Passivhaus Institut

Monitoring passive house indoor swimming pool

Lippe-Bad Luenen

Client: Lünen spa company

BÄDERGESELLSCHAFT LÜNEN

With funding from the
Federal Ministry for the Environment, Nature Conservation and Reactor safety

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

August 2013

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Authors:
Dipl.-Ing. (FH) Søren Peper MPhys.
Jessica Grove-Smith

With the cooperation of:
Florian Gressier
Waldemar Rupps Dr.
Benjamin Krick Esther
Gollwitzer Arthur Dumler

Editor:
PASSIVHAUS INSTITUT Dr.
Wolfgang Feist Rheinstraße
44/46 D-64283 Darmstadt Tel:
06151-82699-0 E-Mail:
mail@passiv.de www.passiv.de

Darmstadt, August 2013

This report was commissioned by the Lünen spa company with funding from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

We thank Dr. Gerd Koch and Thomas Claus from the Lünen spa company for the good cooperation. In particular, we would like to thank the technical planner of the Bad Olaf Ahrens from the engineering office ENERATIO Hamburg for the constructive cooperation as well as the quick answers and good ideas.

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1 Introduction and summary

The energy consumption of swimming pools is very high due to the high room air temperature, the high ventilation heat losses and the energy-consuming water technology. Due to the construction of many pools in the 1970s, in many cities and municipalities there are fundamental renovations or the demolition and possibly new construction of indoor pools. A renovation backlog has arisen and many cities and municipalities are heavily burdened by the high operating costs of the old pools. According to [Heiden / Meyrahn 2012] there are 3,448 indoor, leisure and combination pools in Germany alone - the need to develop and implement energetically improved solutions is high.

Against this background, it was investigated how the passive house concept can also be applied as a guiding principle to indoor swimming pools: The aim is to enable optimum comfort (e.g. due to high surface temperatures even on large glazing areas) with significantly reduced energy consumption. The potential was first determined by the Passive House Institute in a basic study for passive house indoor pools [Schulz et al. 2009] in order to then implement the concrete measures in pilot projects.

The key points of the passive house indoor pool concept emerged:

- The transmission heat losses are significantly reduced by a thermally very high-quality building envelope.
- The thermally improved building envelope, especially the transparent components, result in higher surface temperatures and reduced cold air loss on the components, especially on the glazing and other window components. On the one hand, this quality increases the comfort, on the other hand, the bath can be operated with higher air humidity (up to 64%) without condensate failure.
- Due to the increased indoor air humidity, the heat given off by the evaporation of the pool water and the dehumidification requirement of the indoor air are significantly reduced.
- Through the use of high-quality ventilation heat exchangers and an adapted ventilation control, ventilation heat losses in the swimming pools as well as in the adjoining rooms can be significantly reduced.
- The electricity requirement is also significantly reduced (e.g. by avoiding large amounts of circulating air and using highly efficient devices such as ventilation motors, lamps, pumps, etc.)

- Improved swimming pool technology with energy-efficient electrical systems and the extensive reuse of filter backwashing water (wastewater treatment) are further important pillars of the concept.

The basic study on passive house indoor swimming pools was carried out by the Passive House Institute using the example of the planned new building of the Lippe bath. This was followed by the construction of the Lippe bath as a prototype. The planning and construction of the bathroom was accompanied by the project for integral planning [BGL 2011]. The bath went into operation in September 2011. Since this building is a pilot project of the passive house indoor pool concept, from which basic knowledge about the energy flows in such pools is expected, extensive monitoring was carried out. This report contains the evaluation of the measurement data from the first measurement year and the knowledge gained from it.

The indoor pool is a sports pool with a total of five pools. In addition to the basic concept, low-temperature heat from the case cooling and the exhaust gas cooling (condensing system) of the two neighboring combined heat and power plants of the Lünen district heating network are used in the Lippe bath for heating and hot water preparation. In this way, an extremely cheap primary energy supply was realized. The energy reference area (EBF) of the entire indoor pool is 3,912 m², the water area of the five pools is 850 m². There is a combined parent-child and warm pool (175 m²), an educational pool (100 m²) with lifting floor and two sports pools with a total of nine lanes (length: 25 m / area: 575 m²). The heating takes place exclusively via the supply air reheating, Static heating surfaces and underfloor heating could be dispensed with, which means that the advantages of the passive house concept in terms of technical simplification can be implemented here without hesitation. In 2012, over 208,000 visitors used the indoor pool on the Lippe, with clubs and schools in particular being strongly represented.

The building was designed and planned by the architecture firm "nps tchoban voss" (npstv) from Hamburg. The planning of the entire house, ventilation and swimming pool technology was carried out by the engineering company ENERATIO from Hamburg. The passive house institute, Darmstadt, provided the energetic advice and quality assurance. Builder and initiator is the Lünen spa company.

Details of the building, the integral planning and implementation of the project are presented in the previous report on the integral planning of the bathroom [BGL 2011]. In addition to dynamic simulations, a specially adapted multi-zone PHPP (Passive House Planning Package) for indoor pools was developed and applied for the energy balance of the bath during the planning period [PHPP].

Figure 1: Aerial view of the Lippe bath (source: Lünen spa company)

The final energy consumption values obtained from the building as a whole are of interest for the overall energy assessment of the bathroom. The specific annual consumption values of the Lippe-Bath result for the year period April 2012 up to and including March 2013 [1]:

Heat coverage:	**258 kWh / (m^2_{EBF} a)**
Power consumption:	**156 kWh / (m^2_{EBF} a)**

If one relates these total annual consumption values to the **Pool area** of 850 m², the following specific consumption values result:

Heat coverage:	1,189 kWh / (m^2_{pool} a)
Power consumption:	718 kWh / (m^2_{pool} a)

The comparison with other baths is not easy, because only a few reliable or suitable comparison data are known. The available literature [ages 2007], [DGfdB R 60.04], [Schlesiger 2001] and [VDI 2089Blatt 2] are not individual baths, but rather mean values or ranges of very different baths or bath groups, therefore the range of fluctuation is specified energy consumption is very large. In order to be able to make a first classification of the Lippe bath, the information from the literature was averaged and its range of fluctuation (maximum and minimum value) was given (Figure 2).

[1] A total of twelve months, ie a complete year. The period contains some interpolation calculations in the event of meter failure and meter conversion and includes a period of six weeks with revision work in summer 2012.

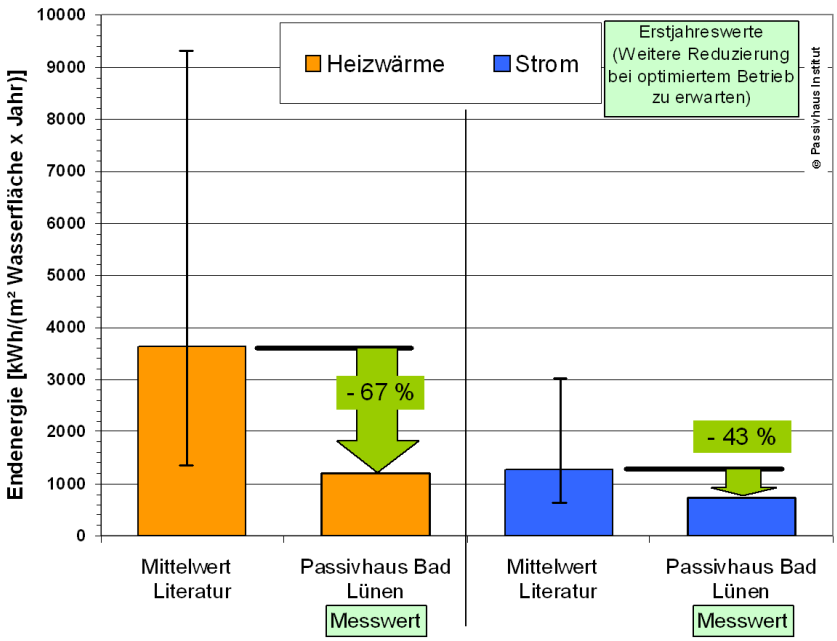

Figure 2: Comparison of the measured consumption values for the entire heat and Electricity supply (final energy) of the Lünen indoor pool with values from the literature. The range of fluctuation of the literature values is indicated by the maximum and minimum values (black vertical lines).

Already this first orientation clearly shows that the consumption values in Lünen are already below the mean values of the literature in the first year of operation: in the heating area the measured value is almost 70% below the mean literature value, for electricity it is more than 40%. The first year of operation in the Lippe-Bad was, as is generally the case with newly commissioned new buildings, characterized by the regulation of the complex building technology. The evaluation of the measurement data in this report shows that there is definitely further optimization potential in operation and that even lower consumption values can be expected in the future.

Heat consumption in the Lünen indoor pool

The heat consumption is divided into three consumption areas:

- Pool water heating / 123.4 kWh / (m²a)
- Post-heating ventilation (air heating) / 93.7 kWh / (m²a)
- Water heating (showering / cleaning) / (35.0 kWh / (m²a)

The pool water heating has the largest share of the heat consumption in this bath with 49%. Within the second largest sub-area, post-heating, the heating of the four halls requires a dominant 72% of the heat consumption. The small difference (2.3%) between the supply of heat to the bathroom and the heat consumption of the sub-areas is due to the heat dissipation from the pipe network and measurement deviations of the heat meters.

An extensive wastewater treatment plant installed in Lünen can treat a maximum of about 70% of the filter backwashing water and feed it into the pool water circuits. This large amount of water (up to over 15,000 m³ / a) does not have to be replenished and heated with cold water from the outside. The facility was during most of the monitoring period **Not** in operation. After technical adjustment, it should be reconnected in a timely manner. Along with this, considerable further savings of approx. 50 to 60 kWh / (m²a) can be expected.

Delivery of heat to the Lünen indoor pool

The heat is supplied to all consumers from these four sources:

- Direct purchase from the biogas CHP (from June 2012) (33.9%)
- Exhaust gas heat exchanger from two CHP plants (condensing boiler use) (33.5%)
- Waste heat from two CHP plants (16.6%)
- District heating network City of Lünen (16.0%),

In this way, a very cheap primary energy solution has been implemented because the two directly adjacent CHP plants can use heat at a low temperature. Normally, this would be vented away as waste heat or released as waste heat. In addition, the district heating network has a very low primary energy factor due to the high proportion of renewable energy. Due to the high efficiency of the bathroom itself, both the temperature level and the quantity structure of these sources are sufficient: The system is a good example of how energy efficiency in buildings and technology as well as the use of renewable energy lead to synergies that enable a truly convincing overall solution.

Electricity consumption in the Lünen indoor pool

The power supply of the bath is ensured by grid connection and own solar power production. The bathroom has a large PV system on the roof (91 kWp) and two outdoor PV staplers (19.7 kWp). Temporary surpluses and the complete electricity production of the PV trackers are fed into the public grid. Almost 12% of the 156 kWh / (m²a) of electricity used in the indoor pool could be covered by solar power. In addition, 6.2 kWh / (m²a) solar electricity was fed in (corresponds to absolutely over 24,200 kWh). In this case, despite the very high efficiency, there is still a significantly higher consumption of electricity in the indoor pool than can be generated with the PV system on an annual average. This underscores the need to develop and use electricity efficient technologies.

Ventilation technology is by far the largest individual electrical consumption area (34%), followed by the circulation pumps of the pool water circuits (24%).

Ventilation concept

To supply the different areas of the building, a total of six ventilation units are operated with post-heating registers, which are located in the basement of the building. Two different device types are used. The hall units are custom-made, each with two cross-flow and one counter-flow heat exchanger in series. One of the devices is equipped with a heat pump to extract further heat from the exhaust air (enthalpy recovery). Because of the thermally high-quality building envelope, it is no longer necessary to blow dry the mullion-transom facades.

The ventilation technology is coming in an energy-optimized indoor pool
Key function too. In the adjustment phase - despite the already good results - the full potential could not yet be exploited: the hall humidity can be increased even further, the control of the devices has to be further optimized.

The analysis also shows that the total circulating air volume flow of all devices in the indoor pool is around 70%, while the outside air volume flow is only 30%. Only the latter is necessary for dehumidifying the halls and for maintaining air quality (removal of pollutants). The circulating air volume flow, on the other hand, is only intended to ensure thorough mixing of the hall air, for which lower circulating air volume flows would also be sufficient. This has been shown by the tests carried out to flow through the hall (fog tests). The objective of the passive house concept for indoor swimming pools is ultimately to operate completely without recirculation, as this results in a significant reduction in the electricity consumption of the ventilation units.

In the course of the monitoring, various test series were carried out to determine the effect of the higher hall humidity and the low circulating air volume flow. In this way, the considerable effects on heating and electricity consumption from the basic investigation could also be confirmed in practice.

Optimization through energy balancing

The ability to be able to reliably predict the energy requirements of a building during the planning phase is a basic prerequisite for achieving high energy efficiency. It enables the optimization of individual components as well as the holistic building concept. The energy flows in an indoor pool are very complex due to many interactions and regulations and are therefore difficult to detect. For this reason

the multi-zone PHPP mentioned above was developed. The tool was adapted to the resulting requirements during the planning phase of the bathroom and is still in development.

The available measurement data from the monitoring were used to check and further improve the assumptions, approaches and calculation methods of the energy balance. A larger adjustment of the calculation assumptions was only necessary in the area of pool water heating. At this point, the measurement data was significantly below the forecast values. The main reason for this deviation was that the evaporation quantities were deliberately high on the safe side during the planning phase, as there was no reliable data available for a plausible assessment. The measurement data presented confirm that the average evaporation quantities in practice during the hours of use are significantly lower than specified in [VDI 2089] for the design of the ventilation units (this is correctly the peak load).

Apart from the pool water heating, the order of magnitude of the remaining main consumers (space heating, water heating and electricity) was correctly represented in the energy balance of the planning phase. The agreement of the measurement data with the calculations with adapted boundary conditions is

in the

Good within the existing uncertainties, which basically confirms the calculation approach and provides a validated basis for follow-up projects.

Overall rating

Despite the expected deviations due to the typical effects of the adjustment period, the indoor swimming pool in Lünen achieved a very good energy value in the first measurement year. The planning measures have achieved the intended success. As described at various points in this report, the energetic optimization with regard to the operating mode is still not exhausted. The updated energy balance for the bathroom under the desired boundary conditions (e.g. 64% hall humidity, reduced circulating air volume flows, 70% filter rinse water treatment) shows that a further operational reduction of the final energy requirement by up to approx. 100 kWh / (m²a) is possible. The largest part of this orientation calculation is the savings made by filter rinse water treatment.

The monitoring was carried out on behalf of the Lünen spa company with funding from the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

2nd Building description

The indoor pool "Lippe-Bad Lünen" was designed as a passive house indoor pool based on the concept of a basic investigation by the Passive House Institute [Schulz et al. 2009] and went into operation in September 2011.

The basic concept of the concept consists of the following building blocks: Thanks to the thermally very high-quality building envelope, the transmission heat requirement can be significantly reduced compared to standard new buildings. The thermal improvement of the building envelope, in particular also the transparent components, results in higher minimum surface temperatures, which makes it possible to operate the bath with higher air humidity (up to 64% RH). This measure significantly reduces losses due to evaporation of pool water and the need for dehumidification. Through the additional use of high-quality ventilation heat exchangers and intelligent ventilation control, ventilation heat losses are significantly reduced.

In the Lippe bath, the various heating circuits use the low-temperature heat from the case cooling (room heat) as well as the exhaust gas cooling (condensing system) from the two neighboring CHP units of the Lünen district heating network. In this way, a very cheap primary energy supply was realized. Furthermore, various energy-efficient electrical systems are used (lighting, pumps, motors). Various optimizations have also been implemented in the field of water technology.

The energy reference area (EBF) of the entire indoor pool is **3,912 m²,** the water surface of the five pools **850 m².** There is a combined parent-child and warm pool (175 m²), an educational pool (100 m²) with lifting floor and two sports pools with a total of 9 lanes (length: 25 m, 575 m²). The heating takes place exclusively via the ventilation, there are no static heating surfaces and no underfloor heating.

The building was designed and planned by the architecture firm "nps tchoban voss" (npstv) from Hamburg. The planning of the entire house, ventilation and swimming pool technology was carried out by the engineering company ENERATIO from Hamburg. The passive house institute, Darmstadt, provided the energetic advice and quality assurance. The client is the Lünen spa company.

Details of the building, the integral planning and implementation of the project are presented in [BGL 2011]. The following pictures give an impression of the building:

Figure 3: West facade of the bathroom with main entrance (left) and Hall 1 + 2 (bottom right)

Figure 4: Aerial view of the bath (Source: Lünen Baths Association)

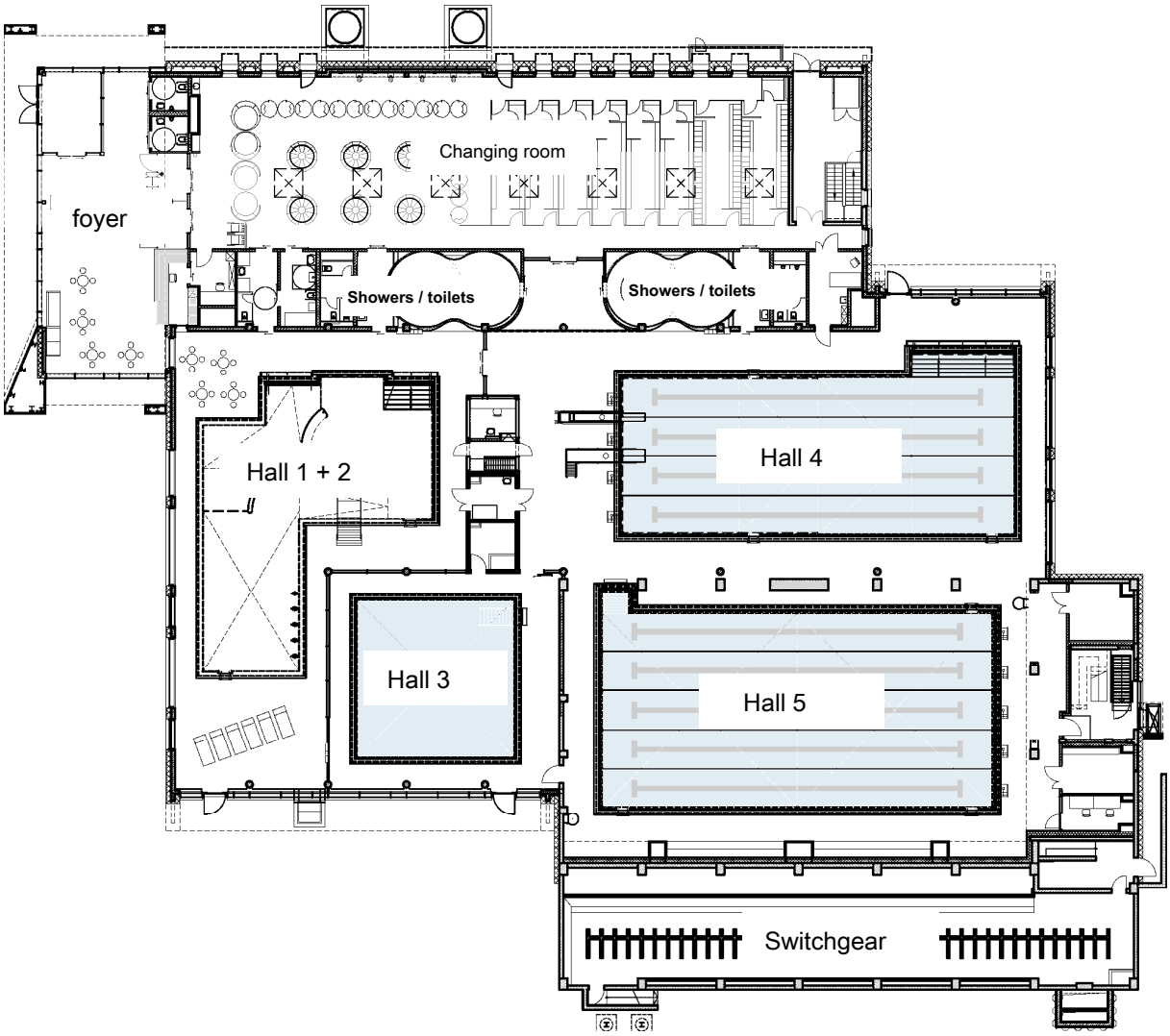

Figure 5: Ground floor plan of the building with the different areas of use (Source: npstv)

Figure 6: Interior views of Hall 1 + 2 with the leisure pool and parent-child area (left from south, right from east)

Figure 7: **Interior views of hall 3 with the training pool with lifting floor (left from south, right from north-east with supply air element)**

Figure 8: **Interior views of Hall 4 with four 25-meter tracks (left from west, right from south)**

Figure 9: **Interior views of Hall 5 (in the old building) with five 25-meter tracks (left from east, right from west)**

Figure 10: Showers (left) and changing rooms (right)

Figure 11: Entrance area / foyer with the checkout area

Figure 12: Water technology (filter) in the basement (left) and ventilation devices in the basement (right)

2.1 Airtightness

The airtightness of a swimming pool is of particular importance due to the increased indoor air humidity. Due to this fact and the size of the building (air volume: 23,962 m³), the required value was reduced to n during the planning period $_{50}$ = 0.2 1 / h fixed. In large buildings - due to the significantly more favorable A / V ratio (here 0.39 1 / m) - the n $_{50}$- Value of only minor significance. The envelope-related characteristic value q is important $_{50}$

with the unit [m³ / (h m²)]. In this building, the requirement is n_{50} = 0.2 1 / h the characteristic value for q_{50} = 0.52 m³ / (h m²).

The PHI carried out the first airtightness measurement of the entire building on August 12, 2011 with an intensive leak search that lasted several hours. In addition to minor individual leaks, leaks in the mullion-transom facade and in the ceiling area from Hall 5 to the previously unused office area were located (see Figure 14 and Figure 15). This preliminary measurement resulted in a measured value that was clearly above the target value of n_{50} = 0.2 l / h.

During the subsequent clarification, a systematic error in the connection of all skylights in the changing area was identified and later rectified. Further control measurements by a service provider showed further improvements in airtightness. The leaks in the roof area of Hall 5 have not yet been reworked. This is planned for the next revision phase. For these reasons, among other things, the planned, increased indoor air humidity levels have not yet been realized in this hall.

Figure 13: Examples of leak detection at 50 Pa negative pressure in the area of the Dachgau be (Hall 1 + 2) (left) and on the windows in the upper area of Hall 5 (middle) as well as the detached adhesive on the sealing of the mullion-transom facade to the parapet (right)

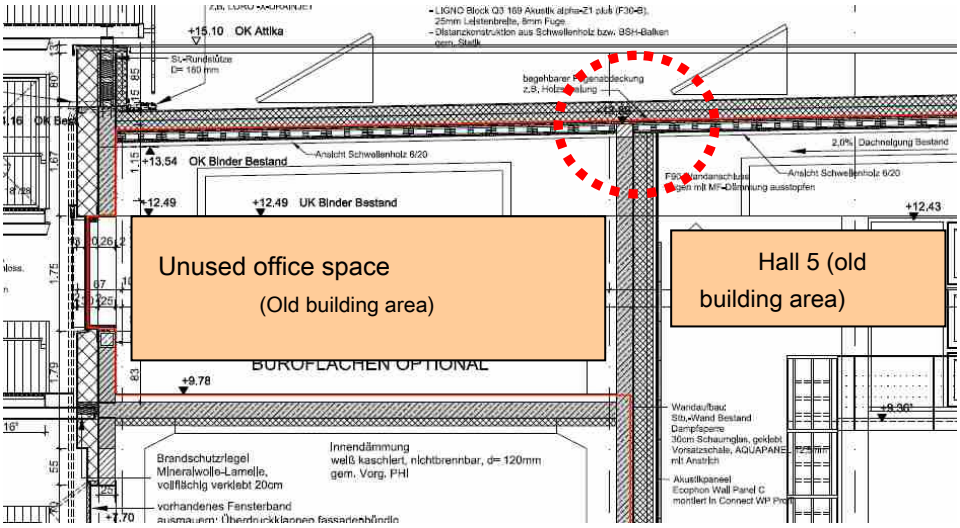

Figure 14: Section of the ceiling area in the old part of Hall 5 and the previous one unused office area. In the ceiling transition above the partition wall, insufficient sealing was found along the entire length (source: npstv)

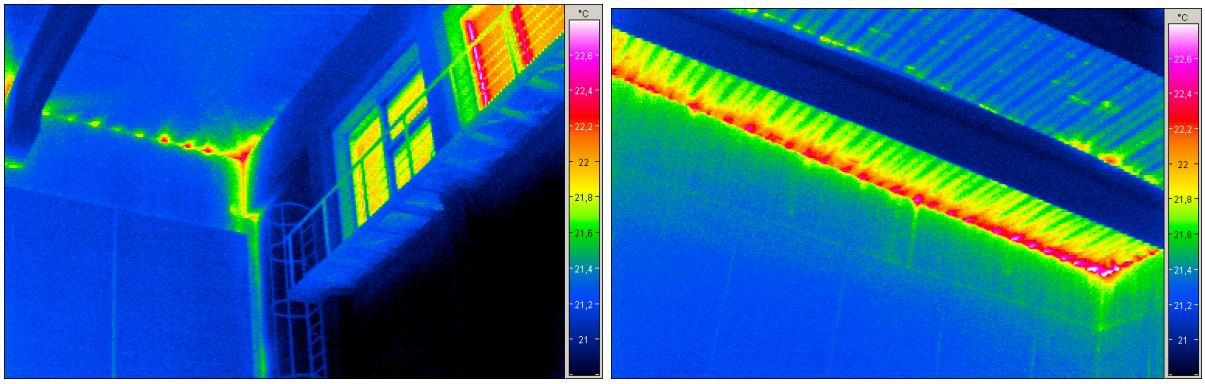

Figure 15: Thermographs of the leaks in the ceiling area of Hall 5 (old component) Vacuum conditions (50 Pa). At the time of the measurement, the bathroom was unheated and the air from the adjoining secondary area was warmer than the hall air.

