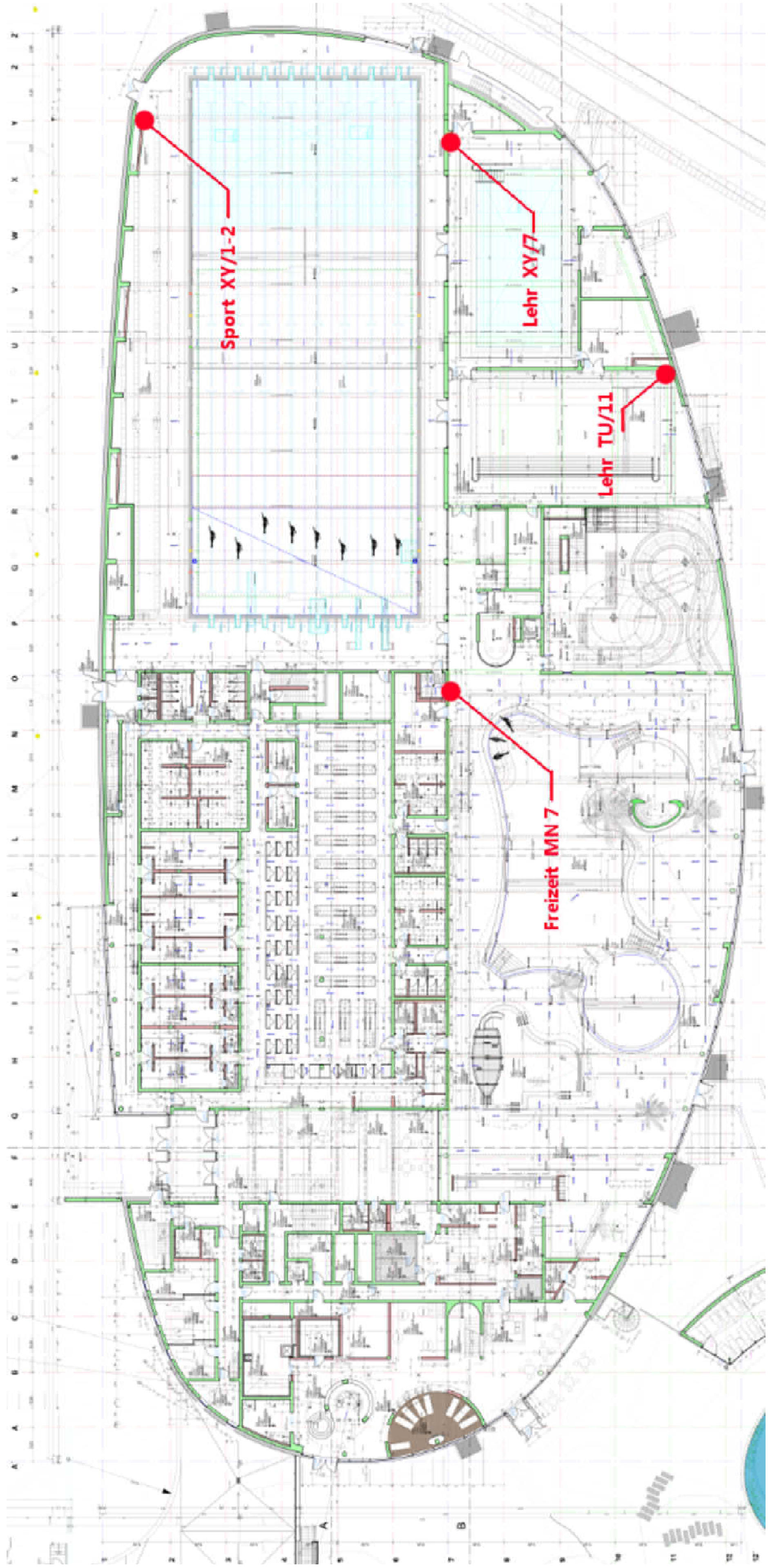

Ground floor plan with positions of the relevant sensors for air temperature and humidity