2.2 heat supply

The indoor pool is heated for heating and water heating from different heat sources. In the old part directly connected to the indoor swimming pool (former heating plant) there is the switching house with the electrical distribution for supplying part of the city of Lünen. In the basement below this area there are two CHP plants (natural gas and biogas) that supply the district heating network of the city of Lünen. The biogas CHP is also directly connected to the heat supply of the bath.

The heating of the hydraulic heating network ("HT") of the bath for the heating of air heaters and water heating takes place in three ways:

- District heating network of the city of Lünen
- Exhaust gas heat exchanger from the geogas and biogas CHP (condensing boiler)
- Heat delivery direct to biogas CHP (retrofit June 2012)

Due to the immediate proximity of the supply systems and the need to use heat at a low temperature for pool water heating (approx. 28 to 32 ° C), it was also possible to tap heat sources that could not otherwise be used sensibly (flue gas condensing). In addition, a second hydraulic network was installed, only to supply the base load to the three pool water circuits. This network is made up of waste heat from the **Case cooling** of the two CHPs is fed and therefore has a lower temperature level (referred to as "NT" for "low temperature"). This heat is fed into the pool water circuits via the HT network before reheating (see also Figure 19 in the following section).

The use of these heat sources and the use of biogas result in very favorable primary energy parameters for the bathroom (cf. [BGL 2011]).

The bath is only heated by reheating the air in the ventilation units. Static heating surfaces, heating benches or underfloor heating are not available.

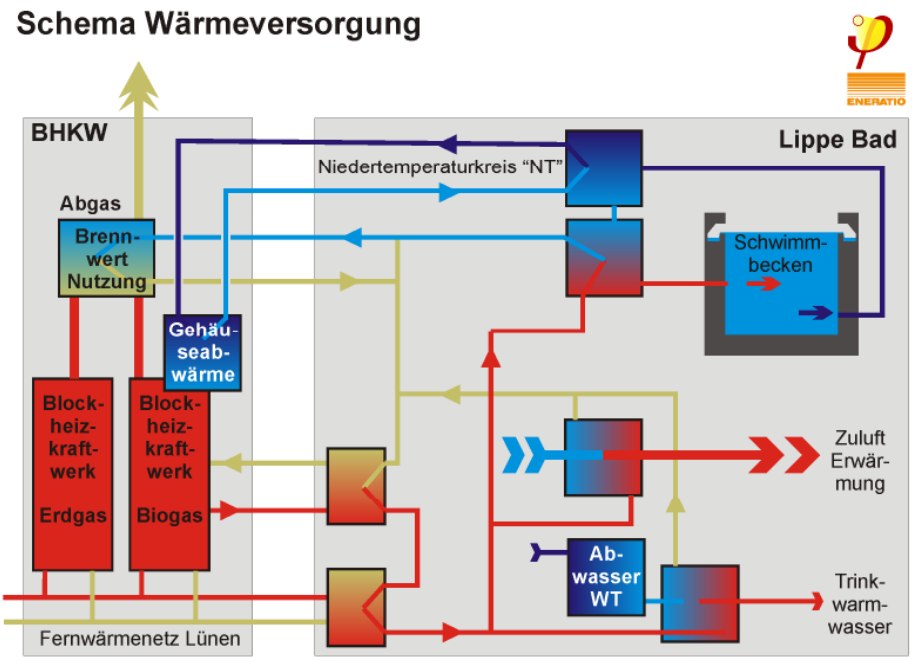

Figure 16: Scheme of the heat supply of the indoor pool from the district heating network the biogas CHP (direct), flue gas condensing boiler use of both CHP plants, and the waste heat from the two CHP casings (adapted according to [BGL 2011])

Figure 17: Boiler room in the basement (old building area) with the two CHP systems (left) and one of the two exhaust gas heat exchangers (right)

The different areas of heat supply are measured using heat meters (WMZ). A total of 19 heat meters are used for this (see table
1). The heat supply was supplemented in June 2012 by a direct heat supply from the biogas CHP. Previously, the two CHP plants only fed directly into the district heating network and the bathroom was supplied from this network. The new meter was activated on September 21, 2012 on the BMS system. The consumption between installation and connection measured by this additional meter was evenly distributed over this period.

All four supply meters are necessary for the complete recording of the energy used (balance sheet preparation), and all remaining heat meters for the distribution according to the acceptance areas. Due to technical delays, the full balance can only be calculated after a few months of operation.

Table 1: Areas of application and number of heat meters used

Area	number	Sub-areas
Heat supply HT 4 pieces		District heating, exhaust gas heat exchanger, heat biogas CHP direct purchase
Ventilation units	6 pieces	Air heating register
Post-heating ventilation	2 pieces	Air heating register showers
Water heating 1 piece		Showers and small consumers
Pool water HT	3 pieces	Three cycles
Pool water NT	3 pieces	Three cycles (Housing waste heat CHP)
total 19 pieces		

The NT network is supplied by the waste heat from the two CHP plants. No distinction is made between delivery (of the housings) and the individual consumption measurements (= acceptance). There are only the three heat meters in front of the three NT heat exchangers in the pool water circuits (= consumers) (see next section). The pipe loss will be relatively low due to the low flow temperature of approx. 32 to 34 ° C and the cellar temperature of just under 27 ° C. In the evaluation, the line loss was neglected and the measured consumption quantities of the three WMZs were used identically as the delivery value.

2.3 Pool water circuits

The indoor pool has 4 pools, one of which is a combined pool with two areas ("warm and parent-child pools").

Table 2: Water areas, volumes and pool depths

	Water area [m²] (including stairs)	Water volume [m³]	Water depth [m]
Basin 1 + 2 (Warm and parent-child pools)	175	185	0.3 to 1.35 m
Basin 3 (Training pool with lifting floor)	100	230	2.3 m
Basin 4 (Sports pool 1 with diving platform, 4 x 25 m lanes)	260	509	up to 3.5 m
Basin 5 (Sports pool 2; 5 x 25 m lanes)	315	565	1.8 m
total	**850**	**1,489**	**---**

The pools are operated via three separate pool water circuits for pools 1 + 2, pool 3 and pools 4 + 5. In each case, surge water tanks, pump groups, water treatment and post-heating are installed via a low-temperature heat exchanger (NT) and a downstream heat exchanger of the main heating network (HT). The chlorination of the bath water takes place in the Lippe bath by splitting the added brine portion by means of electrolysis cells. The schematic representation of a water cycle is shown in Figure 18, the arrangement of the after-heating is shown in Figure 19.

To improve the pool water quality, the temporary addition of activated carbon was retrofitted, which was not originally intended. Then, carbon filters were retrofitted in all three pool water circuits and the metering was removed again (most recently at the end of April 2013). The preparation of the

Backwashing water has not been used since 07/09/2012. Therefore, the rinse water must currently be disposed of completely as waste water. Around 70% of the backwashing water was planned to be treated with the system. For this reason, significantly more fresh water is currently required than planned and thus is also an additional one Energy required to heat the fresh water. The water treatment should be put back into operation after adaptation to the changed filter sizes etc.

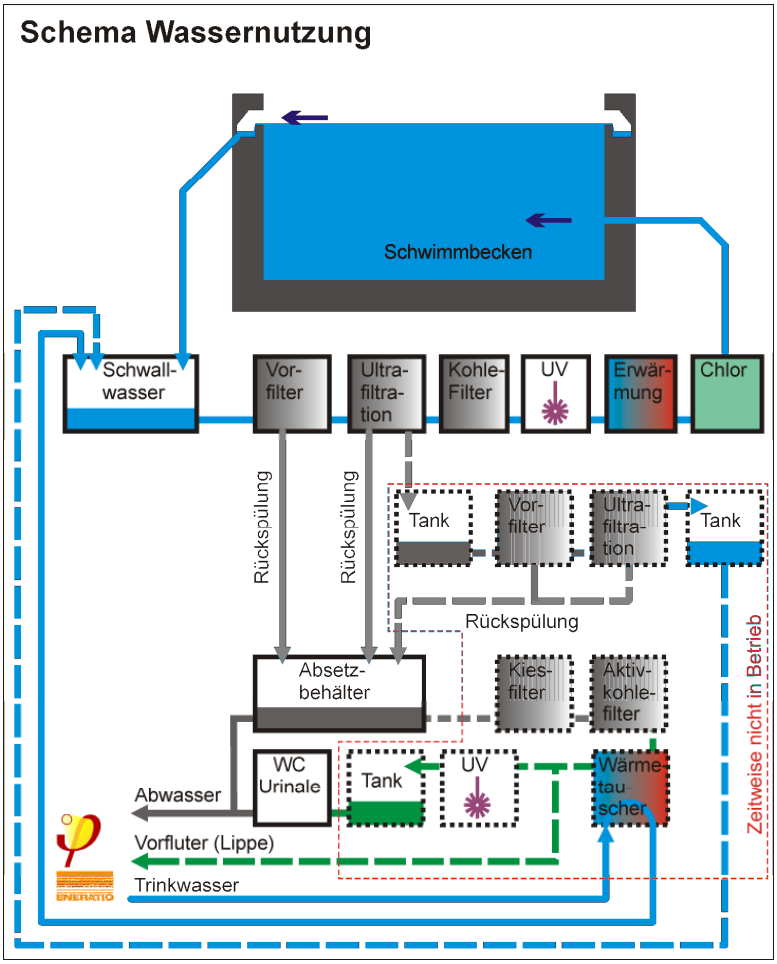

Figure 18: Schematic representation of a pool water cycle in the Lippe bath. The

The area of backwash water treatment has not been in operation since July 2012 (supplemented according to [BGL 2011]).

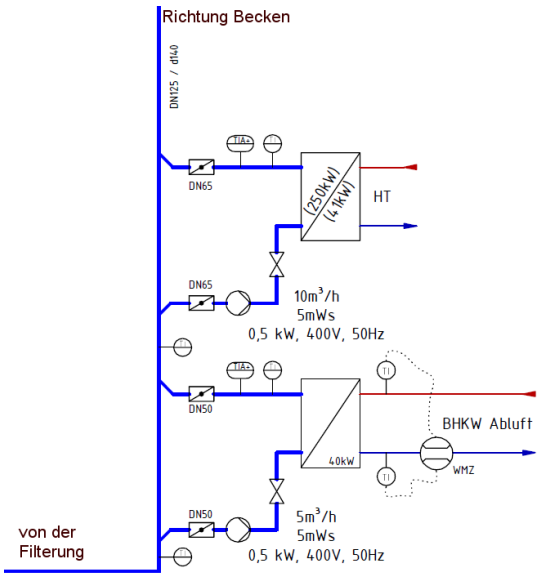

Figure 19: Left: Detail of the heat supply with NT ("CHP exhaust air") and HT network the execution planning for the pool water cycle of pool 3 (source: Eneratio). Right: Photo of a heat exchanger in the pool water circuit.

2.4 Ventilation technology

To supply the different areas of the building with outside air, to dehumidify the swimming pools and for heating, a total of six ventilation units are operated with post-heating registers, which are located in the basement of the building. The intake of the outside air and the exhaust air are carried out jointly for all systems via two central structures. These are approached with two short (a few meters) channel loops that were laid through the ground.

Figure 20: Ventilation towers for the central outside and exhaust air of all six ventilation systems (Left) and ventilation unit "changing rooms / showers" in the basement (right)

The four indoor units are Menerga systems of the "ThermoCond" type with a modified design and control. The device for Hall 1 + 2 also has a heat pump with the heat source (evaporator) in the exhaust air after the heat exchanger and the condenser in the supply air flow before the post-heating register.

The two systems for changing rooms, showers, foyers and adjoining rooms including basement etc. are of the "Dosolair" type from the same manufacturer. In the area of changing rooms / showers there are additional support fans in the basement, which ensure the air transport from the changing rooms to the showers. In these two lines (shower and toilet for women and men), additional post-heating registers are operated after the additional fans in order to achieve the higher air temperature in the showers.

Figure 21: Ducting with additional fan and reheater for the supply air showers Men's

Table 3: Overview of ventilation units (areas, types and volume flows)

investment	Device type	Heat exchanger	Design volume flow
Hall 1 + 2	ThermoCond	2 cross flow + 1 counter flow in series	14,500 m³
Hall 3	ThermoCond		8,150 m³
Hall 4	ThermoCond		12,000 m³
Hall 5	ThermoCond		15,100 m³
Changing rooms / showers	Dosolair	2 cross current in series	10,000 m³
Adjoining rooms	Dosolair		8,875 m³
		total	**68,625 m³**

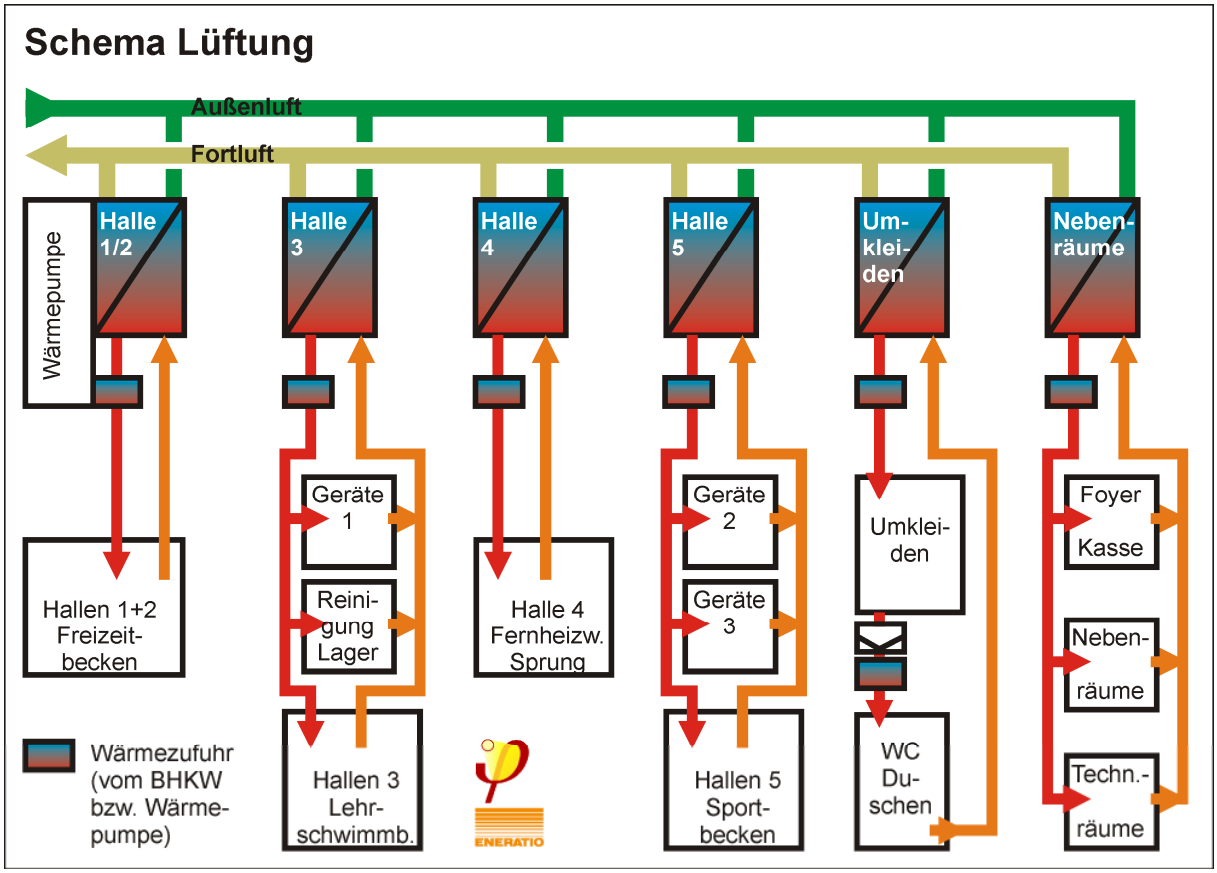

Figure 22: Schematic representation of the ventilation technology of the indoor pool (supplemented after [BGL 2011])

Due to the thermally high-quality building envelope, it is no longer necessary to blow dry the mullion-transom facades. In a bathroom, the ventilation units are usually always operated with the design volume flow during the operating hours. The proportion of outside and recirculated air is regulated using flaps. This permanently high operation causes a high electricity consumption for air transportation. The mode of operation of the

Hall units therefore completely do without a recirculating air component. In the Lippe bath, this could not be fully achieved in the planning planning phase. However, a significantly reduced circulating air volume flow was provided. The duct network, including the control of ventilation technology, was therefore already designed in the planning for the four halls in such a way that flaps in the duct network enable a reduced air volume flow (up to about half the air volume). The flaps ensure that there is still a sufficient pressure difference at the then reduced number of long throw nozzles (motor flaps see Figure 23). This mode of operation was tested later (see section 4.5.5).

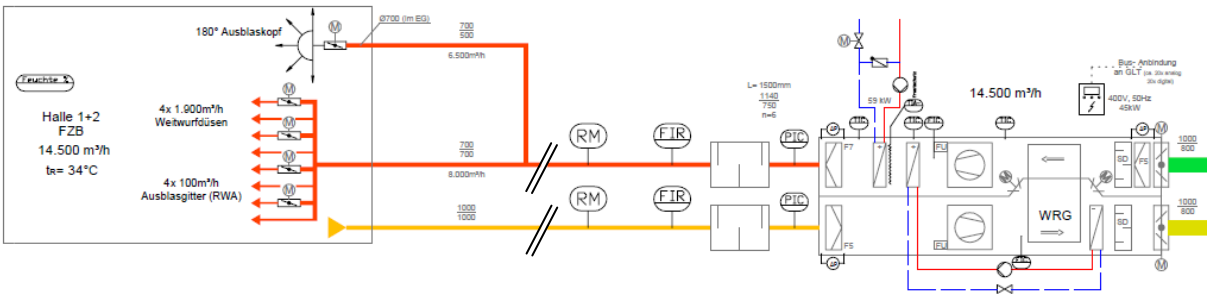

Figure 23: Excerpt from the device Hall 1 + 2 from the "Implementation planning scheme Ventilation "(Source: Eneratio)

Figure 24: Long throw nozzles for the supply air in hall 3. The lower and upper two rows the nozzles can be started separately. The exhaust air opening (with fins) is on the left in the picture.

In the foyer and changing rooms and showers areas, CO_2- or moisture sensors have been implemented with appropriate control. This enables lower volume flows than in normal control mode.

3rd measuring technology

A building management system (BMS) is implemented in the building, with which the entire operation of the building (heating, water technology, lighting, etc.) is regulated or with which the information from separate regulations converge and setpoints are specified. The master computer is also used to read out all meters and sensors in the bathroom. The GLT company Hermes has used a second PC to store the approx. 700 channels, which can also be accessed remotely. Various additional counters and sensors have been installed for monitoring, of which the ones crucial for monitoring are described here.

3.1 Temperature and humidity measurement in the rooms

The indoor air parameters temperature and humidity are mainly measured in the building by means of the combination sensors of the type LC-FTA54VV from the manufacturer Thermokon. 36 combination sensors and seven temperature sensors are used in the halls, changing rooms, showers, foyer and adjoining rooms for continuous measurement via BMS. A total of six surface sensors (Thermokon, type OF14) are installed on the glazing of windows and doors in halls 1 + 2, 3 and 4.

Figure 25: Combined sensor for measuring the temperature and humidity of the room air

Table 4: Number of sensors used in the building to measure the room air parameters in the rooms / halls and the surface temperature of the glazing

number	Combination sensors (Temp./rF)	Temperature sensors	Surface temperature temperature sensors
Hall 1 + 2	10th	-	2nd
Hall 3	6	-	2nd
Hall 4	3rd	-	2nd
Hall 5	3rd	-	-
Changing rooms, showers	8th	4th	-
Side rooms, foyer	6	3rd	-
total	**36**	**7**	**6**

In halls 1 + 2 and 3, three combination sensors are arranged one above the other on five wall areas (e.g. at a height of approx. 2, 4 and 6 m) in order to be able to make statements about possible stratifications (see also Figure 26 in the next section).

3.1.1 Calibration of the sensors

The quality of the sensors used is not sufficient for a scientific measurement, and influences from different cable lengths cannot be ruled out. Therefore, on March 28 and 29, 2012, data loggers were used to carry out calibration measurements on all accessible temperature-humidity sensors and temperature sensors. 28 combination sensors and four temperature sensors were measured, allowing a total of 60 measuring channels to be checked and calibrated. The 16 data loggers used for this (Onset, type: HOBO Pro V2) were previously calibrated in the climate chamber of the PHI at two different temperatures and relative humidity using reference devices (Ahlborn, temperature sensor ZA 9030-FS2 and psychrometer FN A846).

During the calibration in the Lippe bath, the sensors of the data logger were positioned directly on the respective sensor of the continuous measurement and at least one hour of measurement data was recorded (measurement interval 1 minute). The corresponding measurement data of the continuous measurement (BMS) were compared with the measurement data and offset values were determined. All measurement data are offset against these calibration values before further use.

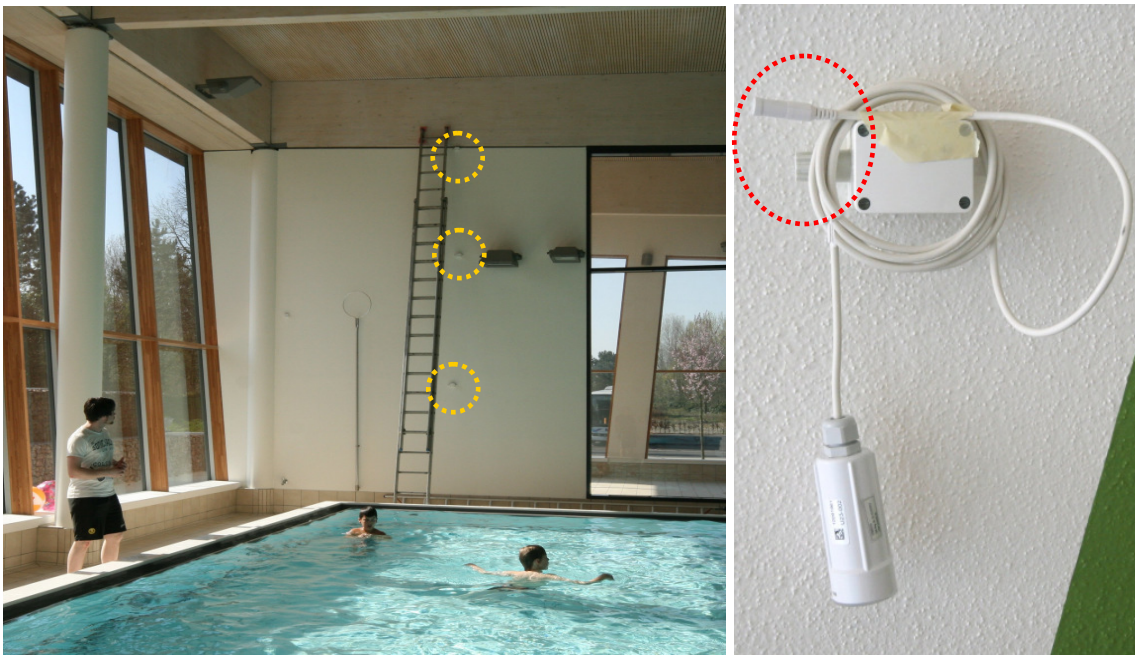

Figure 26: Calibration of the temperature-humidity sensors. Left picture: Position of three stacked sensors in hall 3 before the distribution of the data logger. Right picture: Calibration of the wall sensor (continuous measurement) with a data logger; the two measuring elements are in the dashed circle.

Calibration of the surface sensors

The surface sensors were also calibrated using reference measurements on all six individual sensors. Pt100 film sensors from Ahlborn (type FP 685) were used as reference. These were previously calibrated separately in a water bath. In the halls, they were fixed on the glazing directly next to the permanent measuring points and comparative measurements were carried out over a few hours at night. Due to the very different mass of the sensors (foil or solid aluminum body), solar radiation has a very different time effect. Therefore, only measurement data from the night hours were used for calibration.

Figure 27: Window surface sensor directly on the edge of the glazing (aluminum body) with the surface sensor attached with adhesive tape for calibration measurement.

3.1.2 Average hall values: temperature and humidity

As described above, there are different numbers of temperature and humidity sensors in the halls for measuring the indoor air conditions. For the statement of the average hall humidity or temperature, it has to be defined what is meant by it.

When looking at the summer temperature measurement data, it was noticed that some of the sensors close to the windows in halls 1 + 2 and 3 are illuminated by the sun and thus show temperatures well above the hall air temperature (Figure 28). The relative humidity measured by the sensors drops significantly as a result of this warming (Figure 29). When averaging, this would result in a falsification of the average hall humidity, which is actually interesting in the context of the investigation.

For this reason, the mean hall temperature - which is still used in this study - is calculated from the sensors not directly influenced by the sun by simple averaging. The average relative hall humidity is calculated as follows: The relative humidity of each sensor (including those influenced by the sun) and the associated temperatures are converted into absolute humidity. At the absolute humidities, the solar radiation does not have a disturbing effect, since this is due to the temperature and rel. Moisture data will be charged. The absolute humidity values of a hall calculated in this way are averaged to an average absolute room air humidity (Figure 30).

The procedure described is not necessary in halls 4 and 5 because the sensors are not directly exposed to sunlight. Here the average relative humidity can be achieved by simply averaging the measured values.

The two combination sensors in the dormers of halls 1 + 2 and 4 are not taken into account in the averaging described. They are used in particular to monitor component protection in these exposed areas. Section 4.3 shows later that no critical temperatures are reached in these areas.

The air conditions at the different measuring locations differ by the position (outer or inner wall, height, distance from the pool) and the influence of the air flow (predominantly in the supply air, overflow or exhaust air area).

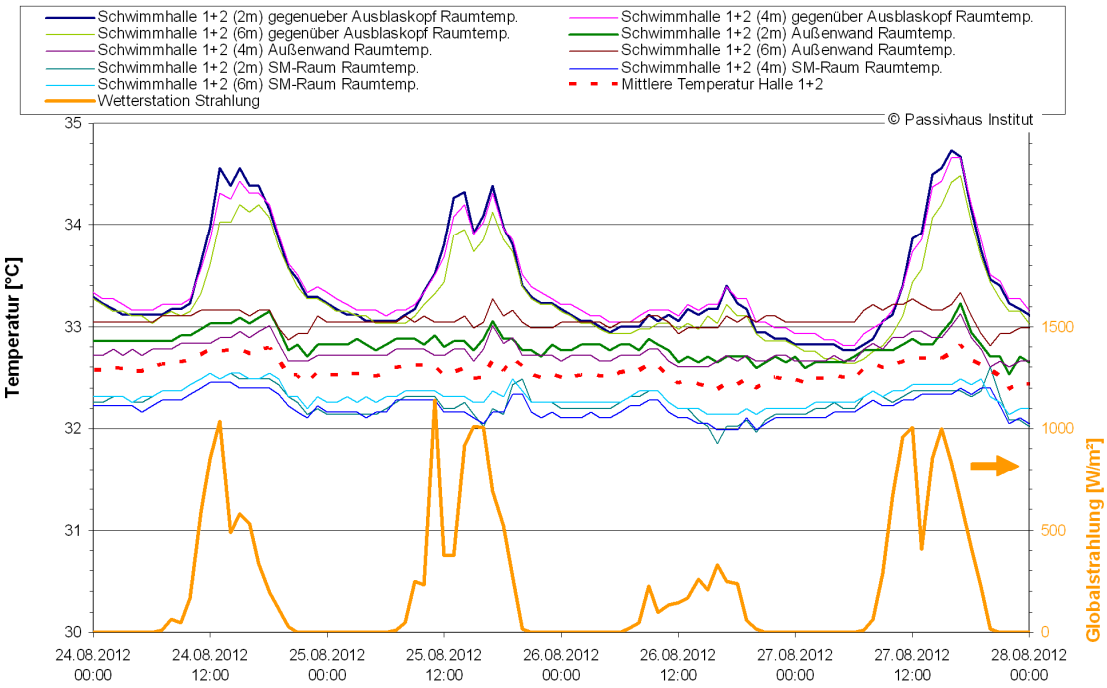

Figure 28: Room air temperatures of the nine sensors in Hall 1 + 2, the "middle hall temperature "(see text) as well as global radiation from August 24 to 27, 2012 (hourly average values).

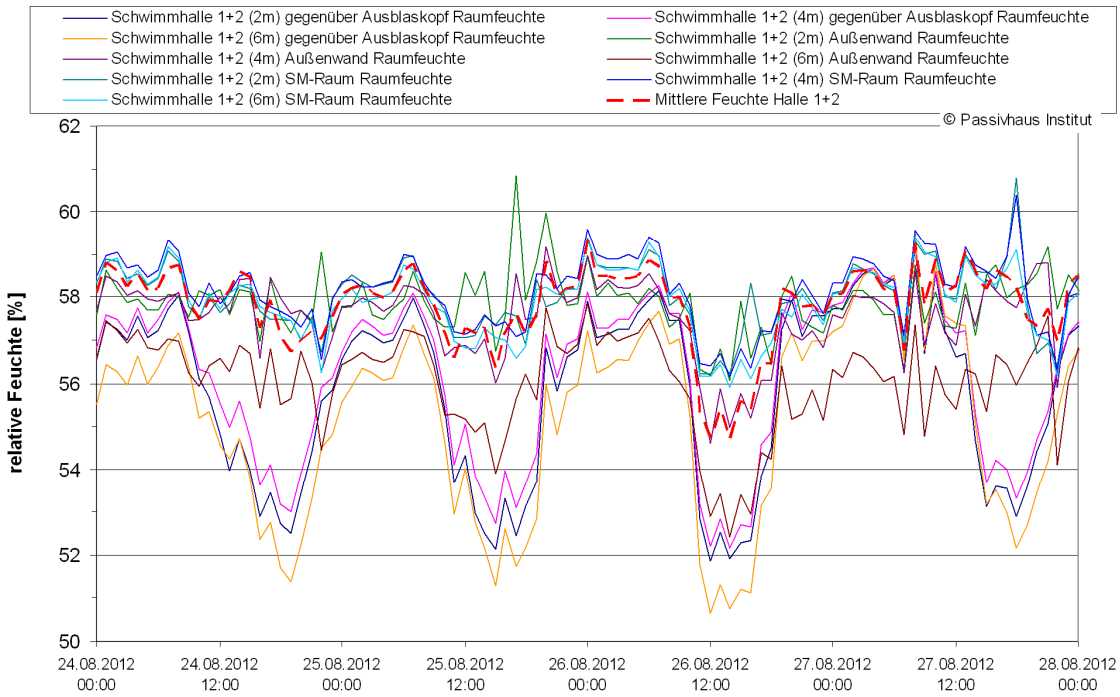

Figure 29: Relative room air humidity of the nine sensors in Hall 1 + 2 and the "mean rel. Indoor humidity "(see text) from August 24 to 27, 2012 (hourly average values).

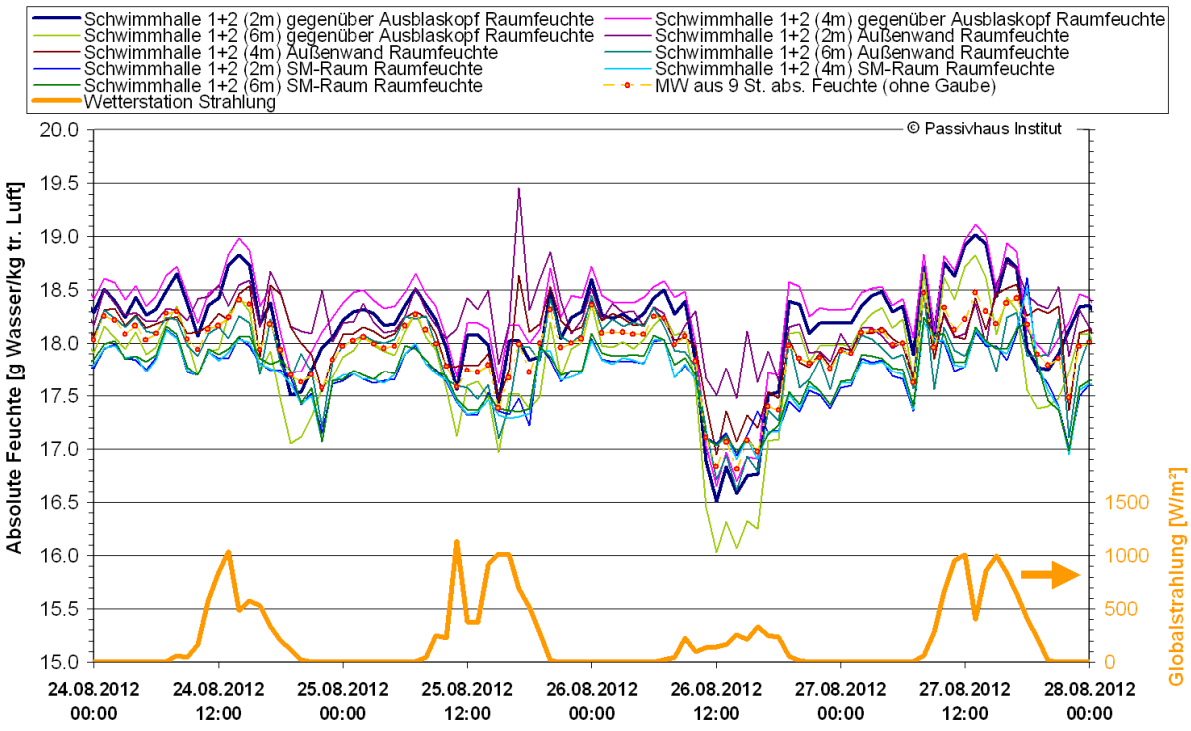

Figure 30: Absolute room air humidity of the nine sensors in Hall 1 + 2 and the "middle one absolute indoor humidity "(see text) and global radiation from the 24th to the August 27, 2012 (hourly averages).

3.2 Pool water temperature

Three measuring cells of the "Topax DX" type from Jesco are used to measure the chemical parameters of the pool water circuits. Pool water flows through them permanently. In addition to the sensors for chlorine, redox potential, salinity and pH, they also contain a temperature measurement using resistance measurement (Pt100). This is used for the permanent measurement of the pool water temperature.

3.3 ventilation units

The manufacturer has installed sensors for volume flow (calculation from pressure difference measurement), temperature and humidity in the ventilation units and the associated ducts. The measurement data are forwarded to the BMS and recorded. The positions of the ventilation flaps and the valve positions are also recorded by the heating register. After the clarification with the manufacturer, additional data points and calculations from the devices were supplied for the monitoring. The volume flow measurement via the heat exchanger (heat recovery unit) should be mentioned in particular. As standard, only the volume flows of the supply and exhaust air volume flow of the fans on the hall side are output (pressure difference measurement). The outside and exhaust air volume flow via the building envelope is therefore missing for energetic assessment. The outside supply air volume flow is calculated in the device by a further pressure difference measurement via the heat recovery unit. When the bypass flap is closed ("Dehumidify flap") between the outside and the exhaust air area of the device, this volume flow corresponds to the outside air volume flow.

The following table lists the measuring points in the devices that are read out for monitoring.

Table 5: List of measuring points (example of device hall 1 + 2 with heat pump)

1	AB moisture 2
	AB Temp 3
	ZU Temp behind heating register (PWW)
4th	AU Temp internal 5
	AU Temp external 6
	AU flap 7
	FO flap 8
	Circulating air flap heating 9
	Circulating air damper dehumidifying 10
	Valve heating register (PWW) 11
	CLOSE volume flow 12
	AB volume flow 13 heat quantity
recuperator	

14	Power recuperator 15 Heat quantity
condenser + PWW	
16	Power capacitor + PWW 17
	ZU Temp external 18
	TOO humidity external 19
	TO external enthalpy 20
	TO Temp v. WRG 21
	TOO humidity v WRG 22
	TO enthalpy v WRG 23
	TO Temp h. WRG 24
	TOO moisture h. WRG 25
	TO enthalpy h. WRG 26
	AB Temp h. AB fan 27
	AB humidity h. AB fan 28
	AB enthalpy h. AB fan 29
	AB Temp h. Evaporator 30
	AB humidity h. Evaporator 31
	AB enthalpy h. Evaporator 32
	Volume flow via heat recovery (AU-ZU)

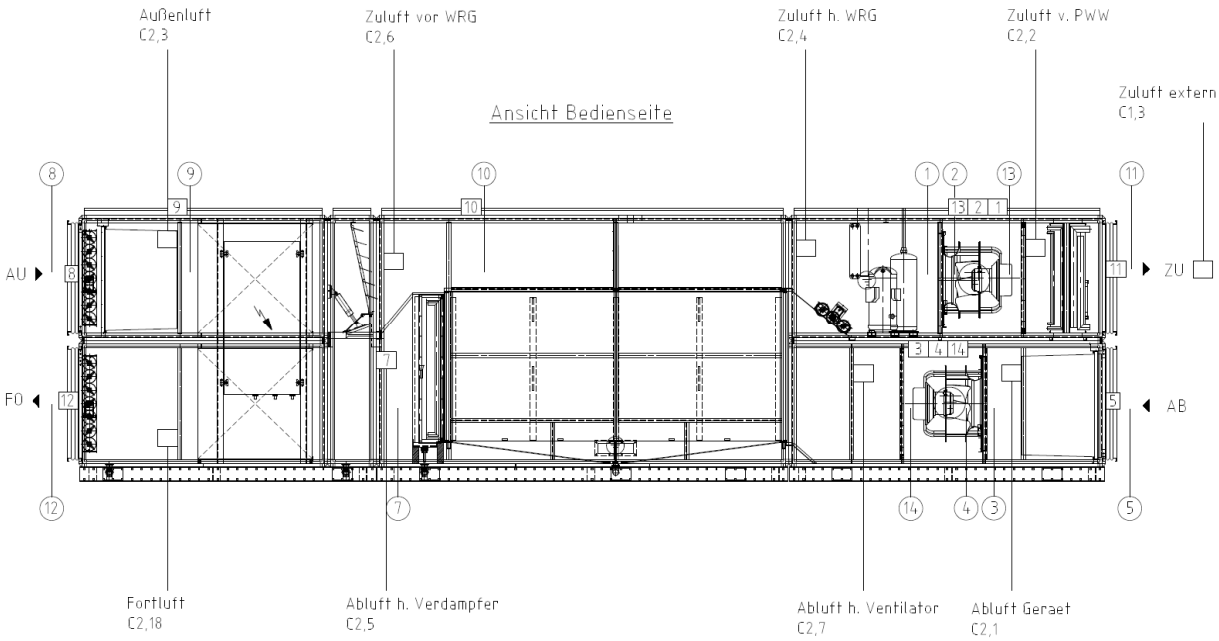

Figure 31: Arrangement of the sensors in the device in Hall 1 + 2 with heat pump (source: Menerga).

When evaluating the temperature and humidity values from the ventilation systems, some implausible values were found. It was therefore on
09/20/2012 calibration of some sensors by the manufacturer. The measurement data for the outside supply air volume flow via the heat recovery repeatedly showed a striking offset of the minimum values (Figure 32). It could determine

that they were related to the automatic calibration of the device, which was carried out every Monday at 6:00 a.m. For this reason, the auto-calibration was later carried out daily or every two days, which eliminated this effect and the outside air volume flow could be used reliably for the energetic data evaluation.

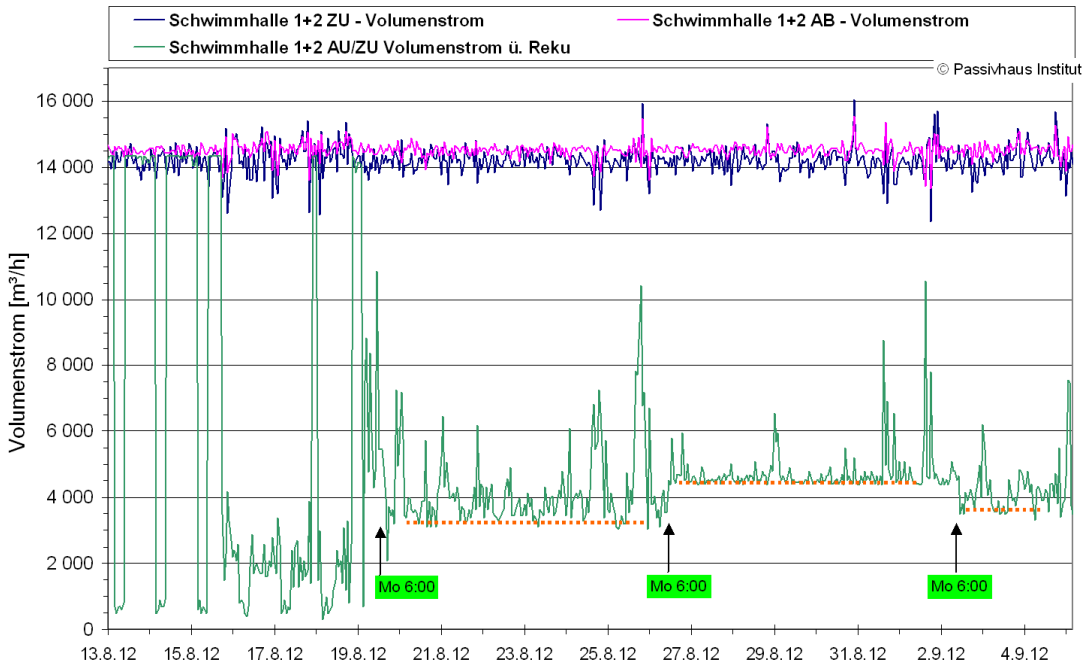

Figure 32: Volume flows of the ventilation unit in Hall 1 + 2 from August 13. until 05.09. 2012 (hourly data). An offset of the minimum volume flows via the heat recovery ("Reku") was found every Monday at 6:00 a.m.

3.4 Power consumption measurements

Commercial electricity meters have been used to measure electricity consumption. The supply takes place via the supply from the public power grid and through the own use of the solar power generated by the PV system on the roof of the building (see next section).

Based on the meter requirements, five main consumption areas can be distinguished (see also Figure 33):

- electricity **Ventilation (** six ventilation units individually and separately sub-meter for the heat pump of ventilation 1 + 2)
- Stream of three **Double circulation pumps** of the three water circuits (four additional pumps for wastewater treatment; currently not in operation)
- electricity **lighting** and sockets (eight sub-meters)

- Electricity for **Plumbing and heating (** Heating: heating pumps, pumps on six heating registers, circulation pumps, exhaust gas heat exchangers / sanitary: dosing pumps for chemicals and lifting systems)

- Electricity "Diverse": **Swimming pool technology** without circulation pumps as well **all other consumers** of the bath (UV burner, electrolysis cells, lifting systems, hair dryers, measuring water, dosing and pressure booster and submersible pumps, data cabinet, loudspeaker system (ELA), security light, cash register system, barrier, electric cooker, microwave etc.)

In the last consumption area "Diverse" (all "remaining" consumers Incl. Swimming pool technology without large pumps) is not a directly measured value, but the difference between the four measured sub-areas and the total consumption.

The measurements of all consumption areas of interest for the monitoring (e.g. complete swimming pool technology) or individual consumers could not be fully implemented due to the effort involved.

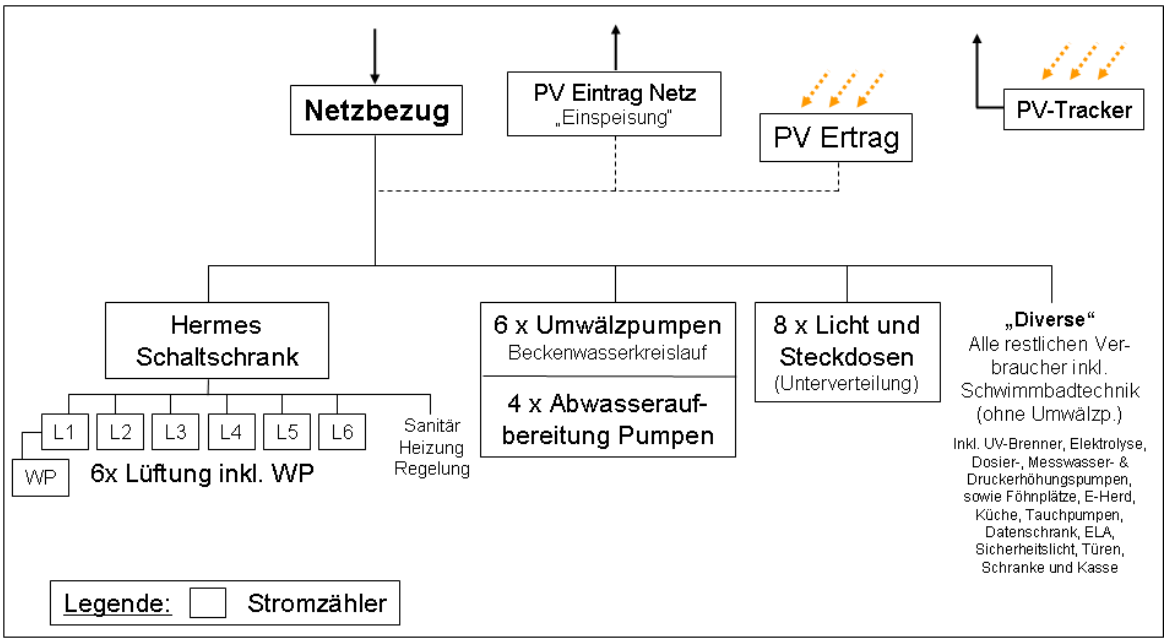

Figure 33: Arrangement and consumption areas of the electricity meters used

3.4.1 Generation of solar electricity (PV)

The PV system on the roof of the building has an output of 91 kWp. This consists of a total of 387 modules, each with 235 Wp. The PV electricity is used entirely in the building if required, current surpluses are fed into the public power grid. For this purpose, a yield and a feed meter are installed. The difference is the PV electricity consumed directly in the bathroom.

In addition, two “solar tracker” systems have been built on the premises of the Lippe bath. The free-standing systems are movable PV areas that align themselves with the sun. The two trackers have a total of 84 PV modules, each 235 Wp (overall system: 19.7 kWp). The PV power of the trackers is completely fed directly into the public power grid because the Renewable Energy Sources Act (EEG) does not provide for self-consumption regulation for floor-standing systems. The measurement is carried out using a separate feed meter.

A distinction must therefore be made between the following variables for assessing the power consumption or the power feed-in:

- Network connection
- PV electricity own consumption
- PV power supply (excess)
- PV current tracker (full feed)

The total consumption of the bathroom is made up of the network connection plus the self-consumption of the PV electricity from the solar system on the roof of the building.

3.5 Other sensors

For the operation of swimming pool technology there are still various temperature sensors in the pool water circuits, air heaters and heat exchangers. In addition, a weather station is installed on the roof of the old building area, which provides data such as outside temperature, humidity and global radiation data. There are also various operating hours counters that record the running times of pumps and ventilation systems. The arrangement of the heat meters used is already described in 2.2. In addition, a pool scanner is installed in Hall 1 + 2, which counts the number of people in the pool (see next section). All of the sensors mentioned are connected to the BMS system and are partly used and evaluated here in separate tests.

4th Measurement data evaluation

The measurement data can mainly be used for the evaluation of the data from February 2012; In some cases, fully usable data such as modifications and additions to the heat meters are only available a little later. The data up to March 31, 2013 will be used for the evaluations in this report. If annual values are determined, these generally refer to the period from April 1, 2012 to March 31, 2013. Otherwise, individual deviations from this year are indicated. In the summer of 2012 the bathroom was renovated

July 9 closed for revision work until August 21, 2012. The central data collection was from July 17. completely switched off by 2.8.2012.

4.1 Visitor numbers

Data on the daily visitor numbers are available from the cash register system of the bath. The monthly totals show visitor numbers between 14,281 and 22,980 people per month in the regular operating months, on average 19,751 people / month. Throughout 2012, 210,006 people visited the swimming pool (47.6% public, 23.3% schools and 29.1% clubs).

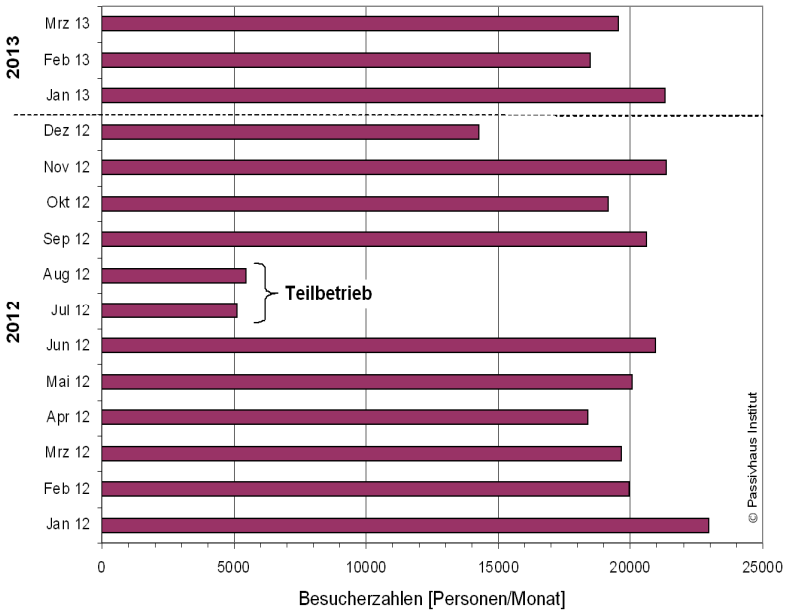

Figure 34: Monthly visitor numbers from January 2012 to March 2013

The daily visitor numbers show that the occupancy of the bath varies by day of the week. In January 2013, for example, the number of visitors on opening days was between 503 and 999 people. Saturdays are the days with the lowest number of visitors.

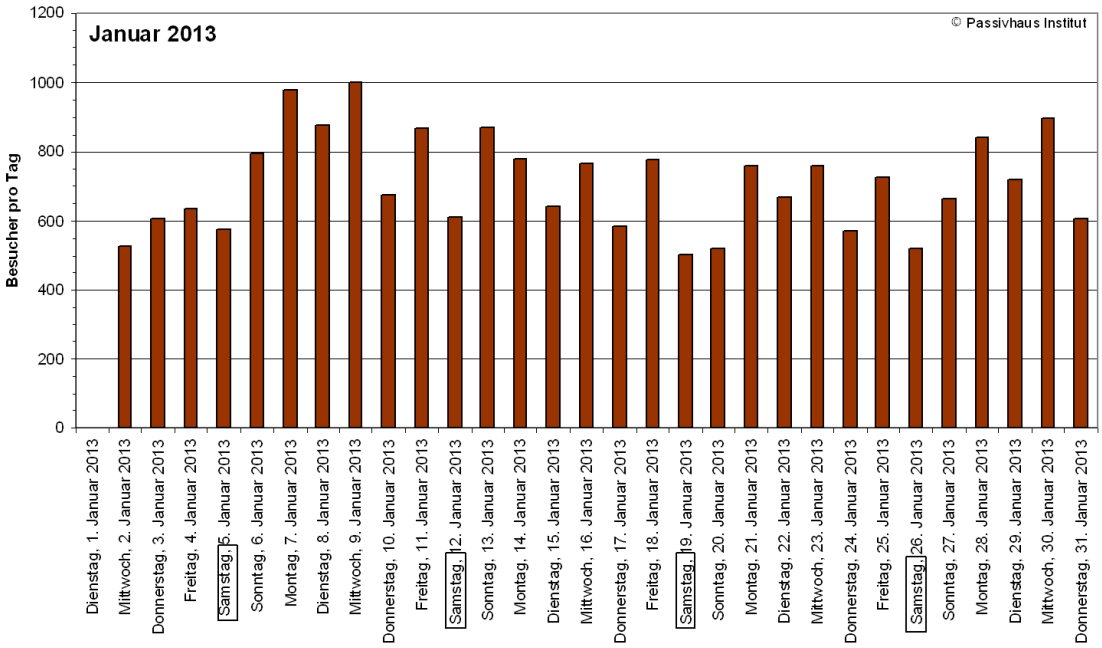

Figure 35: Daily visitor numbers in January 2013. On January 1, 2013 was the swimming pool closed.