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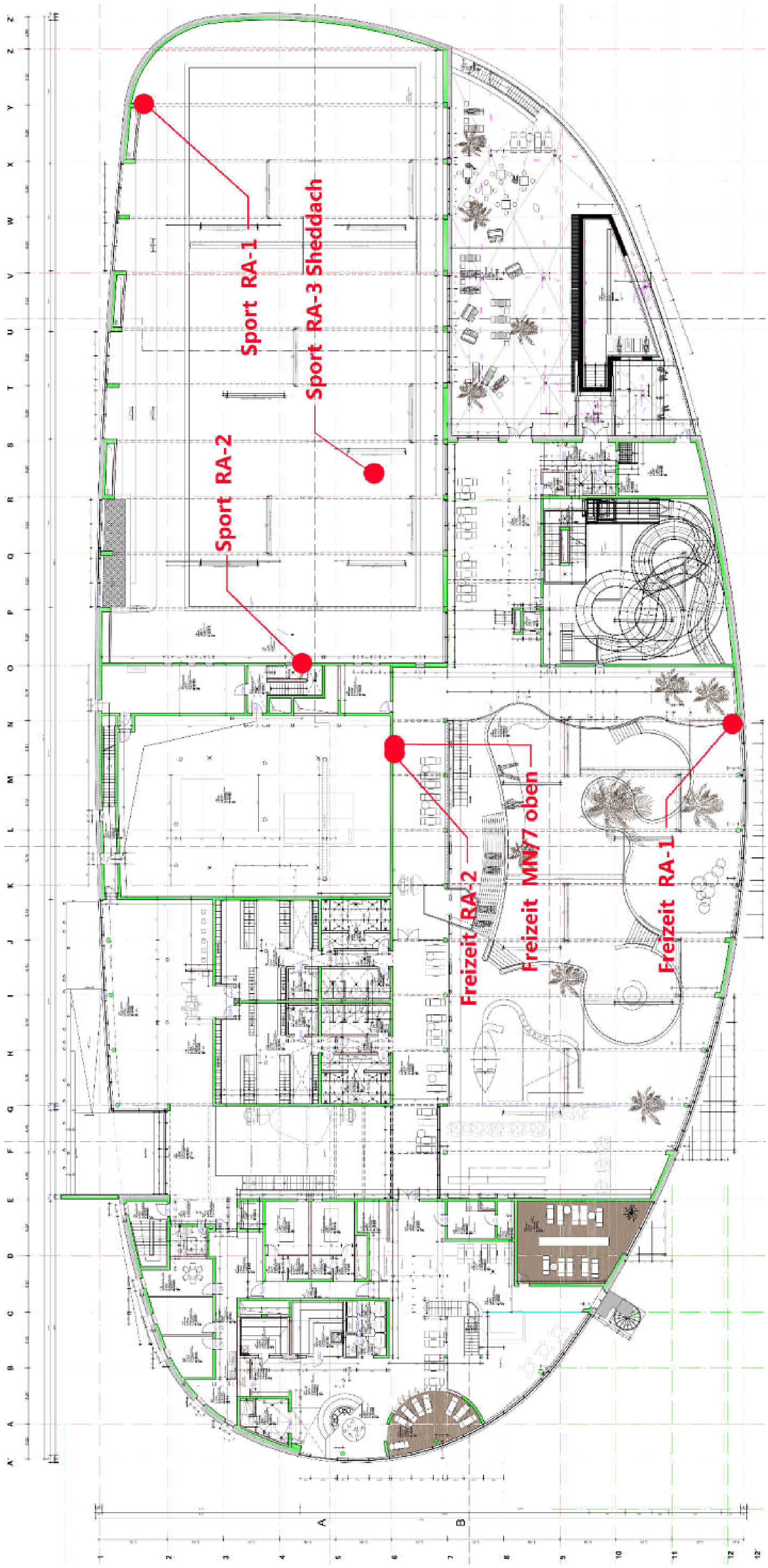

Floor plan upper floor with positions of the relevant sensors for air temperature and humidity