Further information on the number of people is recorded using a pelvic scanner. The device specially adapted for this task counts the people who are in the Pools 1 and 2 are located (without taking into account the pool circulations). Random checks during on-site visits have shown that the number of people corresponds to one to three people. By means of this information

For example, energy consumption and evaporation data can be evaluated depending on the people in the pool (see section 5.1.1.1). Figure 37 shows data for pool users from November 1, 2012 to the end of April 2013 as averages over a course of an average week ("average week"). This diagram shows the typical weekday distribution of the pool use: Sundays are the most heavily used in this area, Mondays the least.

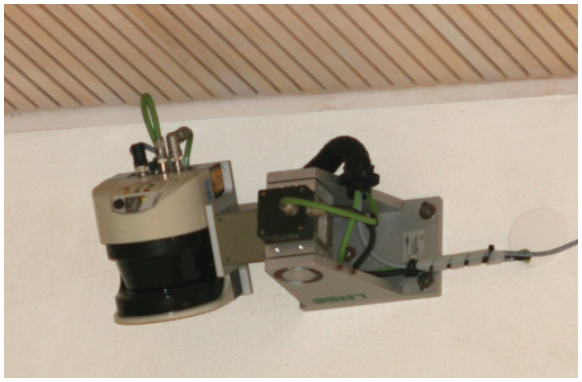

Figure 36: Pelvic scanner under the hall ceiling for counting people in pools 1 + 2.

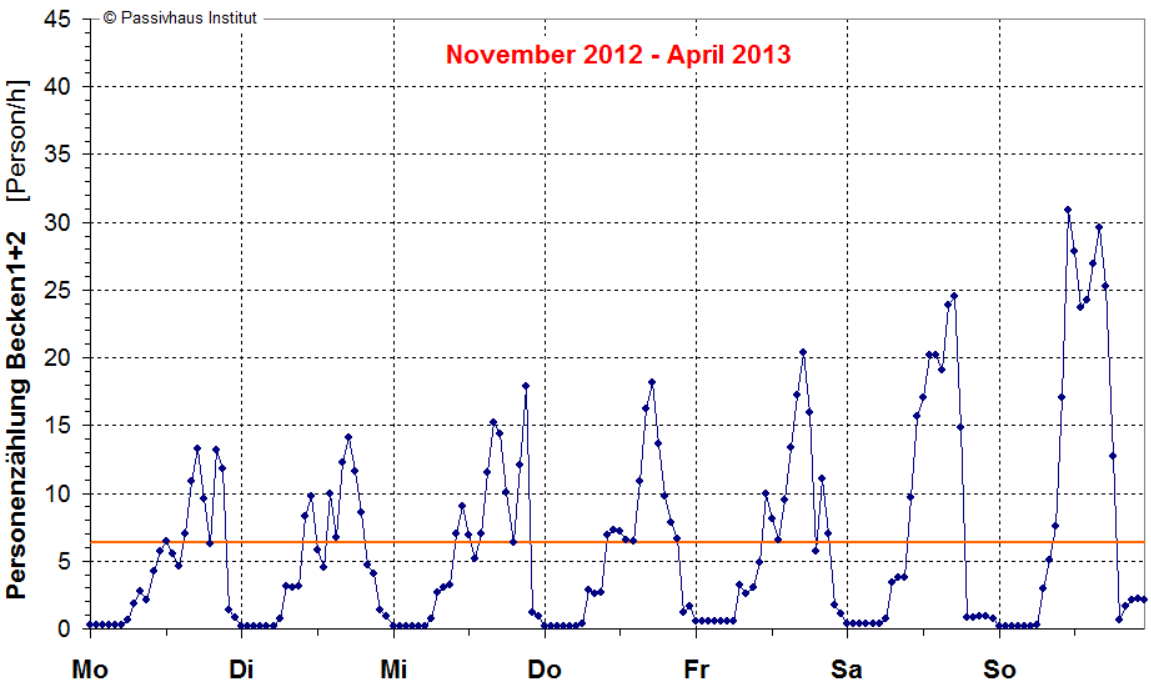

Figure 37: Occupancy of pools 1 + 2 of the "average week" after the Counting of the pelvic scanner from November 1, 2012 to April 30, 2013 (from hourly mean values). The mean values are shown over the entire period. The horizontal orange line represents the overall mean.

4.2 Weather data

The weather station mounted on the roof of the former heating plant is used to measure the weather data. Like all other measurement data, the data is recorded on the BMS. The measured variables air temperature, air humidity, wind speed, wind direction, amount of precipitation and the horizontal global radiation are recorded (measuring height approx. 15 m above ground level). The parameters relevant for the evaluation are shown here as the course of the daily values and as monthly mean values or totals.

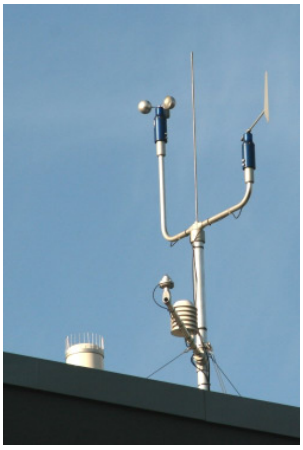

Figure 38: Weather station on the roof of the old building area of the bath.

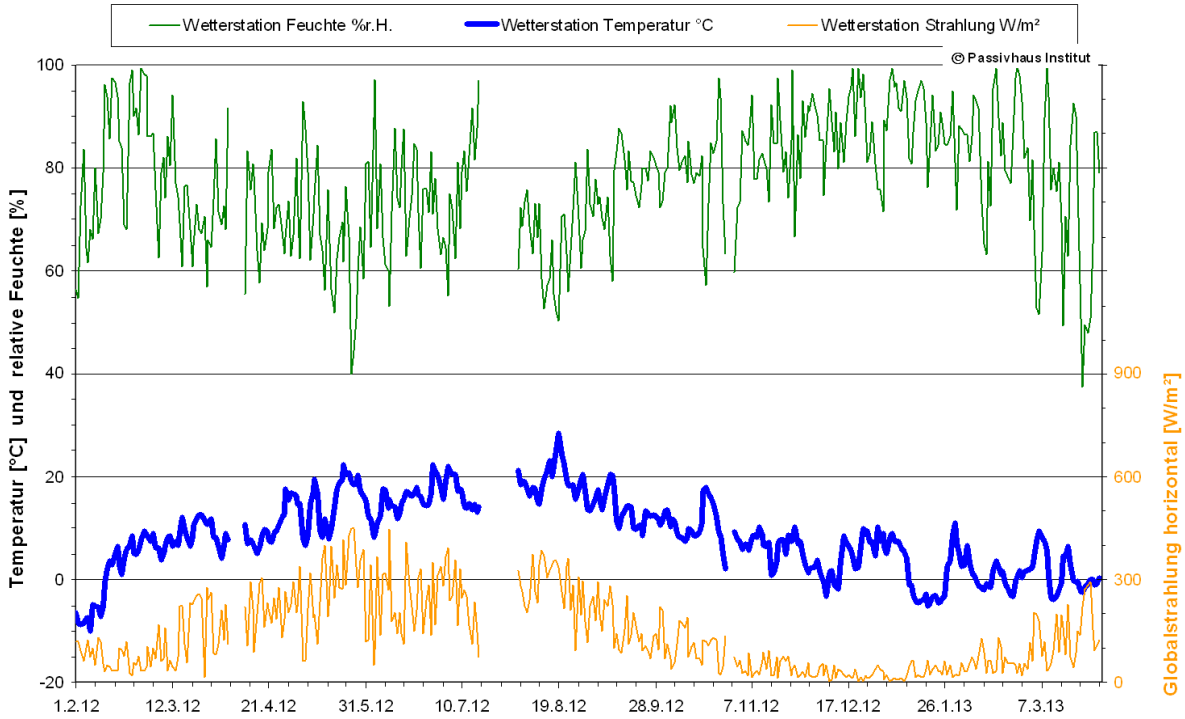

Figure 39: Measured daily mean weather data of the outside air temperature, relative Humidity and horizontal global radiation (February 1, 2012 to March 31, 2013).

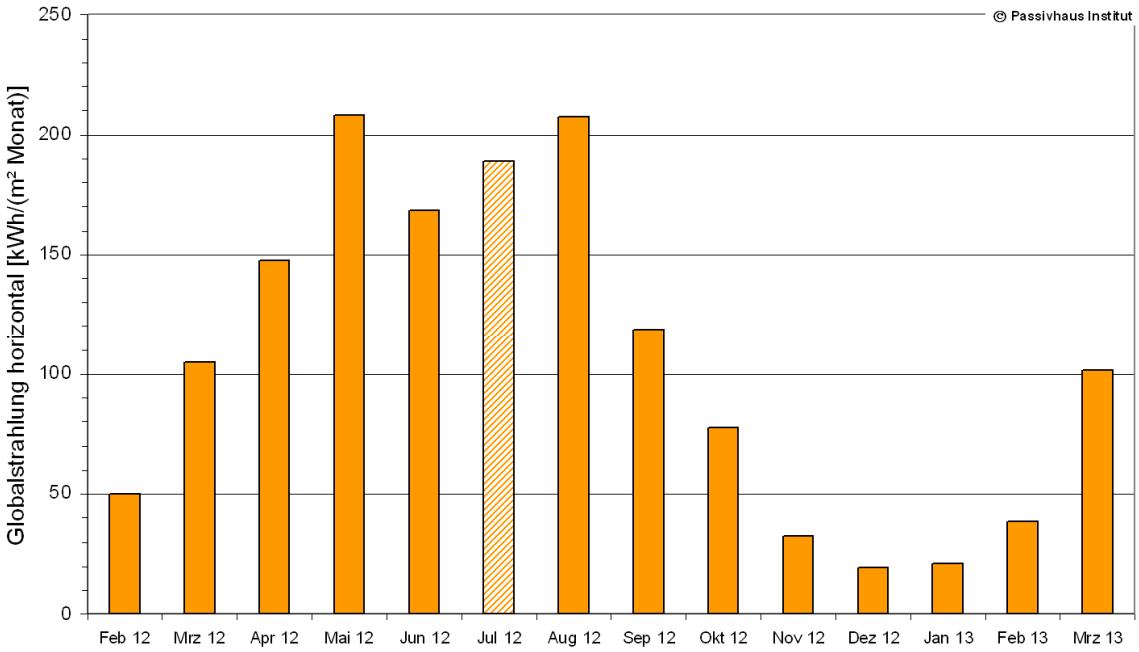

Figure 40: Measured monthly totals of horizontal global radiation (February 2012 to March 2013). Due to the fact that data collection was switched off on several days in July 2012, the measured mean radiation was extrapolated to the monthly value.

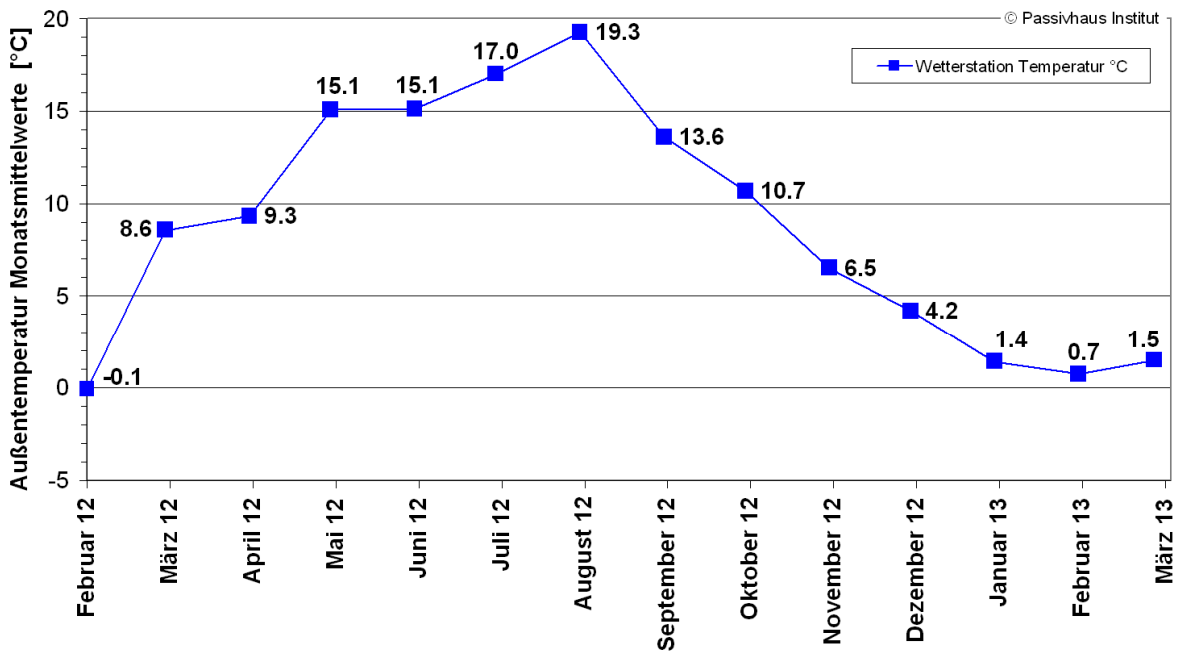

Figure 41: Measured monthly mean values of the outside temperature (February 2012 to March 2013). Due to the fact that data collection was switched off on several days in July 2012, the average of this month was only calculated from the measured values of the measured period.

4.3 Air temperatures and air humidity in the building

The air temperatures and air humidity in the building are evaluated using the calibrated measurement data (see section 3.1.1). Figure 42 shows an example of the course of the hall temperatures in halls 1 + 2 and that of the outside air temperature from November 15, 2012 to February 15, 2013 as hourly mean values. Overall, a temperature band of about 1 to 1.5 K (without individual outliers) is shown in the hall. As an exception, the sensor can be seen in the dormer. This air temperature drops slightly at lower outside temperatures (by about 1 K when the outside temperature drops by 10 K). The dormer area is not separately supplied with supply air, which is the reason for this low and uncritical temperature reduction.

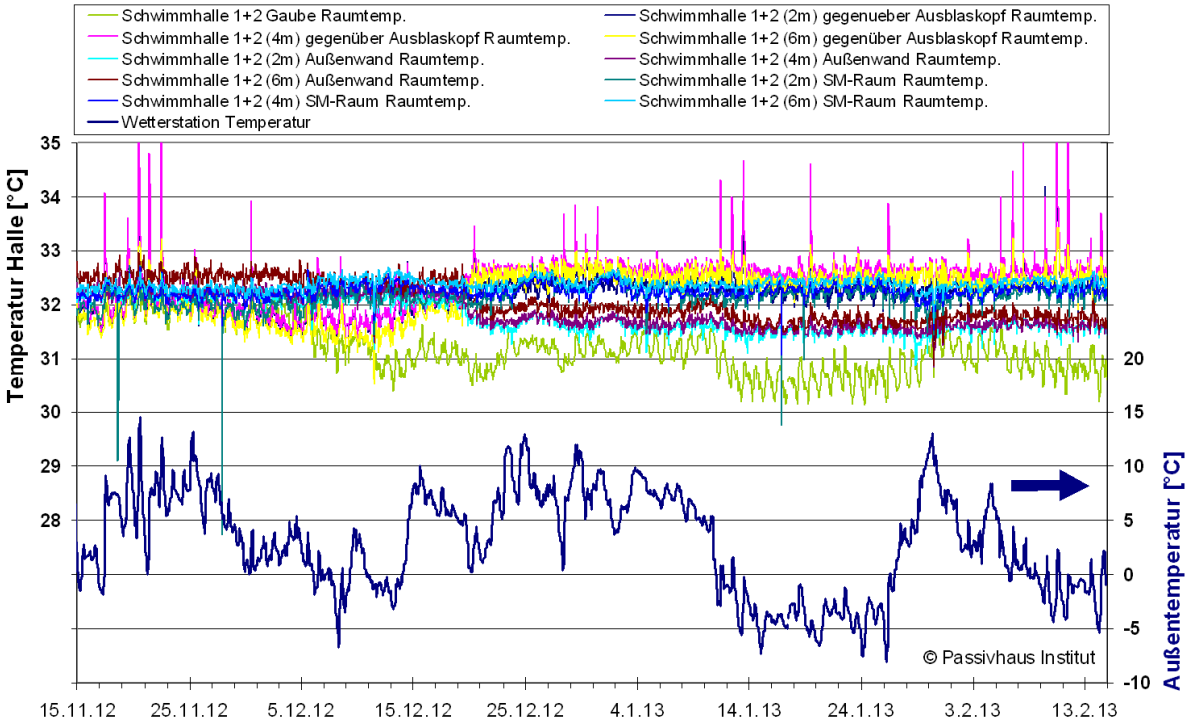

Figure 42: History of all ten hall temperatures in halls 1 + 2 and the outside air temperature in the period from November 15, 2012 to February 15, 2013 (hourly data)

The air temperature and humidity sensors are converted by averaging (cf. 3.1.2) the course of the average hall humidity (relative and absolute) as well as the temperatures for the period from February 1, 2012 to March 31, 2013 for halls 1 + 2 (Figure 43). The changes in the operating conditions can thus be seen over time: While the hall temperature remains relatively constant over the entire period, significant changes can be seen in the hall humidity. As the changes in operating conditions were examined in this hall, some of the changes are test requirements. The two periods before the revision with significantly increased moisture values are unintentional changes or control errors.

After the summer revision period, a sudden reduction in indoor humidity was carried out on September 18, 2012. The higher moisture levels that were actually aimed for - after the increase on December 7th, 2012 (by around 10%) - were gradually achieved with values of up to 60%.

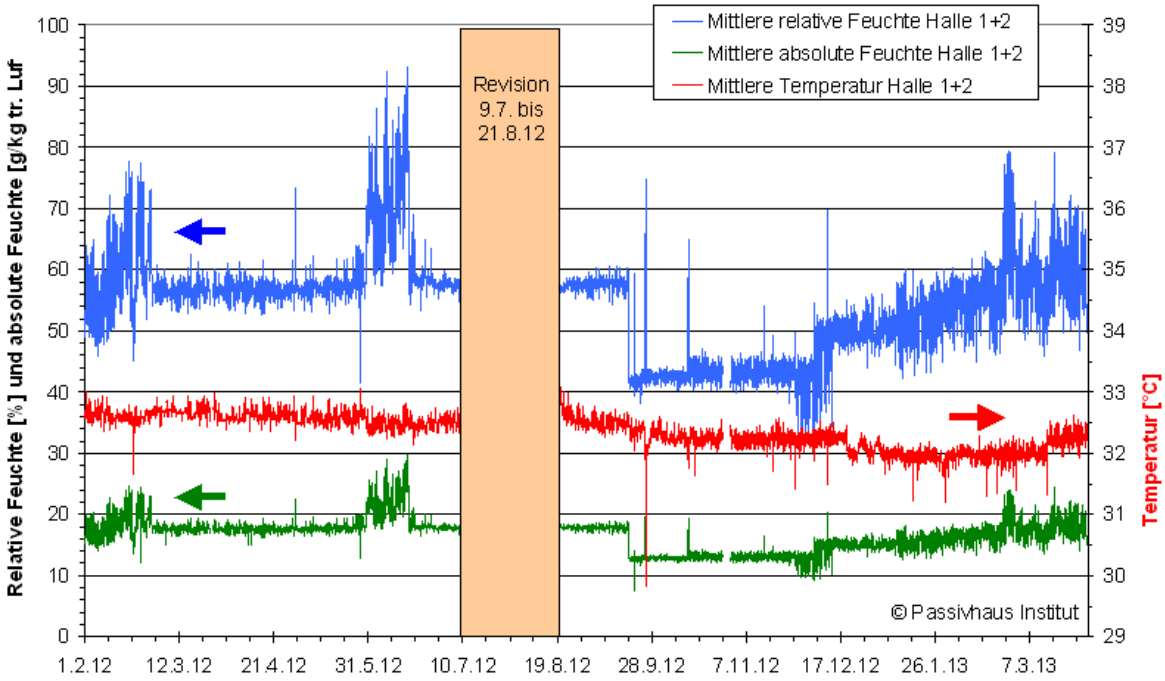

Figure 43: Course of the average hall temperature, the relative and absolute humidity in Hall 1 + 2 from 01.02.2012 to 01.04.2013 (hourly data)

The indoor air conditions of the other three halls in the same period are shown in the following three graphics:

In Hall 3, the indoor air temperature was reduced by up to about 2 K in spring and summer 2012 for more than six months. The sudden changes in the hall humidity are similar to those in Hall 1 + 2, but up to 20%. The significant levels of hall humidity on December 5, 2012 and January 9, 2013 are deliberate increases in hall humidity as part of the test series carried out by the PHI (see also section 4.6).

From February 13, 2013, strong fluctuations in the hall humidity of hall 3 can be observed. The cause lies in the adjustment of the control parameters of the ventilation unit by the manufacturer with unintended consequences. The adjustment was also made for the devices for halls 1 + 2, 4 and 5, which also means that from the
13.02.2013 much stronger fluctuations in humidity can be observed.

Since the reduction on September 18, 2012, the relative humidity in halls 4 and 5 has been below 50% on average (Figure 46 and Figure 47). Due to the remaining leakage in the old building area, low air humidities are to be realized in halls 4 and 5. In Hall 5, the sudden rise in temperature from mid-December 2012 to the end of January 2013 is particularly noticeable.

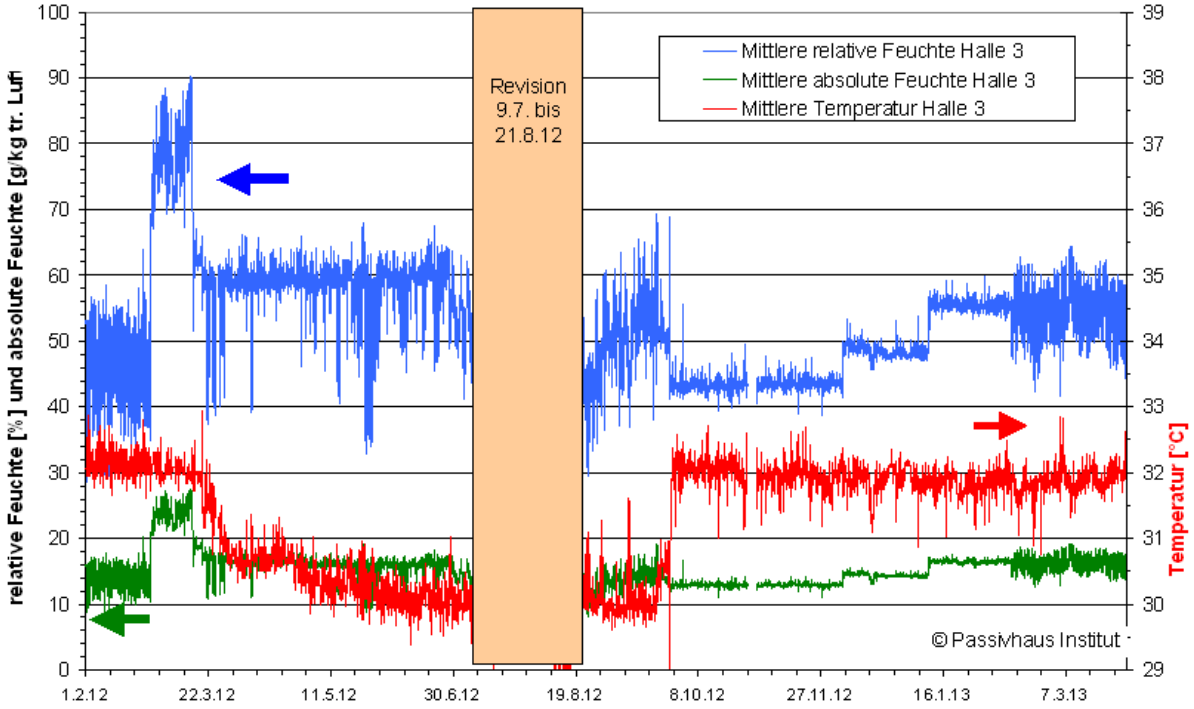

Figure 44: Course of the average hall temperature, the relative and absolute humidity in Hall 3 from 01.02.2012 to 01.04.2013 (hourly data)

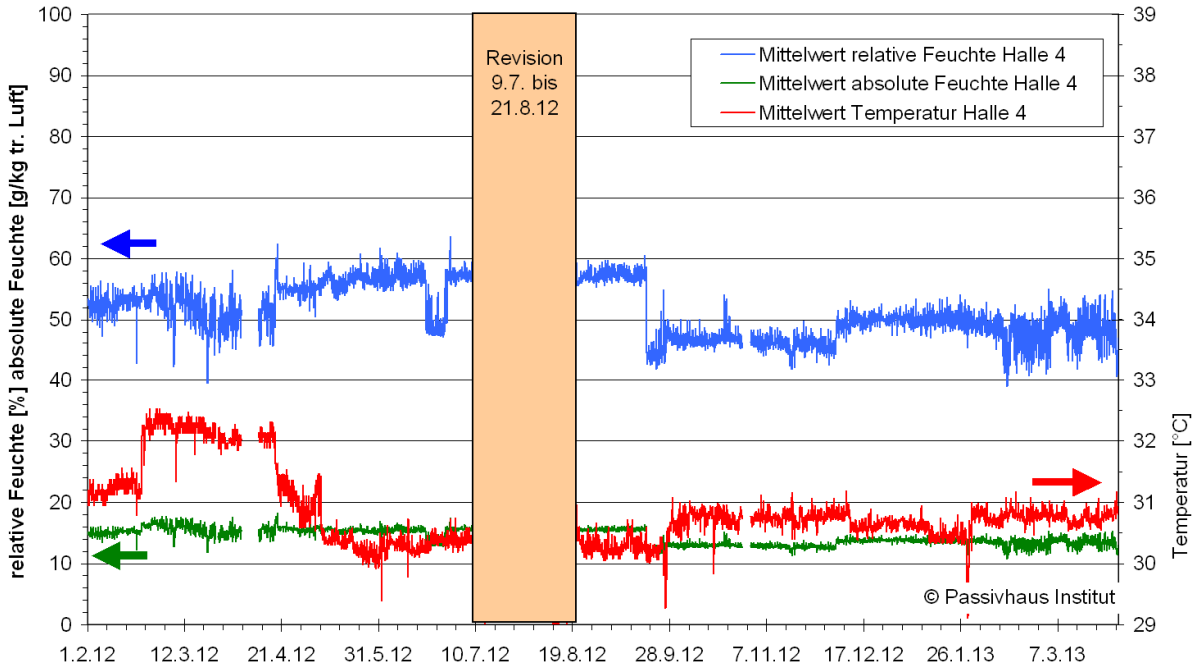

Figure 45: Course of the average hall temperature, the relative and absolute humidity in Hall 4 from 01.02.2012 to 01.04.2013 (hourly data)

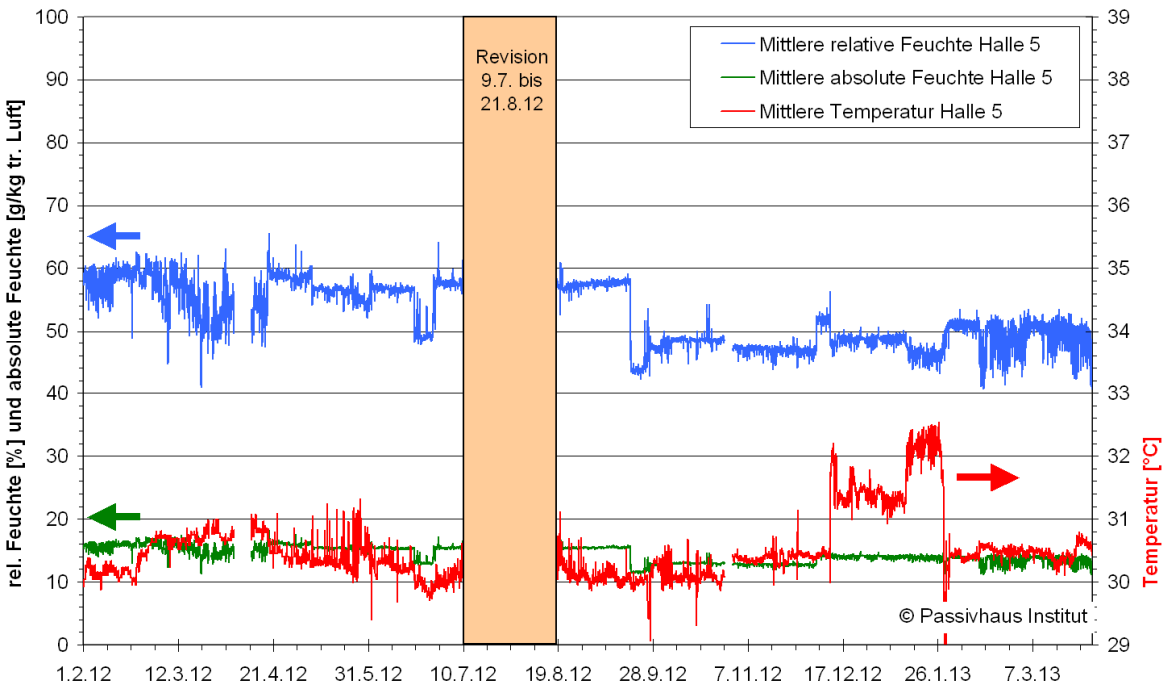

Figure 46: Course of the average hall temperature, the relative and absolute humidity in Hall 5 from 01.02.2012 to 01.04.2013 (hourly data)

In the secondary zones, the indoor air temperatures - less the humidity - are of particular interest. As expected, there is a greater spread of temperature levels and very different large dependencies on the outside air temperature depending on the location of the rooms or areas.

The axes are set differently in the following three figures in order to better represent the different temperature levels.

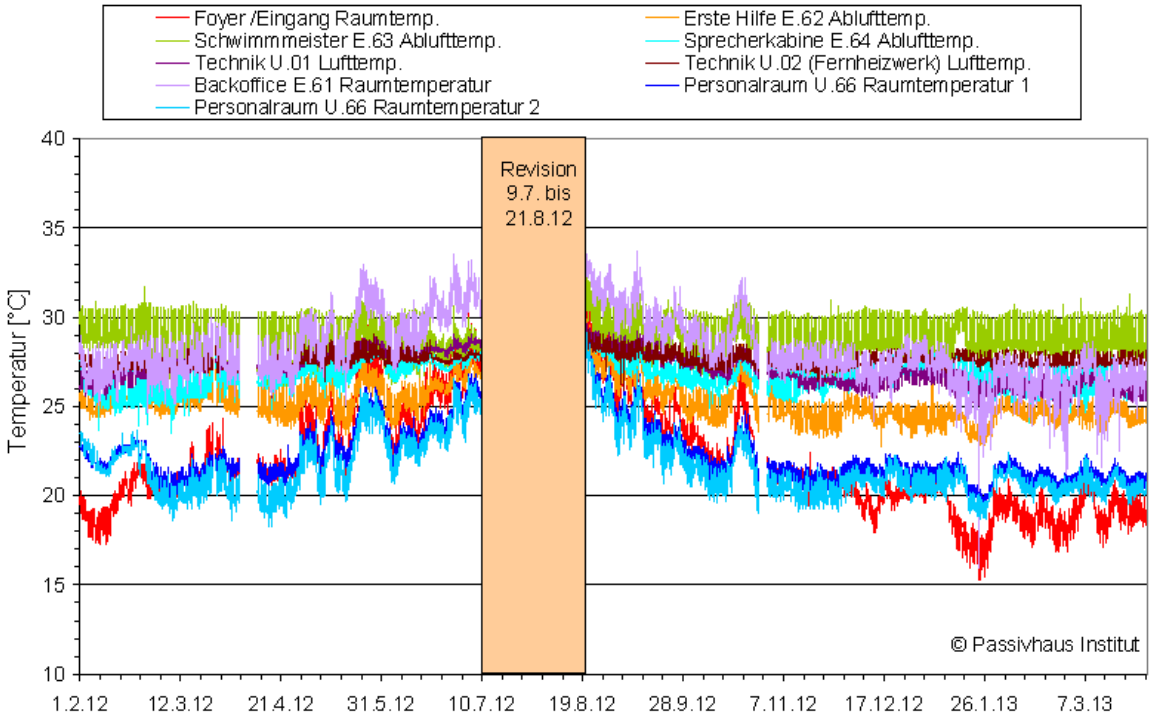

Figure 47: Course of the ambient air temperatures of the adjoining rooms from 02/01/2012 to 04/01/2013 (hourly data)

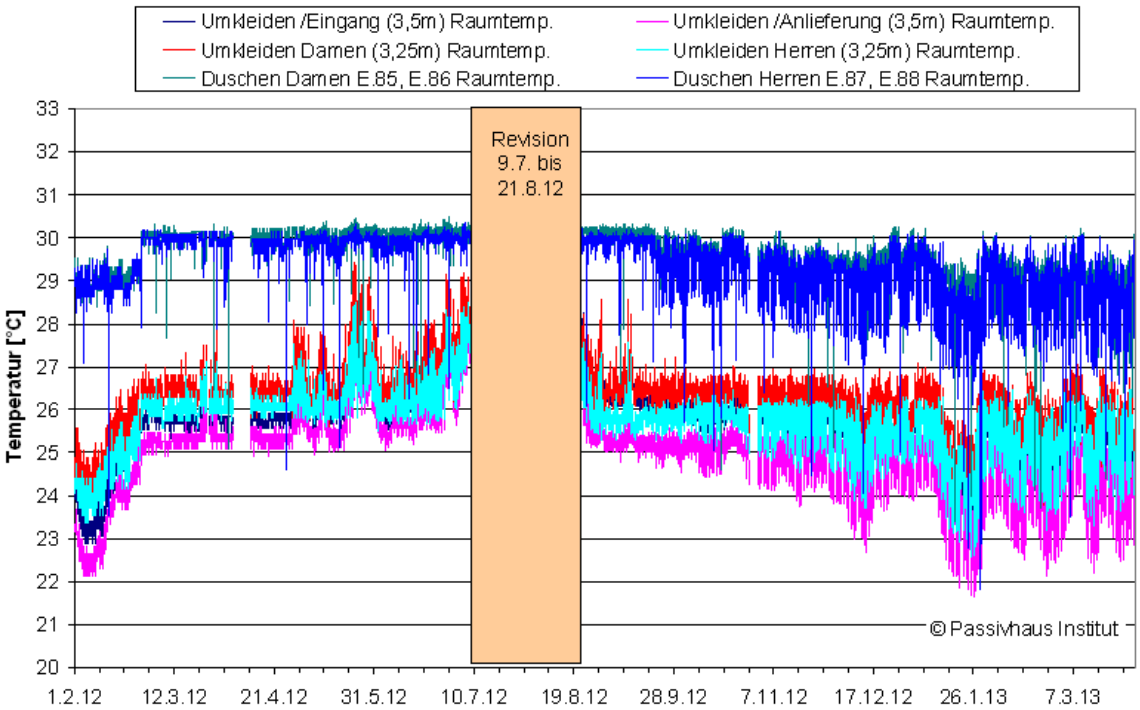

Figure 48: Course of the room air temperatures from the changing area and the showers from February 1, 2012 to April 1, 2013 (hourly data)

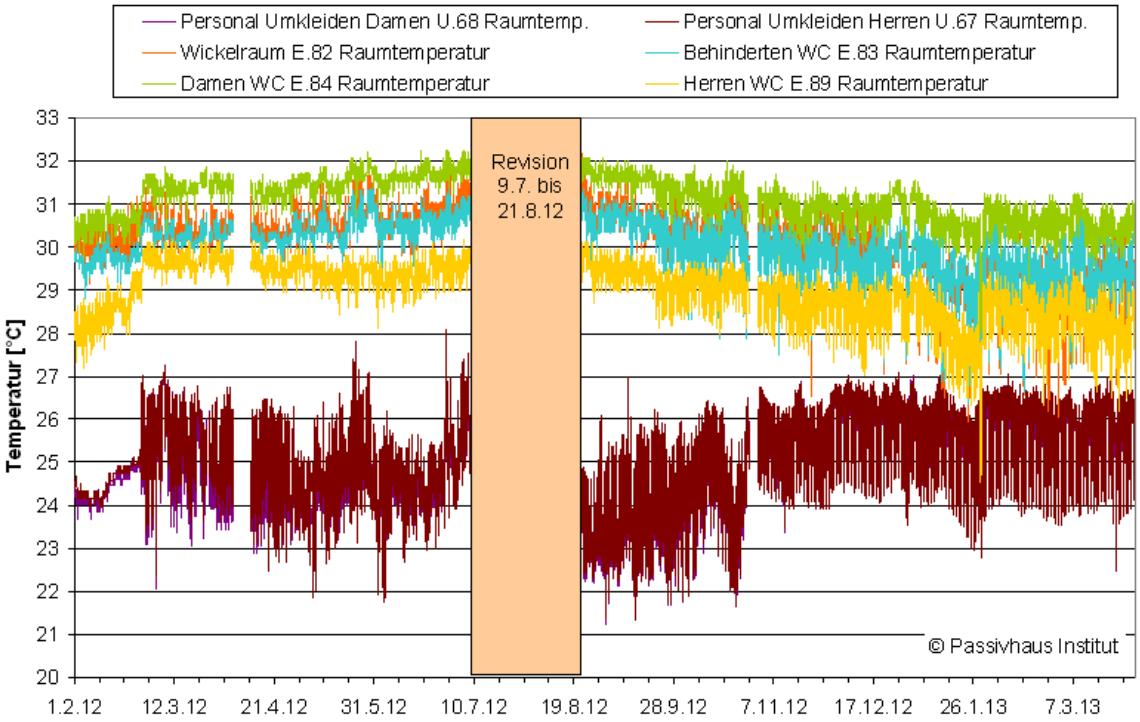

Figure 49: Course of the indoor air temperatures of the toilets and the staff rooms in the basement from 01.02.2012 to 01.04.2013 (hourly data)

The "changing room" ventilation unit is regulated according to the air humidity in the shower areas: the air from the changing area is transported to the showers after further heating. If the air humidity there exceeds a threshold value, the outside air volume flow of the device should be increased. In order to get an overview of the average relative humidity of the showers, the hourly values of the two sensors (women's and men's showers) were averaged and shown in Figure 50. The day and night hours are shown in the illustration. The fluctuations result on the one hand from the different uses (day / night) and the influence of

seasonally different

Outside humidity.

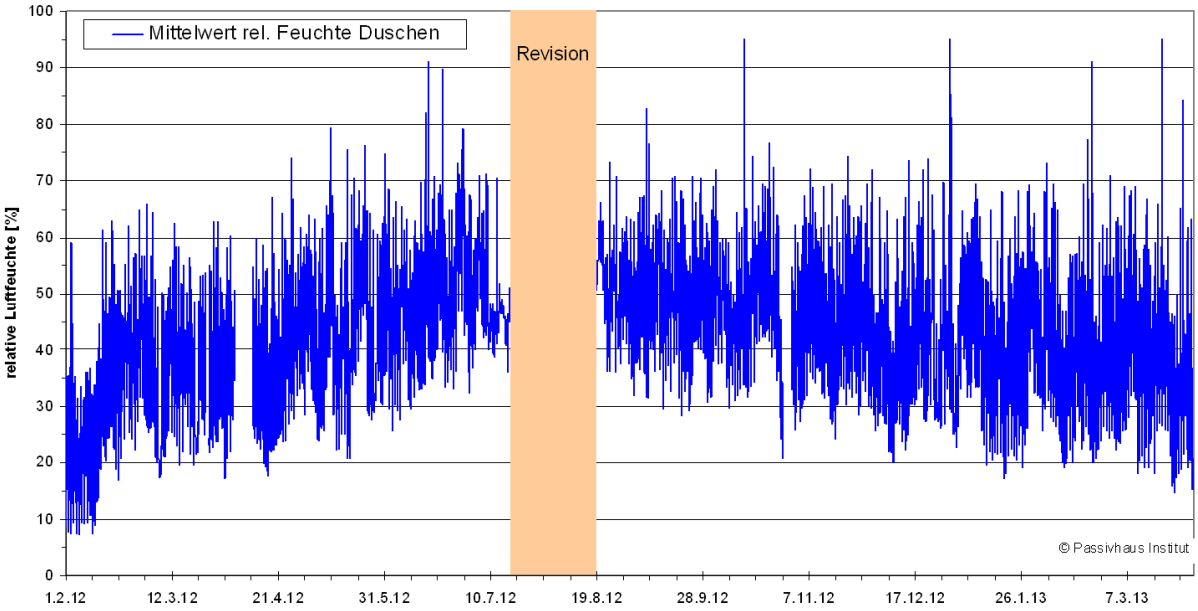

Figure 50: Course of the average relative room humidity of the showers (men and women Women) 01.02.2012 until 01.04.2013 (hourly data). See text for explanations.

4.3.1 Glazing surface temperature

The measurement of the six surface temperatures of the glazing close to the edge of the glass is carried out permanently. The lowest measured hourly average outside air temperature during monitoring was recorded on February 7, 2012 at -14.3 ° C. The surface temperatures of the glazing in Hall 1 + 2 also show the lowest values at this time. A minimum of 18.8 ° C was measured on the glazing of the mullion-transom facade. At the same time, an air temperature of 32.7 ° C and a moisture content of 15.0 g / kg dry air were measured in the hall. The measured values of the surface temperature show the significant influence of solar radiation on these cold but sunny days (Figure 51): during the day the values are significantly higher than at night. With the boundary conditions of the hall air, a surface temperature of 20, Do not drop below 4 ° C (dew point) to prevent condensate failure. This was observed several times at the lower edge of the glazing. The intended and necessary thermal quality does not seem to exist here. The reasons for this have yet to be determined.

The same observations are made for the measurements in halls 3 and 4. Figure 52 shows no great solar influence for Hall 4 on the same days of the lowest outside temperature due to the pane position on the north side; the surface temperatures are much quieter. In this hall, too, the surface temperature falls significantly below 20 ° C; a minimum of 18.0 ° C is reached. With the air conditions in the hall, surface temperatures must not fall below 19.3 ° C in order to remove condensate.

shut down. Here too, the observation of temporary condensate coincides with these calculations.

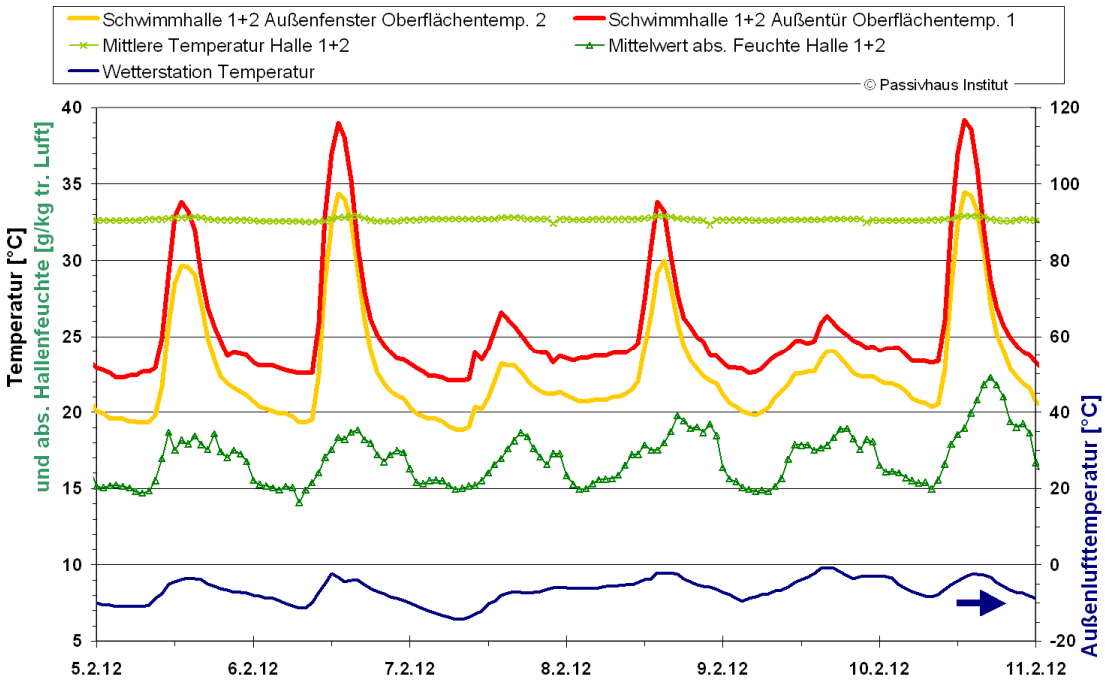

Figure 51: Course of the surface temperatures of the glazing in Hall 1 + 2 and the associated mean hall humidity and hall temperature as well as the outside air temperature from 07.02. until February 11, 2012 (hourly data)

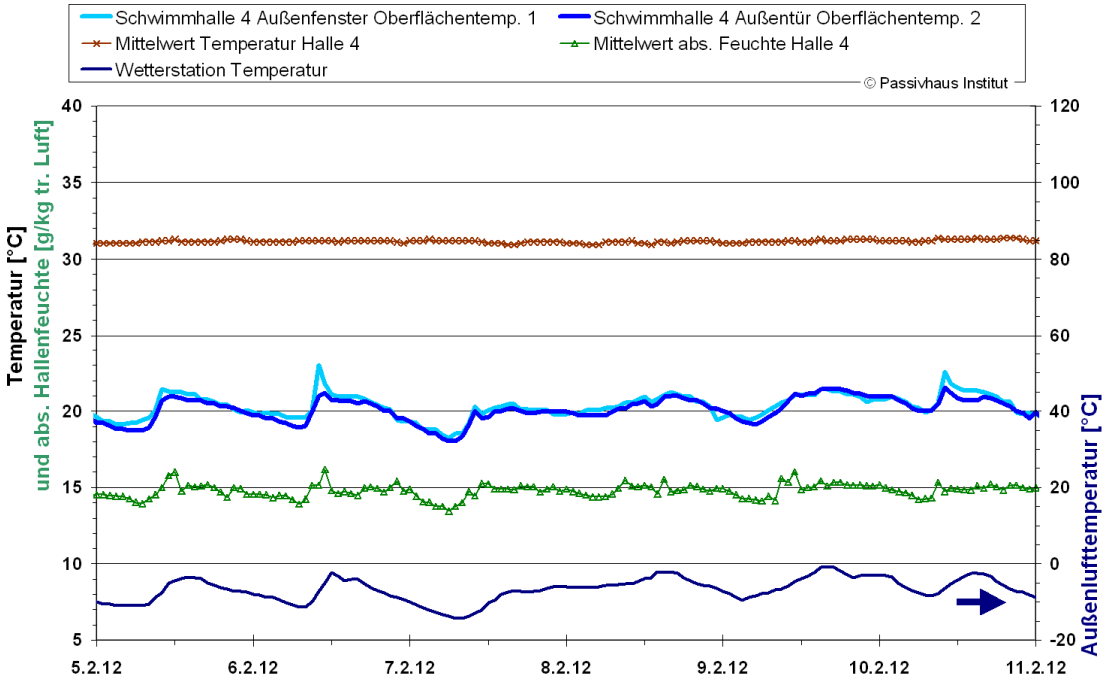

Figure 52: Course of the surface temperatures of the glazing in Hall 4 and the associated mean hall humidity and hall temperature as well as the outside air temperature from 07.02. until February 11, 2012 (hourly data)

4.4 Water temperatures

The water temperatures in the four pools are different due to the desired use. The temperatures in the 25-meter pools 4 and 5 are constantly between 27.5 and 27.8 ° C (see Figure 53). The water temperature in the teaching pool (pool 3) is mostly between after the revision period

29.4 to 29.8 ° C and thus significantly higher than in the two 25-meter pools. Before the revision period, it was slightly higher.

Pool 1 + 2 with the parent-child area has the highest pool temperature at 30.5 to almost 33 ° C. On 06.12.2012 the water temperature was raised significantly; previously it was reduced a little by September 26, 2012. Overall, there are significant fluctuations in the water temperature in this pool. The detailed view of just ten days in Figure 54 shows that the fluctuations in pools 1 + 2 are daily cycles: the lowest water temperatures can always be found in the morning at 6:00 or 7:00 a.m., the peaks at Evening at 10 p.m. This mode of operation is not intended and is due to the control parameters for heating by the NT and HT circuits in conjunction with the intermittent circulation operation of the ultrafiltration.

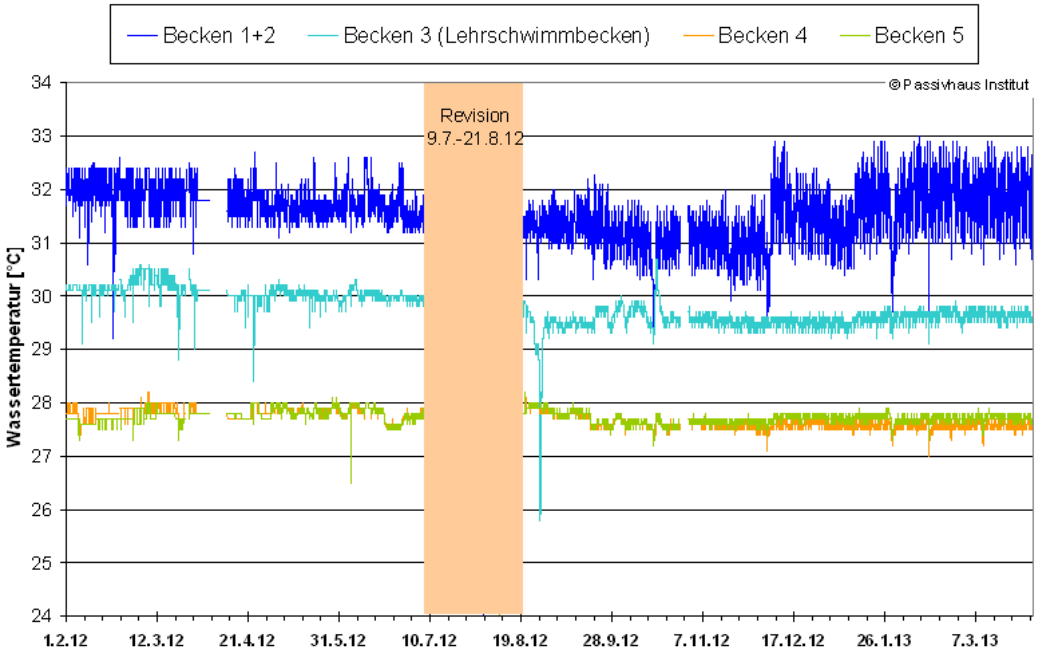

Figure 53: Course of water temperatures in the four pools (February 2012 to March 2013, Hourly data). Representation with suppressed zero point.