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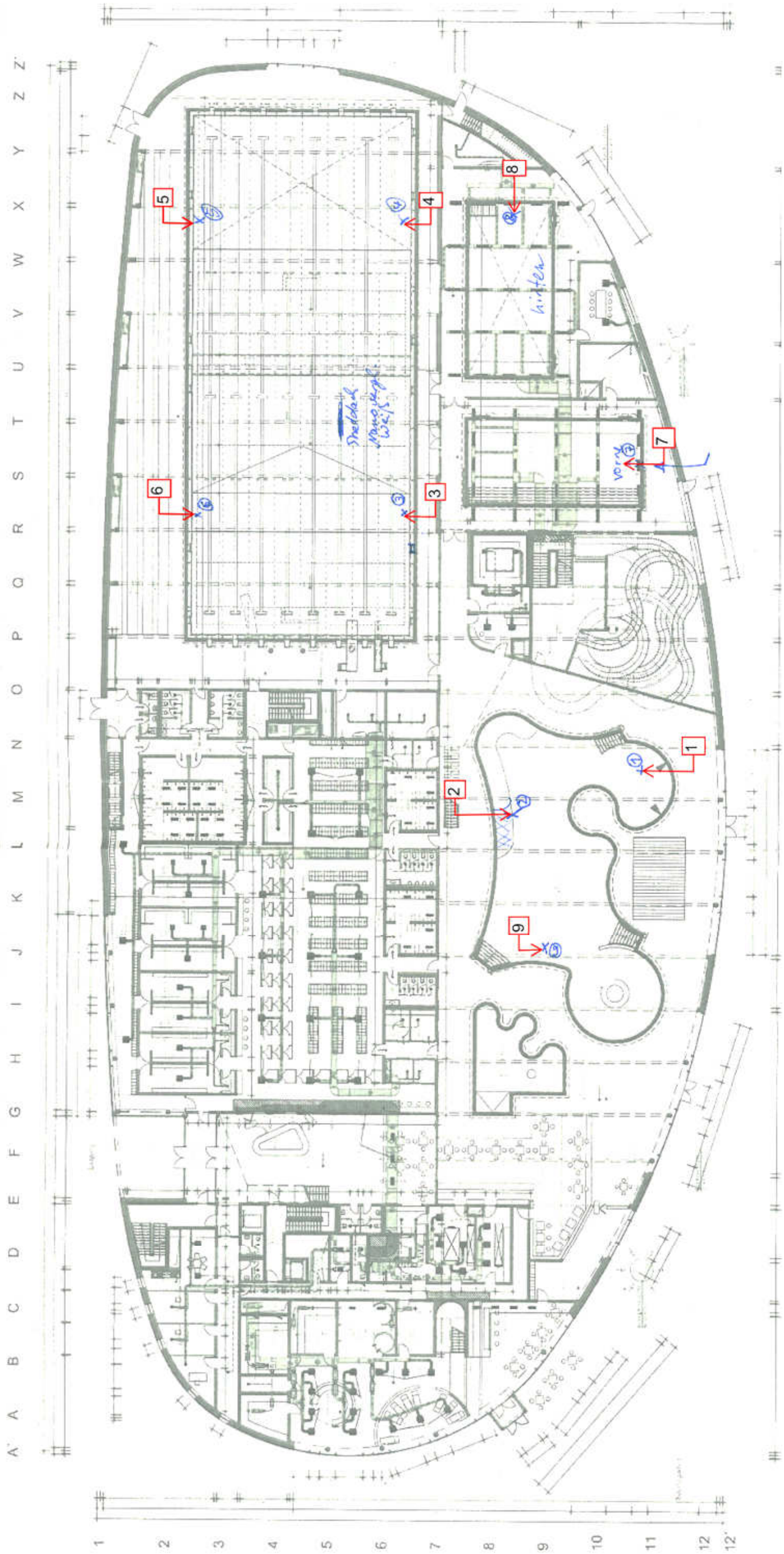

Ground floor plan with positions of the trihalomethane measuring points

Source: pbr

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