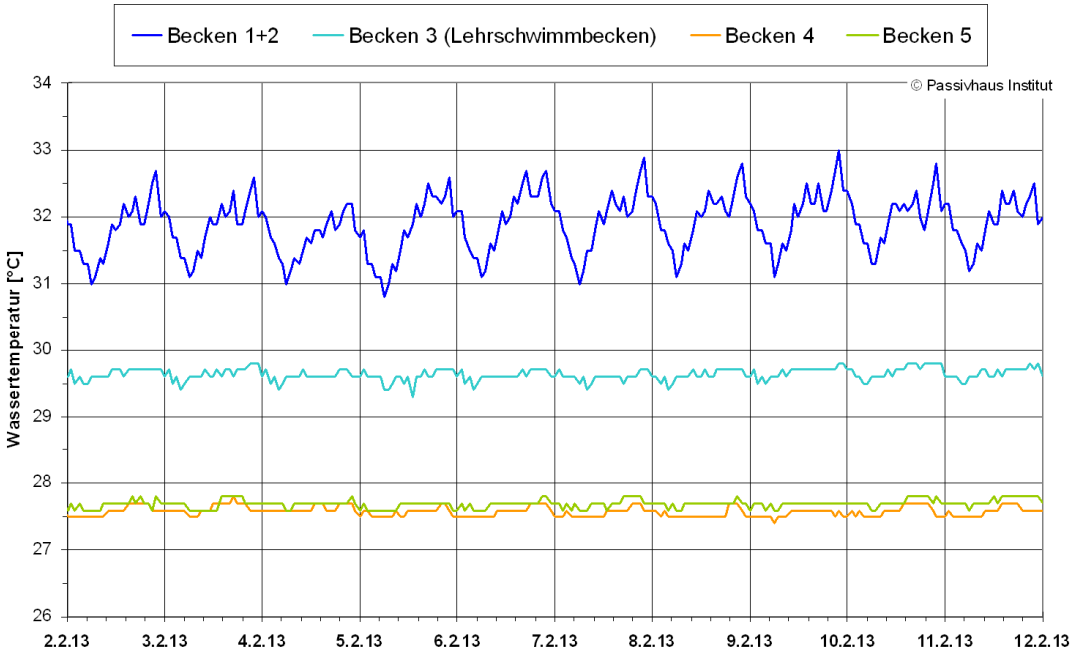

Figure 54: Detail of the water temperatures of the four pools (02.02. To 11.2.2013, hourly Data). Representation with suppressed zero point.

The monthly mean values of the pool water temperatures are shown in the next figure. Due to the emptying of the pool during the revision period, the temperatures in July and August 2012 are not meaningful.

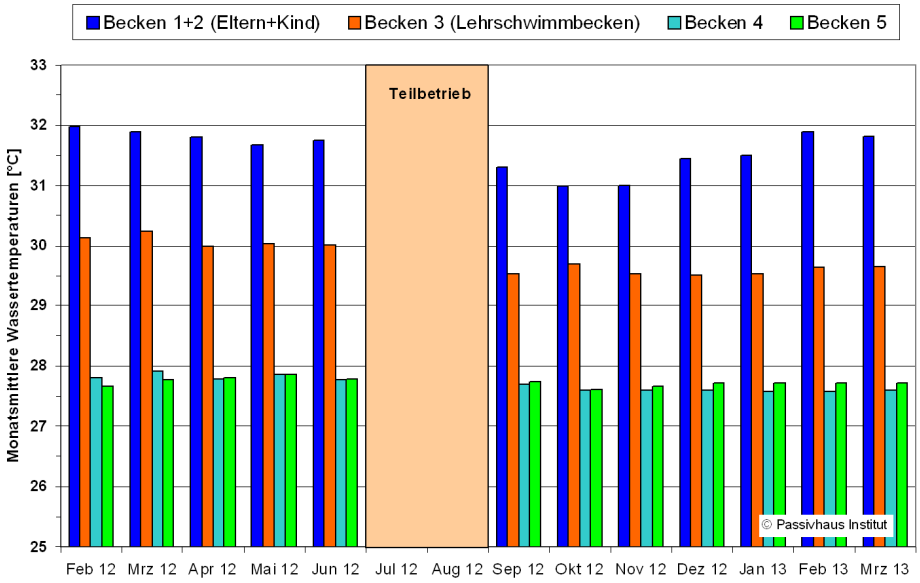

Figure 55: Average water temperatures in the four pools (February 2012 to March 2013). Representation with suppressed zero point.

4.5 ventilation

After the bathroom was opened, the ventilation units were initially operated in normal operation with the design volume flows. The reduction of the circulating air volume flows and the increase of the hall humidity according to the concept of a passive house swimming pool should take place gradually. In the first months of operation, the systems were first set up, followed by some technical improvements (including correction of installation of the WMZ). During the revision period during the summer break, internal air and condensate leaks in the devices were reworked. Due to the need to optimize the water quality and the remaining leaks in the building envelope in the old building area (Hall 5), tests with increased hall humidity and reduction of the circulating air volume flow could only be carried out in Hall 1 + 2 and 3.

4.5.1 Volume flow of hall units

The outside air volume flow (for air quality) and the recirculating air volume flow are of particular interest for the operation of an indoor pool. To illustrate the two modes of operation, these are shown schematically in Figure 56.

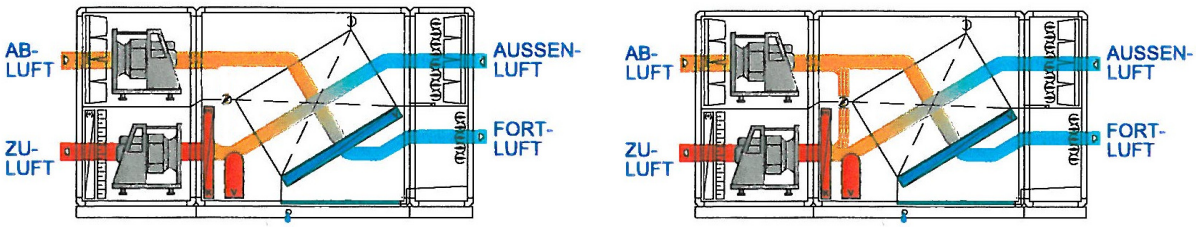

Figure 56: Schematic representation of a hall ventilation unit with heat pump, with (left) and without (right) air circulation (source: Menerga, supplemented)

The circulating air volume flow is not measured directly in the devices; it can be calculated as the difference between the supply or exhaust air volume flow and the outside air flow. The following graphics result:

- Outside air volume flow: "AU / ZU volume flow via recu" (= recuperator)
- Recirculated air volume flow: difference between AU / ZU volume flow and ZU or AB volume flow

For a complete overview, the supply and exhaust air volume flows as well as the volume flow via the heat recovery unit (outside / supply air volume flow) of the four hall units are shown (Figure 57 and Figure 58).

The volume flow curve of the device for hall 1 + 2 shows that there have been significant changes in the control behavior and in the circulating air volume flow. Are in this hall experiments have been carried out by the PHI. These are described below

wrote and analyzed. The design volume flow of 14,500 m³ / h was permanently reduced to 8,300 m³ / h from December 19, 2012 for about two months. After that there were periods with high and low circulating air volume flows.

In Hall 3, no reductions in the circulating air volume flow (i.e. the supply / exhaust air volume) have yet been carried out. The volume flow - at least after the revision work - is permanently around 8,000 m³ / h on average. In contrast to the winter period, the increased demand for outside air for dehumidification can be read from the course of the outside air volume flow ("AU / ZU via Reku").

This effect is also present in Hall 4 and Hall 5, but is not so pronounced. The unit from Hall 4 is permanently on the supply / exhaust side with approximately
12,000 m³ / h operated. In hall 5, the values are initially somewhat higher at 15,500 m³ / h. From the end of November 2012 there will be a reduction to almost 15,000 m³ / h. This volume flow reduction leads to a reduction in the power consumption of the system of approximately 23 kWh / day, which corresponds to 690 kWh / month.

All four indoor units are operated with slightly higher exhaust air than supply air volume flow in order to maintain low vacuum conditions in the hall for component protection (manufacturer standard).

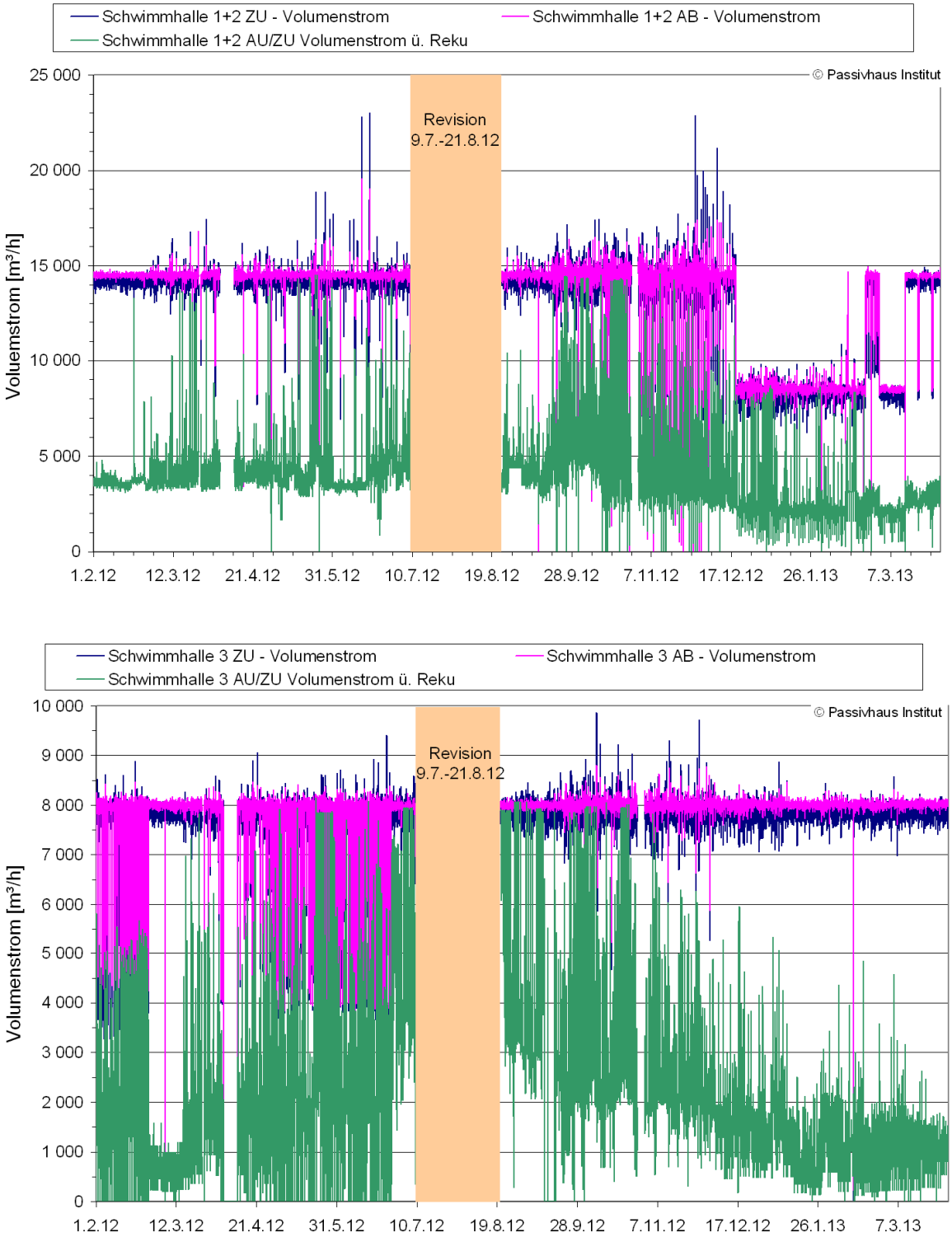

Figure 57: Volume flows of the ventilation systems in Hall 1 + 2 and Hall 3 from 01.02.2012 until March 31, 2013 (daily values)

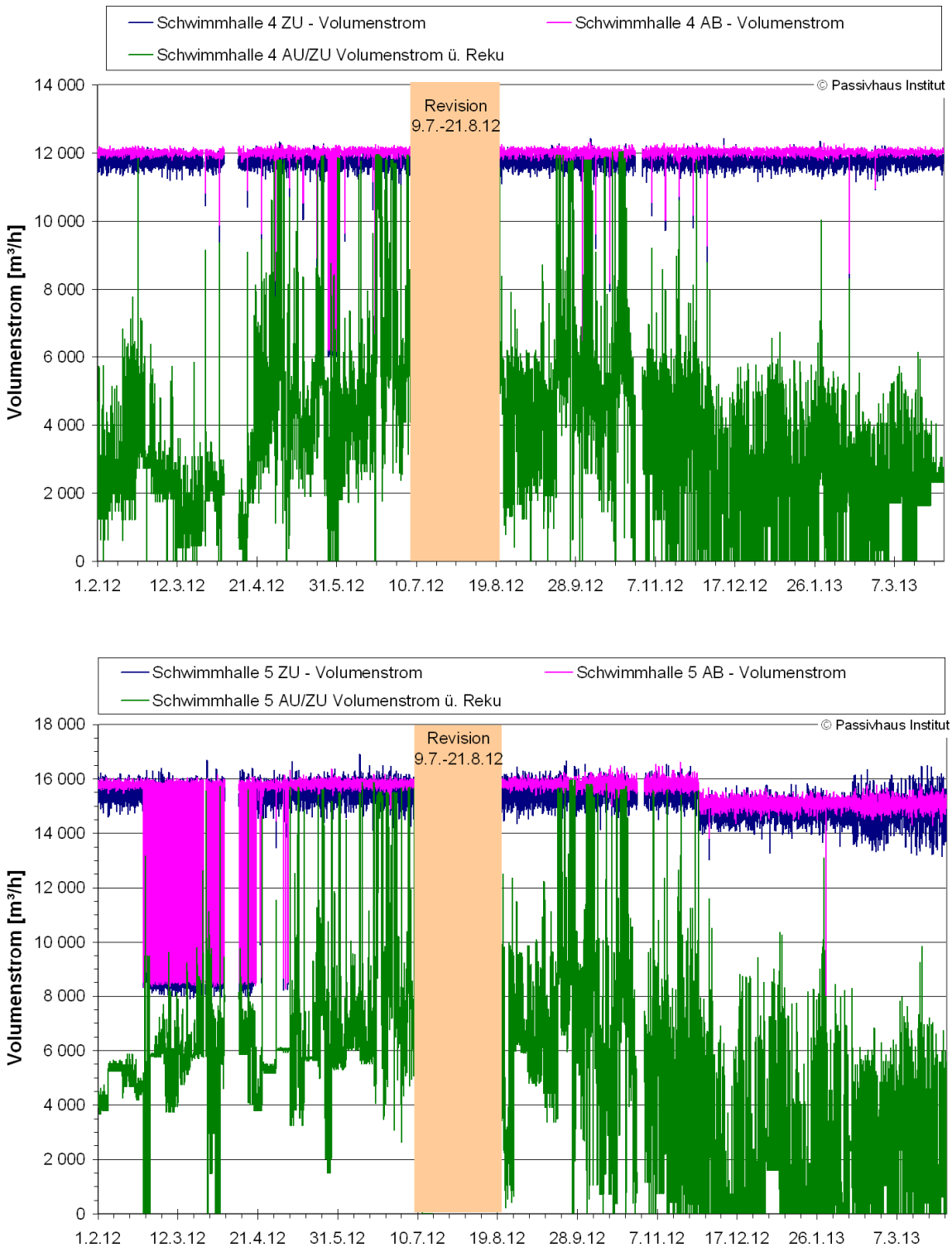

Figure 58: Volume flows of ventilation systems in halls 4 and 5 from 02/01/2012 to 3/31/2013 (daily values)

4.5.2 Volume flow devices of the secondary zones

The control strategy of the two ventilation systems in the secondary zones is completely different from that of the indoor units. There are other device types, which

work without air circulation. Here the volume flow of the supply air corresponds to the outside air volume flow and the exhaust air volume flow corresponds to that of the exhaust air.

4.5.2.1 “Changing / showering” device

In Figure 59 it can be seen that the supply air and extract air volume flow from the unit changing rooms / showers between the operating mode with about 6,000 and
10,000 m³ / h fluctuates. At night from 20.09.2012 there will be a nighttime shutdown from 11:00 p.m. to 6:00 a.m. The volume flow fluctuations from April 11th, 2012 result in part from the control of the air requirement after the humidity control from the shower area: If the relative humidity exceeds the maximum value of 80% there, the outside air flow is increased. In addition, a CO_2- Monitoring of the changing area available, which additionally increases the volume flow when the limit value is exceeded.

As a rule, the device would be operated continuously with the design volume flow of 10,000 m³ / h, if necessary a night shutdown would be implemented. Due to the implemented mode of operation, the average volume flow including night shutdown is only 4,800 m³ / h (01.11.2012 to 31.3.2013). This difference creates a significant saving due to the reduced ventilation heat losses and the power consumption of the device.

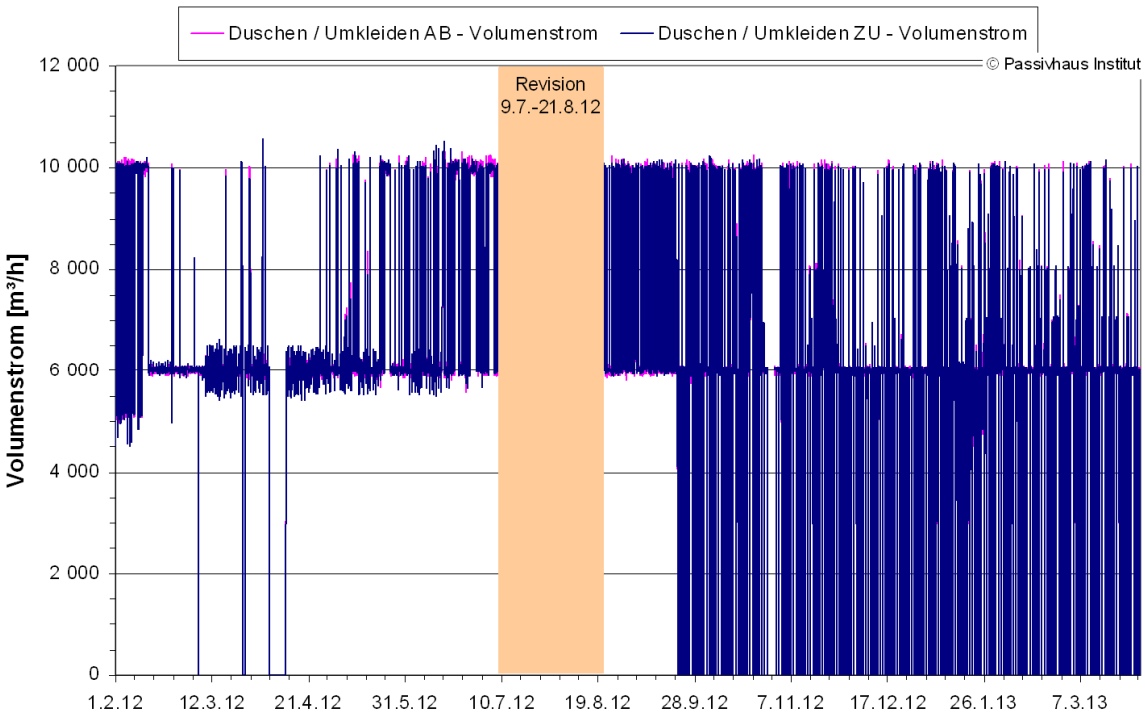

Figure 59: Volume flows of the ventilation systems changing rooms / showers from 02/01/2012 to as of March 31, 2013 (daily values)

4.5.2.2 “Additional rooms” device

The "adjoining rooms" device supplies the foyer and entrance area, the entire basement and various ancillary and technical rooms. Figure 60 shows that, as intended, the device is operated almost continuously with an active night shutdown. It usually runs at about during daily operation

8,000 m³ / h. The unintended, significantly higher air volumes in the time before and after the revision are considered in section 4.5.3.2.

In the foyer, a CO_2- Sensor monitors the air quality. If the CO_2-
Concentration exceeds the threshold of 900 ppm, the flap opens further for the foyer area in order to improve the air quality there. The CO_2- Measured values are therefore only as peak values, briefly above the threshold value (see Figure 61). Overall, the CO_2- Measured values a very good air quality in the foyer.

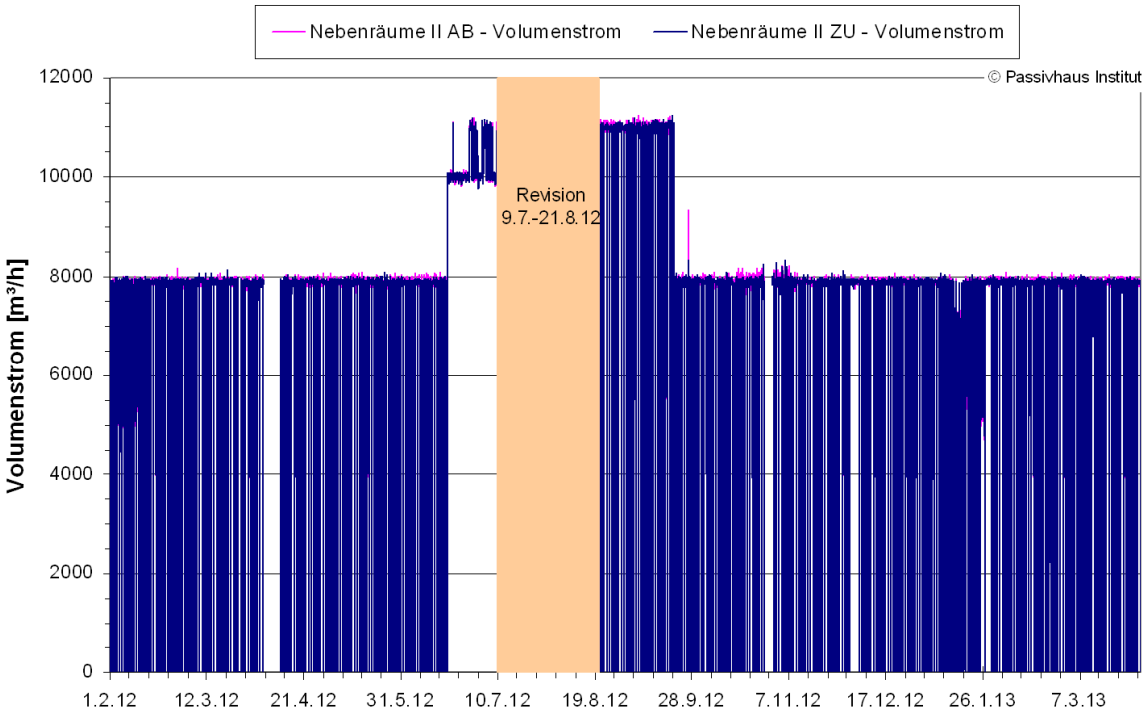

Figure 60: Volume flows of ventilation systems in adjoining rooms from 02/01/2012 to 3/31/2013 (daily values)

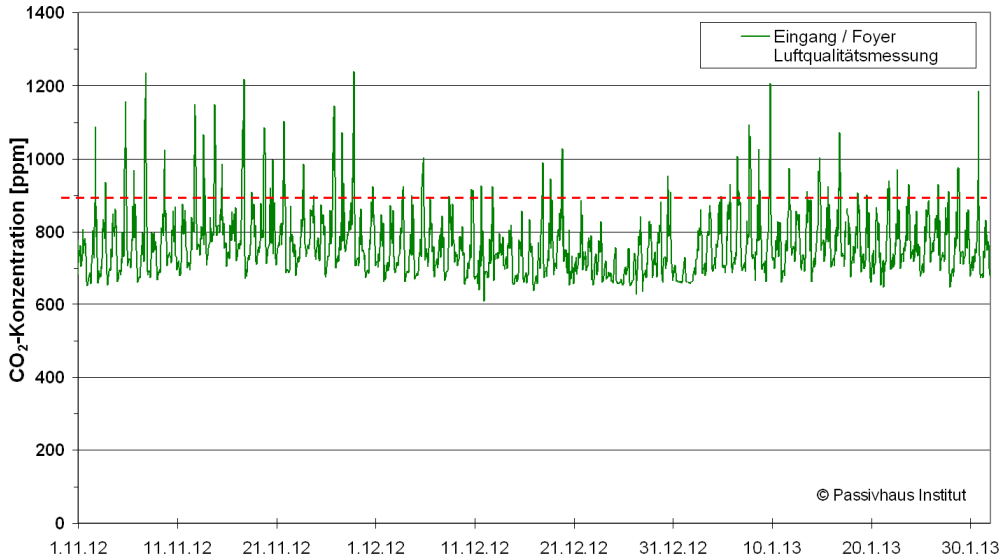

Figure 61: The CO_2- Measured values of air quality monitoring in the foyer from November 1st, 2012 to as of January 31, 2013 (daily values) show high air quality with rare violations of the 900 ppm limit selected here.

4.5.3 Effects of changes in volume flow (sub-zone devices)

Some changes in the volume flows at the two ventilation units in the secondary zones are examined as examples. The influence of the changes on the power consumption can be clearly seen from the changes in the operating mode of the devices. Through targeted changes and unwanted operator interventions, the air volume flows have been significantly changed several times, for example in the "adjoining rooms" and "changing rooms" devices.

4.5.3.1 “Changing / showering” device

On August 21, 2012, the device “changing rooms / showers” switched from constant volume flow of 6,000 m³ / h to temporarily increased operation at 10,000 m³ / h when it reopened after the summer break. No night shutdown was activated at the same time. As expected, this generated a significantly higher power consumption (about plus 20 kWh / day). Figure 62 shows the supply and exhaust air volume flows as well as the electricity consumption. The planned nighttime shutdown of the device was only activated for the first time on 20.09.2012 after an on-site visit by PHI employees. This measure significantly reduced power consumption, but is partially overlaid in the days after September 23, 2012 due to longer operation at the higher level with 10,000 m³ / h.

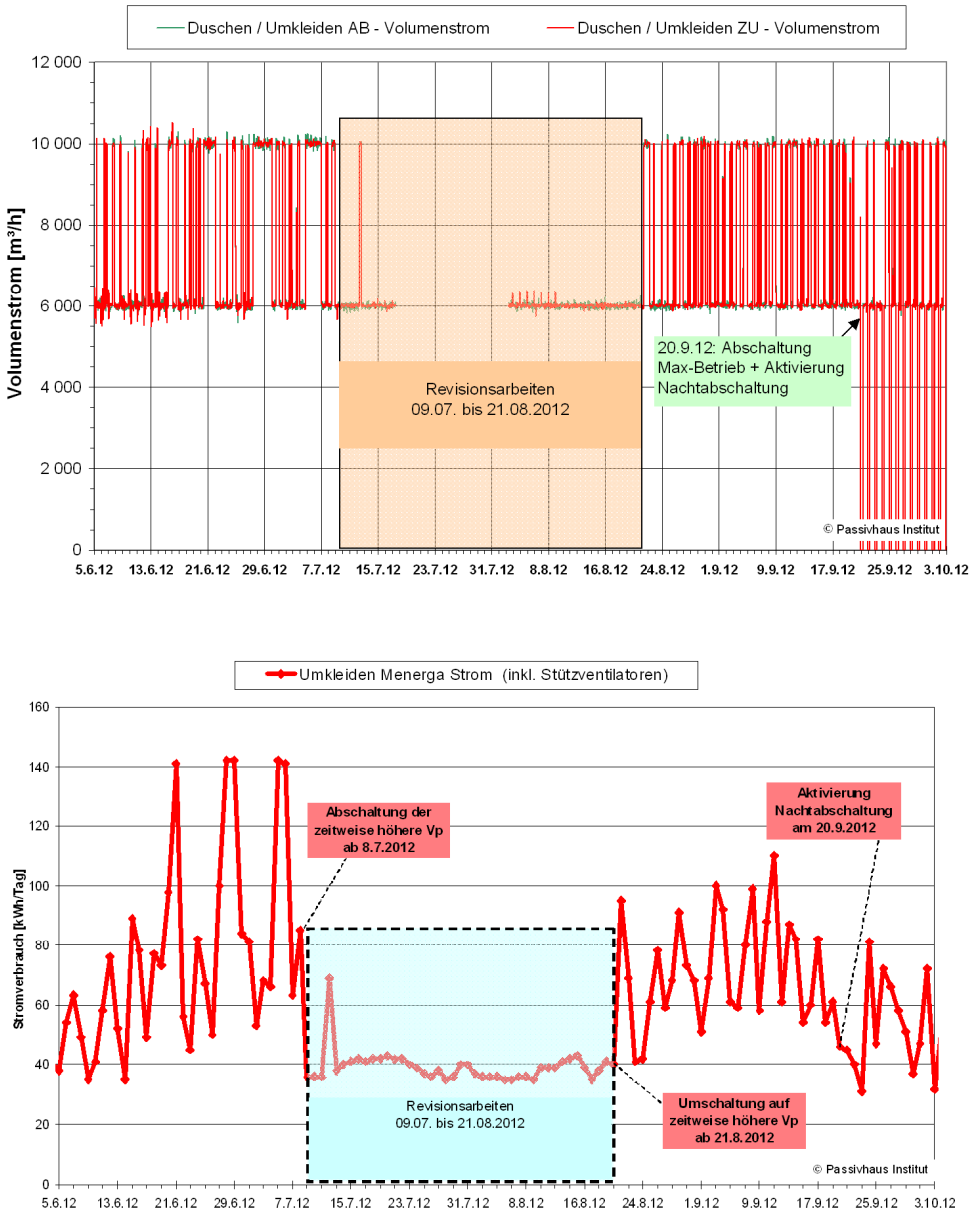

Figure 62: Changes in the air volume flow of the ventilation unit “changing room” with the associated electricity consumption values of the systems (daily values from 05.06. to 10/03/2012).

4.5.3.2 Device “side rooms”

The same can be observed with the ventilation unit "side rooms" (see figure 63): From June 18, 2012, electricity consumption will increase drastically by increasing the volume flow from approx. 8,000 to 10,000 m³ / h and preventing nighttime shutdown (plus 54 kWh / day). Even before the revision work on the device (July 17 to August 2, 2012), the "Manual control" button was accidentally activated (July 12, 2012), or it was not canceled. With that, the device

operated with maximum air flow (12,000 m³ / h), but at the same time the planned night shutdown was activated. Overall, this reduced electricity consumption by around 16 kWh / day. The actually desired operation was then again from the
09/20/2012 (on-site appointment PHI employees) realized: volume flow of 8,000 m³ / h in daytime operation and a night shutdown from 23:00 to 06:00. This measure resulted in a reduction in electricity consumption from 40 kWh / day to only about 30 kWh / day. The daily heat supply does not change noticeably due to the changes in the air volume flow.

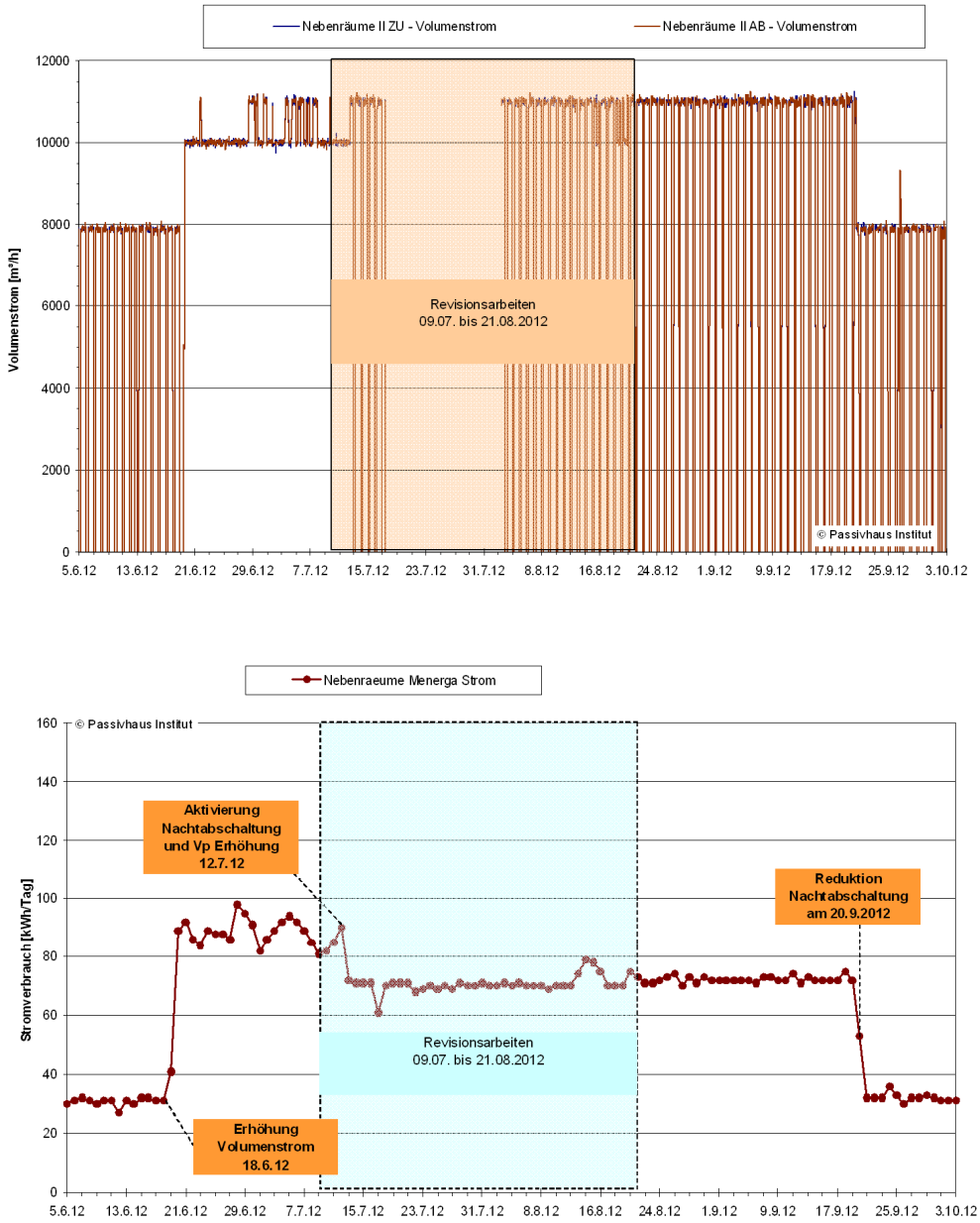

Figure 63: Changes in the air volume flow of the ventilation unit "Additional rooms" with the associated electricity consumption values of the systems (daily values from 05.06. to 10/03/2012).

4.5.4 Current efficiency of the ventilation units

To assess the electricity efficiency of the ventilation units, the electricity consumption of the day of the ventilation system including regulation was based on the average value of the supply / exhaust air volume flow of the entire day on four exemplary days. For device 1 + 2, the power consumption of the heat pump was subtracted from the device consumption (with the exception of September 15, 2012; at that time there was no separate measurement of the power consumption of the heat pump).

In the case of the "changing room" device, it must be taken into account that the fan flow of the two additional fans for air transport through the two post-heating registers and channels to the shower areas is included in the measured value.

Table 6: Average daily air volume flows and current efficiency of the six ventilation units four exemplary days.

	Hall 1 +2		Hall 3rd		Hall 4		Hall 5	
	m³ / h W / m³ / h	m³ / h W / m³ / h	m³ / h		m³ / h W / m³ / h	m³ / h		W / m³ / h
September 15, 2012	14322	---	7930	0.40	11893	0.43	15656	0.35
12/22/2012	8433	0.22	7956	0.36	11921	0.39	14878	0.31
07/01/2013	8388	0.22	7965	0.38	11895	0.40	14939	0.32
January 16, 2013	8317	0.21	7938	0.34	11916	0.39	14917	0.30

	Changing room the *		Neb n rooms	
	m³ / h W / m³ / h	m³ / h W / m³ / h	m³ / h	
September 15, 2012	6494	0.35	7486	0.40
12/22/2012	4354	0.38	5696	0.29
07/01/2013	4725	0.44	5372	0.28
January 16, 2013	4240	0.34	2425	0.24

* including support fans for the shower areas

The measured values show good to very good results, which suggests good current efficiencies of the devices and low pressure losses in the sewer network.

4.5.4.1 Standby power consumption

Due to the poor resolution of the electrical meters of one kilowatt hour, the standby power of the devices can only be roughly limited. This is only possible with devices that have sufficient downtimes. The "locker room" and "adjoining rooms" devices are completely switched off for more than 6 hours during normal operation at night. At night, 1 or 2 kWh of electricity is regularly consumed, which corresponds to an electrical output of around 150 or 300 W. The standby power is clearly too high. The indoor units in the Lippe bath are operated continuously in the selected mode of operation, which means that no measurements of the standby consumption of the units can take place.

4.5.5 Flow through the hall / fog tests

It should be examined whether the halls can also be operated with the planned, significantly reduced supply air or recirculated air volume flow without impairing the bathers. Of particular interest is whether there are areas in a hall that are not or only insufficiently flowed through by the air (so-called “dead corners”). The goal is to reduce the supply air volume flow for the same outside air volume flow.

For this reason, fog tests were carried out in Hall 1 + 2 in the night from December 5th to December 6th, 2012 after the end of public bathing from 10 p.m. For this purpose, two fog units were positioned in the associated ventilation unit and fog was introduced into the hall through the supply air nozzles at different supply air volume flows. The distribution of fog in the hall was examined using film cameras at three positions in the hall and additional photos.

Figure 64: Fog tests in Hall 1 + 2 in the night from 5th to 6th December 2012. Look at the outer wall (left) and the wall to the changing areas (right). The picture shows two supply air nozzles (circles) and the exhaust air grille (arrow).

The supply and exhaust air volume was reduced for the test from 14,300 m³ / h to 8,300 m³ / h, which corresponds to a reduction of 42%. By closing about half of the supply air nozzles using servomotors, the necessary pressure at the nozzles remains.

It was shown that the mist was distributed very quickly and evenly in the hall, even with a reduced supply / exhaust air volume flow. After about 40 seconds, the entire hall 1 + 2 was evenly fogged (Figure 65). It was therefore decided with the specialist planner and the operator that the reduced circulating air volume flow is completely sufficient for operation and that the systems can be operated with reduced circulating air volume flow. The resulting significant savings potential through lower power consumption for the ventilation unit is described in section 4.6.2.

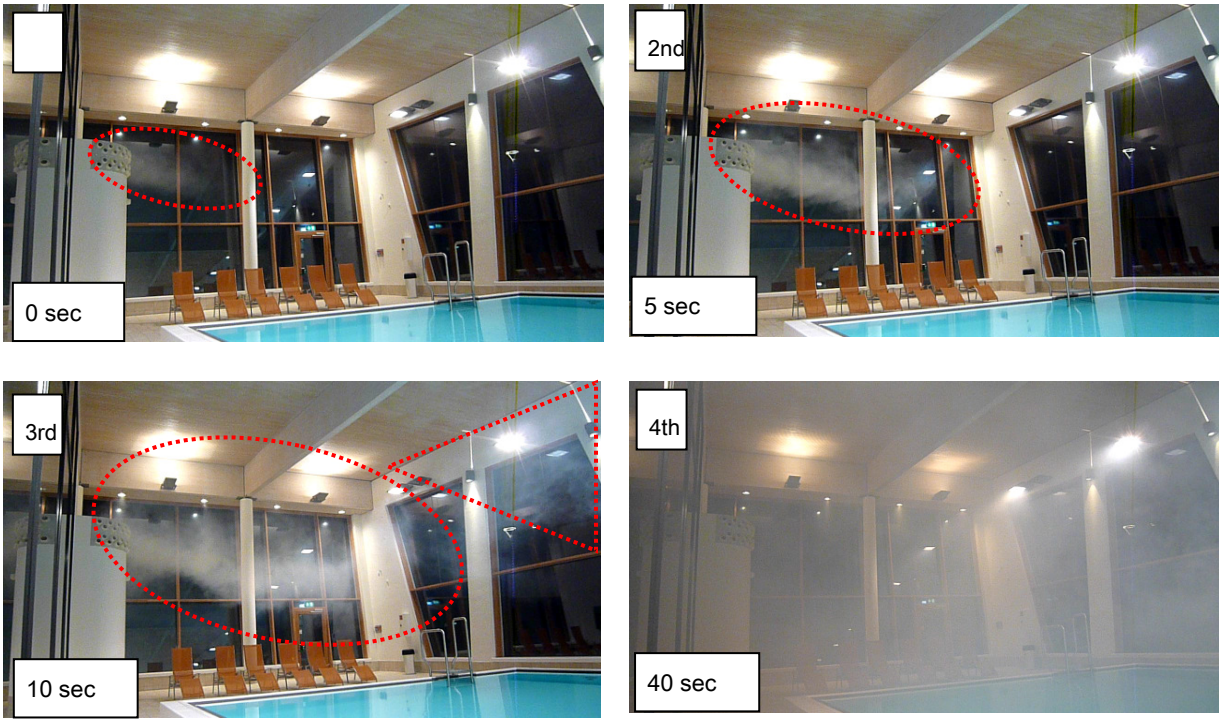

Figure 65: Photo gallery showing the spread of fog on the facade of Hall 1 + 2

Mist escapes from the ventilation tower (reduced volume flow). In Fig. 3, the mist from the supply air nozzles has already reached the inside wall in the hall area shown (red triangle). The hall is evenly nebulized after approx. 40 seconds.

influenced. When implementing the - through the Nebelver- 1

4.5.6 Outside air share

In each ventilation unit, the supply and exhaust air volume flow of the fans are measured internally. The energetically interesting proportion of outside air in the hall units is determined by means of an internal pressure difference measurement via the heat recovery unit (recuperator). These measurements are adjusted by regular, automatic, nightly calibrations to compensate for the change in pressure loss of the heat exchanger unit. Initially, this adjustment was carried out weekly, but this led to relevant deviations in the volume flow. For this reason, the indoor units were converted to daily calibration.

According to [VDI 2089], the minimum proportion of outside air is independent of the hall humidity ≥ 30% of the outside air design mass flow fixed. If the calculated value for the THM concentration (trihalomethane) in the pool water is permanently undershot, the outside air mass flow can increase according to the guideline [VDI 2089] ≥ 15% can be reduced.

When reducing the supply / exhaust air volume flows, the minimum outside air volume flow should be Not to be

such (see previous section) - supply air reduction on December 19, 2012 unexpectedly showed a clear influence on the outside air volume flow. In Figure 66, the two dashed horizontal lines each mark the minimum outside air volume flow before and after the circulating air volume flow reduction (approx. 2,300 and 1,200 m³ / h). These outside air volume flows correspond to approximately 16% and 8% of the design volume flow. The technical causes are still being clarified. One reason is the limited accuracy of the pressure cells at low volume flows. The sockets have now been exchanged for improved ones; another test measurement is still pending.

To ensure the consistently good indoor air quality, the supply or recirculated air volume flow reduction must first be dispensed with until the minimum outside volume flow can be permanently ensured.

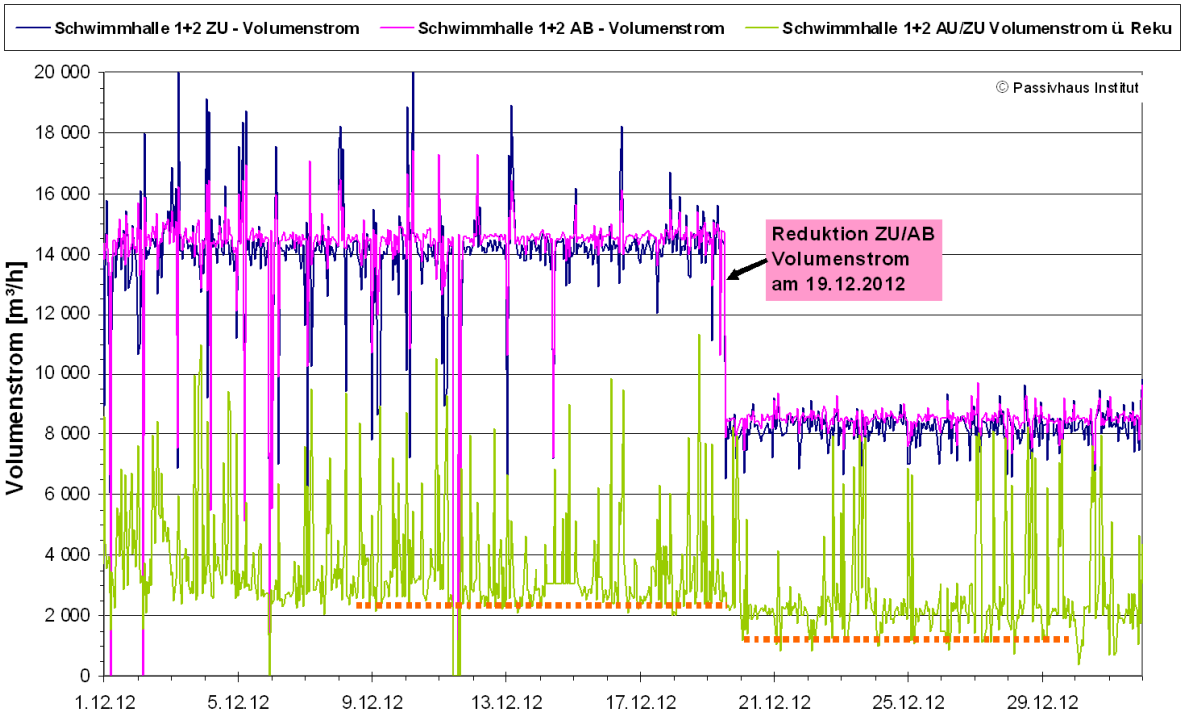

Figure 66: Development of volume flows around December 19, 2012. See text for explanations.

The first orientative air quality measurement was carried out on February 26th, 2013 from 9:30 a.m. to 1:00 p.m. by LVHT GmbH in three halls [Funcke 2013]. At this time (3.5 hours) an outside air volume flow of 3,000 m³ / h was measured in device 1 + 2 (corresponds to 21% of the design volume flow). In hall 3 it was 1,330 m³ / h outside air (corresponds to 16.9%), in hall 5 only 1,281 m³ / h (corresponds to 8.6%). The indoor humidity was relatively high between 57.4 and 58.4% during the sampling period (20 cm above the water level).

To examine the air samples for THM, the process of enrichment on activated carbon, liquid desorption and subsequent gas-chromatic analysis was

lysis applied. The short report of the measurement shows that all measured values in the hall air are below the detection limit (5.0 or 1.3 µ g / m³ air). It was therefore not possible to determine an increased contamination of the indoor air with trihalomethanes - even with the very low outside air volume flows. Further studies on specifically different indoor air humidities and outside air volume flows in the Lippe bath can help to improve the level of knowledge on this topic in the long term.

4.5.7 Change in control behavior

Changes in the programming of the ventilation systems by the manufacturer resulted in changes in the control behavior of the systems. If there were any abnormalities in the data control, the measurement values first had to be used to determine whether there were sensor defects, malfunctions, setpoint adjustments by the operator or changes to the regulations by the manufacturer. Due to multiple occurrences and the time until the causes have been remedied, the measurement data show undesirable effects or operating modes over longer periods. These periods can only be used to a limited extent for a representative evaluation.

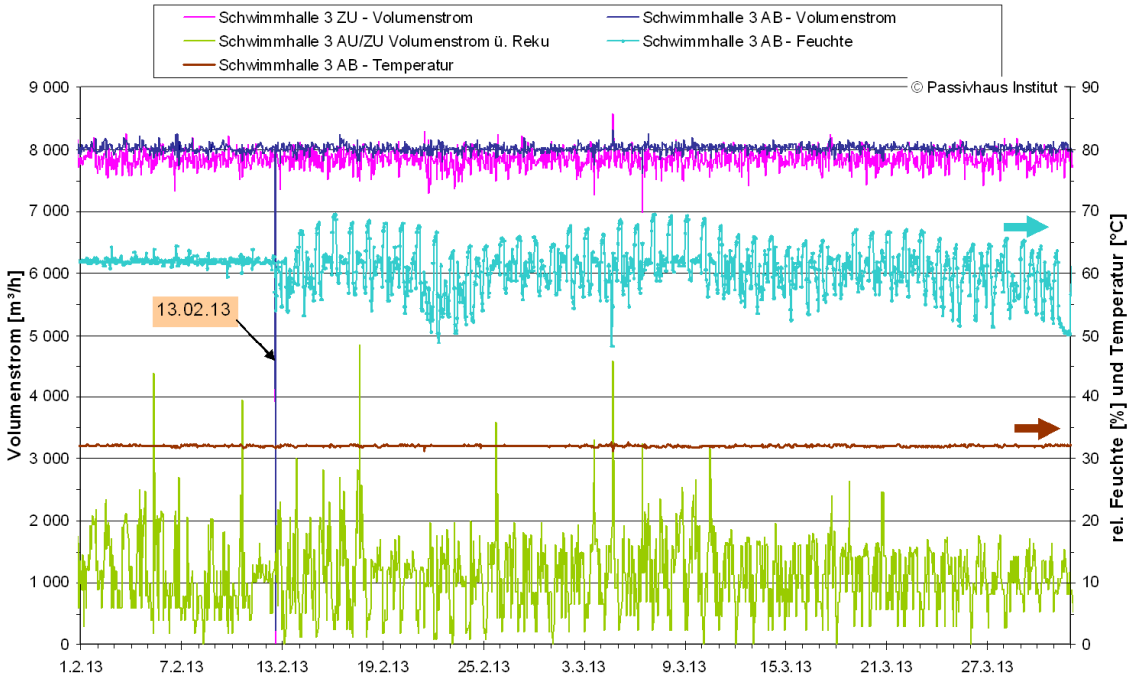

Figure 67: Effects on the hall humidity by changing the control behavior (Activation day / night operation) from ventilation unit hall 3 on February 13th, 2013 (hourly data from February 1st to March 31st, 2013).

Figure 67 shows the effects of an intervention on February 13, 2013 by the manufacturer. By adapting the control parameters and simultaneously activating a different day / night driving style (setpoint

default) there is a clear day / night fluctuation of the hall humidity of over 10% which could only be explained after some research.

4.5.8 Air speed above the water surface

It is of interest whether the change in the supply air volume flow has a significant influence on the air speed above the water surface. This could have an impact on the evaporation of the pool water. For this reason, air velocity measurements above the water surface of pools 1 + 2 were carried out on December 5th, 2012 with the two different circulating air volume flows.

Four measuring points 35 cm above the water surface near the pool edge were chosen. The measurement positions and the supply and exhaust air positions are entered in the sketch (Figure 68). The positions differ due to different influences of the supply and exhaust air openings.

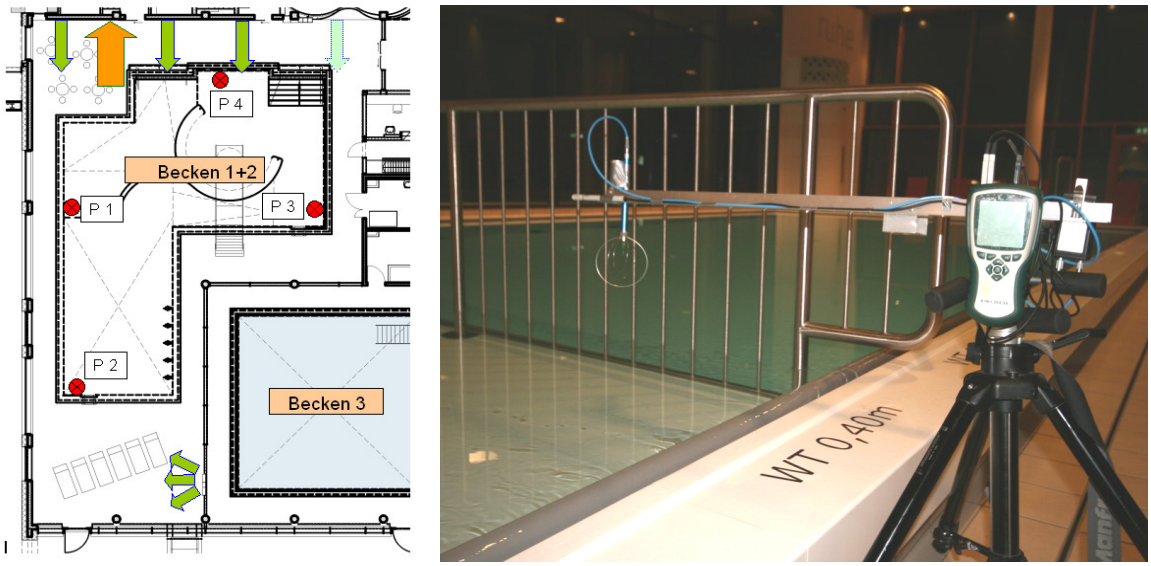

Figure 68: Left: The four measuring positions P1 to P4 above the water surface of Beck en 1 + 2. The supply air positions are marked with the green arrows and the extract air position is marked with the orange arrow. Right: Photo of measurement position P1.

At times the pool was still used during the measurements. The use has resulted in disturbances in the measurements. Therefore, only the measurement data were used for which there was no use of the pool.

The evaluation of the air speed measurement above the water surface of pools 1 + 2 at the four different positions shows that:

- the difference between reduced and full ventilation volume flow above the water surface is hardly measurable,

- Too many disturbances existed during the measurement for statements on the degree of turbulence according to EN ISO 7730.

In this way, it could not be determined whether the differences in the mean flow velocity had a relevant impact on water evaporation.

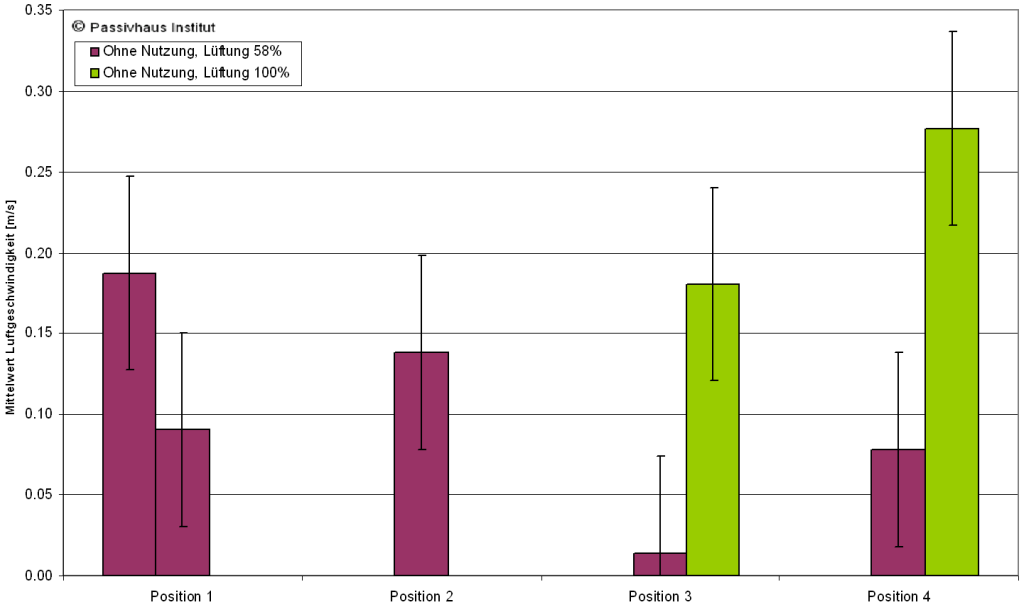

Figure 69: Air velocities at 35 cm above the water surface of basin 1 + 2

four measuring positions with different supply / exhaust air volume flow. At position 1 two measurements with 58% ventilation volume flow could be evaluated. The measurement deviations are also entered in the diagram.

4.6 Series of tests and changed operating conditions

The effects of the different indoor humidity, circulating air and outside air volume flows on the energy consumption were examined within the scope of the monitoring to support the approaches of the passive house swimming pool basic study [Schulz et al. 2009] to be checked. For this purpose, various variations of these parameters were carried out and the effects examined. The following table shows some exemplary changes to the operating parameters:

Table 7: Extract from the plan for the test series for changing the mode of operation the setpoints or the hall ventilation devices

#	begin	The End	activities	Halle n				
				1 + 2	3	4	5	
1	05.12.12	permanently	Humidity increased by 5%	xxxx				
2	12/19/12	permanent	Reduce air flow to / from.	x				
3	09.01.13	permanent	Humidity increase + 5% (Hall 1 + 2) or + 7% (Hall 3)	xx				

Also due to changes in the operating conditions (e.g. hall humidity) outside of this targeted examination program, there were some abrupt adjustments, which can also be examined for their effects (see also 4.5.3).

4.6.1 Variation of the hall humidity

The ventilation units are controlled according to the setpoint value for the room air humidity. Lower indoor humidity levels require higher outdoor air changes to dry the air, which results in higher heat consumption - caused by ventilation heat losses. On September 18, 2012 - as already mentioned - the hall humidity in three halls was significantly reduced (approx. -15% points or 4.4 g / kg), which led to a considerable increase in heat consumption. The lowering of the relative and absolute humidity with the same temperature level is shown in the left part of Figure 70 as an example for Hall 5. In the right part of the figure, the increase in heat consumption due to moisture reduction is shown using the measurement data from the air heating register of the three halls concerned.

The consumption in halls 4 and 5 shows significant increases in heating. In hall 1 + 2, the heating coil had not been used for reheating because the heat pump of the device was sufficient for heating. As a result of the change, post-heating via the heating register is now also necessary in this hall. The additional consumption by reducing the humidity of the three halls is approximately plus 410 kWh / day. The heat inputs from the heat pump are still there Not considered,

since at that time no separate current measurement of the WP was active. This confirms the theoretical approaches from the basic study [Schulz et al. 2009].

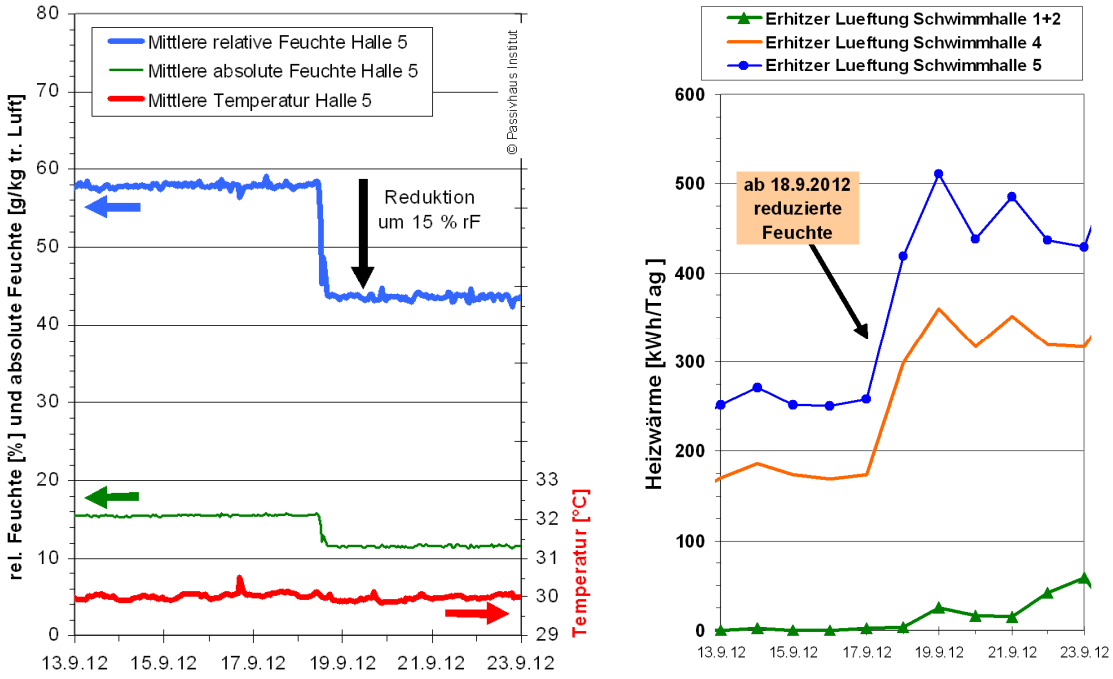

Figure 70: Change in hall humidity on September 18, 2012 (example on the left for Hall 5 shown). Right: Effects of changes in hall humidity on the heating energy consumption of the ventilation units in three halls (daily values; 13th to 09/22/2012).

With the lower hall humidity, a higher outside / exhaust air flow is necessary for the higher removal of the moisture loads from the halls. The increase in the outside air volume flow with constant supply / exhaust air volume flow at the time of the moisture reduction on September 18, 2012 is shown in Figure 71. Since this volume flow is routed through the heat recovery of the ventilation unit, the pressure loss and thus the power consumption of the unit inevitably increases. As already mentioned above, the heat pump must be taken into account for units 1 + 2: If the heating energy required to heat the larger volume of outside air increases, the heat pump is operated longer or more intensively; this increases your electricity consumption. These two effects increase the electricity consumption of the three ventilation units by 94 kWh / day.

This makes it clear that reducing the hall humidity has two energy effects: heating energy consumption and electricity consumption increase significantly. In total, these changes will cause an increase in consumption of 410 kWh / day + 94 kWh / day = 504 kWh / day in the three halls in September 2012.

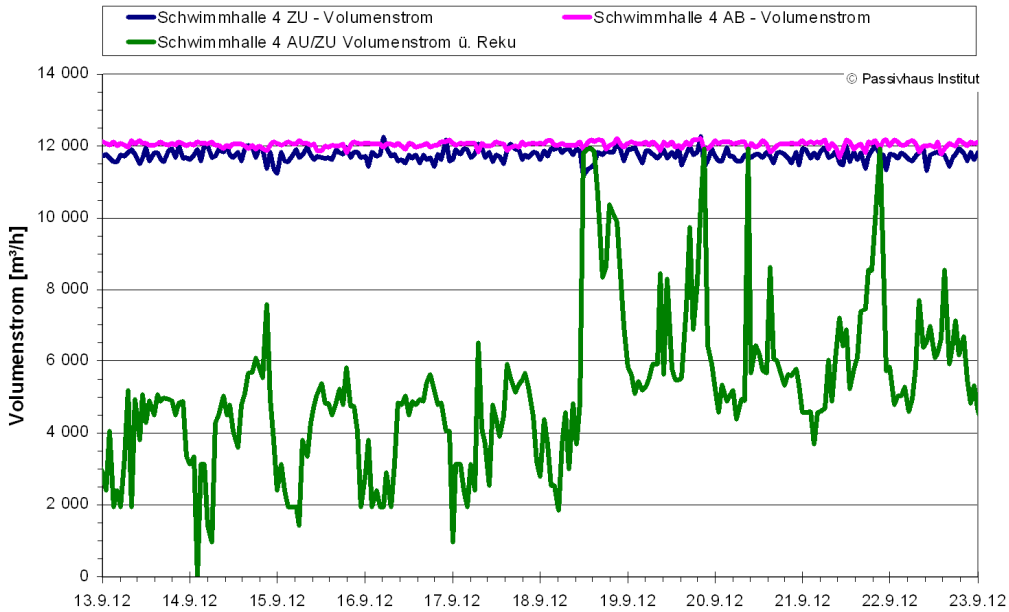

Figure 71: Increasing the outside air volume flow by reducing the hall humidity on September 18, 2012 in Hall 4 (hourly values; September 13 to 22, 2012).

The reduced evaporation of the pool water at higher indoor humidity can also be read directly from the measurement data. The dehumidification performance can be calculated from the temperature and humidity measurements of the supply and exhaust air volume flows in a hall. This corresponds approximately to the water evaporated in the hall per unit of time (see section 5.1.1.1). Figure 72 shows these values together with the relative hall humidity as an example from hall 4. This is also the period of the moisture reduction around September 18, 2012. At the higher humidity, 30.7 kg / h of water were removed on average, at the lower humidity (minus 13.3% RH), it was 41.1 kg / h. For this higher amount of evaporation, increased heat losses occur due to the required evaporation enthalpy, which increases the heating energy consumption.

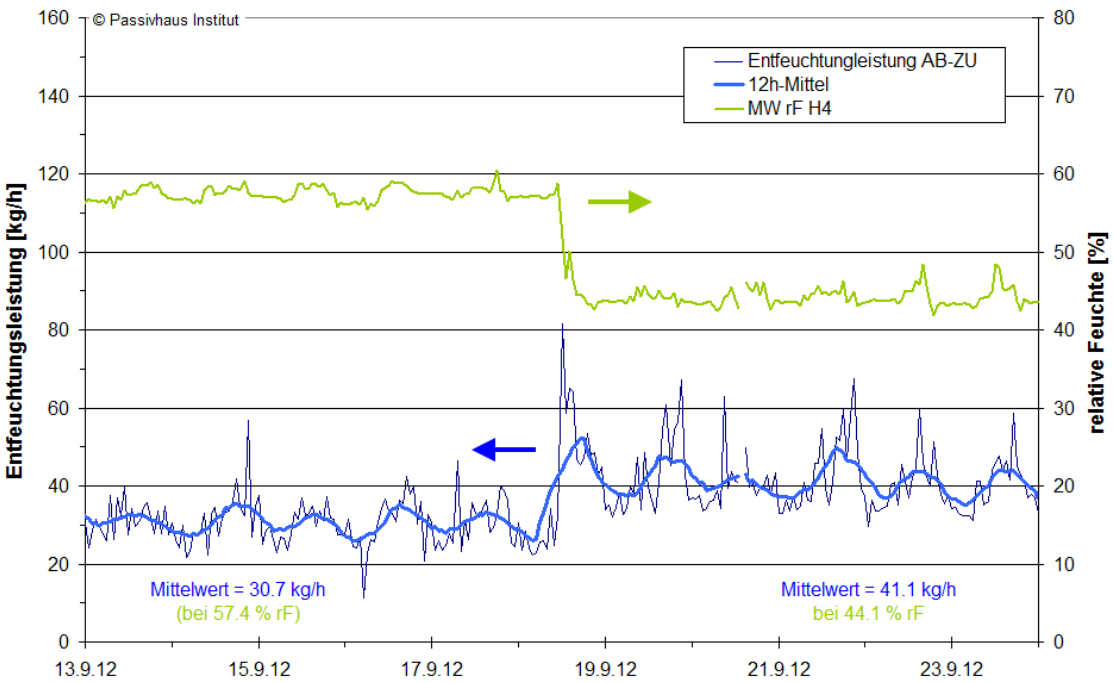

Figure 72: Dehumidification performance (calculated from the difference between the supply and extract air humidity) as well as relative hall humidity in hall 4 (hourly values, September 13 to 23, 2012)

4.6.1.1 Increase in humidity on January 9, 2013

As part of the test series, the target values for the hall humidity were raised in Hall 1 + 2 and 3 on January 9, 2013. The effects are evaluated here to secure the energetic changes calculated above.

In Hall 3, the humidity was raised from an average of 48% to 55.5%, i.e. by 7.5%. The outside temperature averaged 5.3 ° C on January 9, 2013, and an average of 4.1 ° C from January 6 to January 12, 2013. The heat consumption has been reduced by 21.4 kWh / day due to the increase in humidity. The power consumption drops as described above - due to the lower proportion of outside air required, it also drops. With this increase in humidity, 6.3 kWh / day was saved in electricity consumption. In total, this saves 21.4 kWh / day + 6.3 kWh / day = 27.7 kWh / day of final energy in this smallest hall.

As expected, the same effects are observed as in the example of the three other halls explained above.

4.6.2 Reduction of the supply air volume

With the reduction of the supply air / exhaust air volume flow in hall 1 + 2 already described in figure 66 (section 4.5.6), the effect on the power consumption of the ventilation unit can be examined. The fog test to visualize the indoor air flow on December 5, 2012 found that too

with significantly reduced supply air volume flow (with the same humidity) in the hall no problems with the flow occurred (see section 4.5.5). For this reason, on December 19, 2012 in Hall 1 + 2, the air volume was reduced from the design according to VDI 2089 with approx. 14,500 to only approx. 8,500 m³ / h (by 41%). The outside air volume flow must remain unchanged for reasons of air quality, but this did not actually happen (see the explanations in 4.5.6). This measure alone reduced the electricity consumption of the ventilation unit by around 74 kWh / day (corresponds to 63%) (Figure 73). This corresponds to a saving of 2200 kWh per month through this change in just one hall. These measurement data confirm the considerations of the previous investigations, that through clever ventilation planning and the reduction in the proportion of recirculated air that this enables, considerable energy savings can be achieved. The prerequisite is always that the minimum outside air volume flow is not undercut and that there can be no restriction of the air quality.

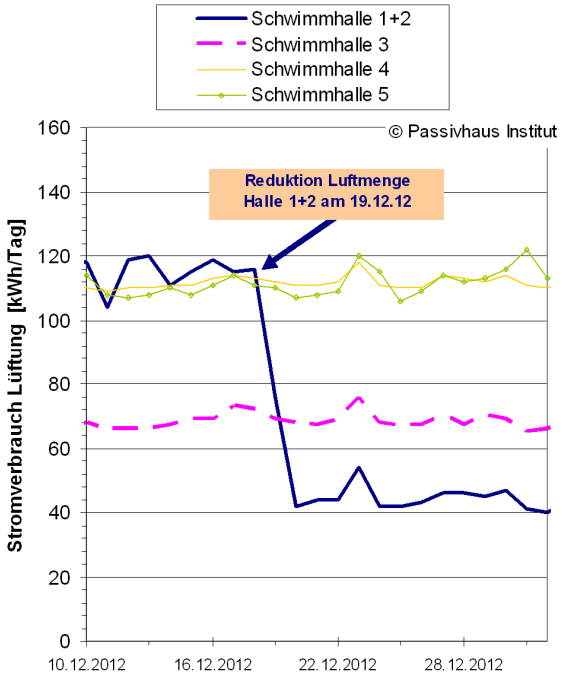

Figure 73: Effects of changes in the supply / exhaust air volume flow from December 19, 2012 on the power consumption of the ventilation unit in halls 1 + 2 (daily values; 13th to 09/22/2012). The power consumption of the other devices remains unchanged.

4.7 Water consumption

The fresh water consumption of the bath is measured separately for the largest consumption areas or can be calculated as difference values from the meter readings of the sub-meters. Commercial water meters are used. The diagram below shows the schematic arrangement of the supply lines with the water meters:

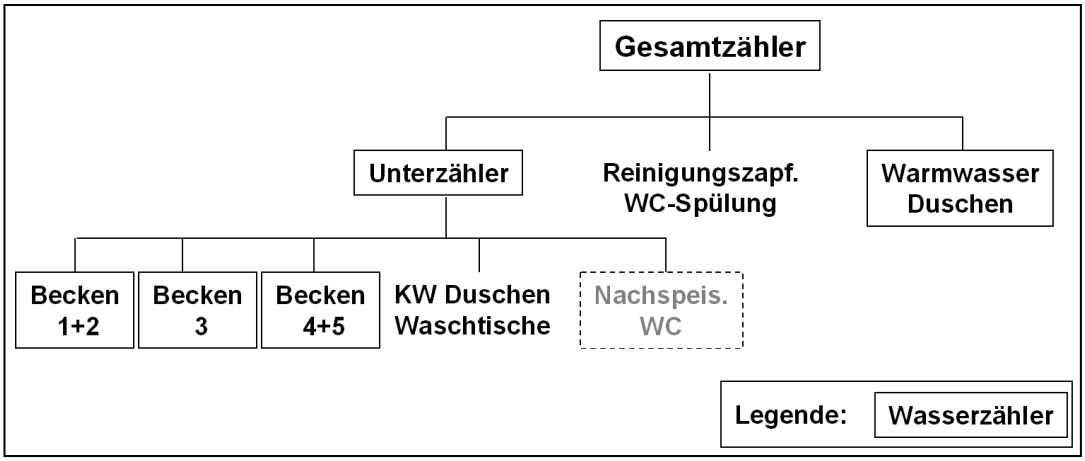

Figure 74: Arrangement of the water meters without the water treatment area.

Consumption areas without a meter (without a frame in the sketch) are calculated as difference values. The "make-up toilet" is only required if the wastewater treatment is in operation and the gray water for the toilets is not sufficient (only up to March 2012).

The indoor pool is open monthly in operating months between **2,093 and 3,107 m³**
Fresh water required (535 to 794 liters / (m² EBF Month)). This corresponds to average daily consumption between **72 to 104 m³ / day.** The largest amounts of water are discarded in the basin circuits during filter backwashing and must then be replaced with fresh water. About 70% of the backwashing water should actually be treated and reused. Since the entire treatment plant is currently not in operation, the backwashing water has had to be completely replaced with fresh water since February 2012. The plant is to be put back into operation in the near future. This not only saves a significant amount of fresh water, but also significantly reduces the energy required to heat water. Further explanations can be found in section 5.2.

Figure 75 shows that in August 2012 - due to the refilling of the pools - the highest consumption value of 3,168 m³ was reached. Filling was carried out by the "cleaning taps + toilet flushing" section and not by the usual fresh water replenishment of the three basin circuits.

It can be clearly seen that the retrofitting and enlargement of the filter technology in the pool water circuits leads to a higher backwash water consumption.

have led. After the revision period, the consumption of the three pool circuits rose from a total of 1,450 m³ / month to approximately 2,200 m³ / month. The other consumption areas have remained almost unchanged.

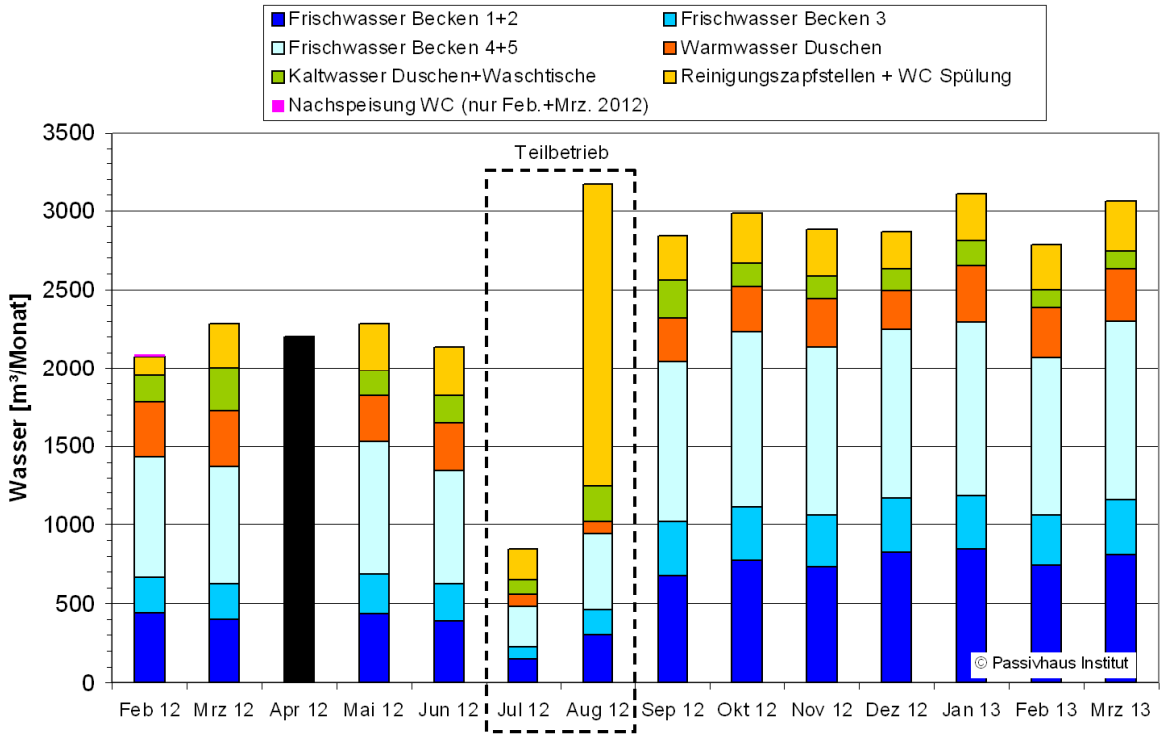

Figure 75: Monthly water consumption values of the different sub-areas from February 2012 to March 2013. In April 2012 wg. Partial failures of data collection only the total amount can be specified.

4.8 Energy consumption

The final energy consumption values, which were obtained from the building as a whole, are of interest in the overall energy assessment of the bathroom. Due to the assembly errors of the executing company and the retrofitting of some heat meters, extrapolations have to be added to the first months until May 2012 (Figure 76). Revision work was carried out during the summer bath closure (09.07. To 21.08.2012). During this time, however, energy was also needed: the ventilation systems were operated almost permanently, the water was drained completely and the pools were refilled and heated.

The specific annual consumption values of the Lippe-Bad result for the year period April 2012 up to and including March 2013 with some extrapolations in case of meter failure or conversion as well as including the period with the revision work in July / August:

Heat coverage: **258.1 kWh / (m² EBF a)**

Power consumption: **155.9 kWh / (m² EBF a)**

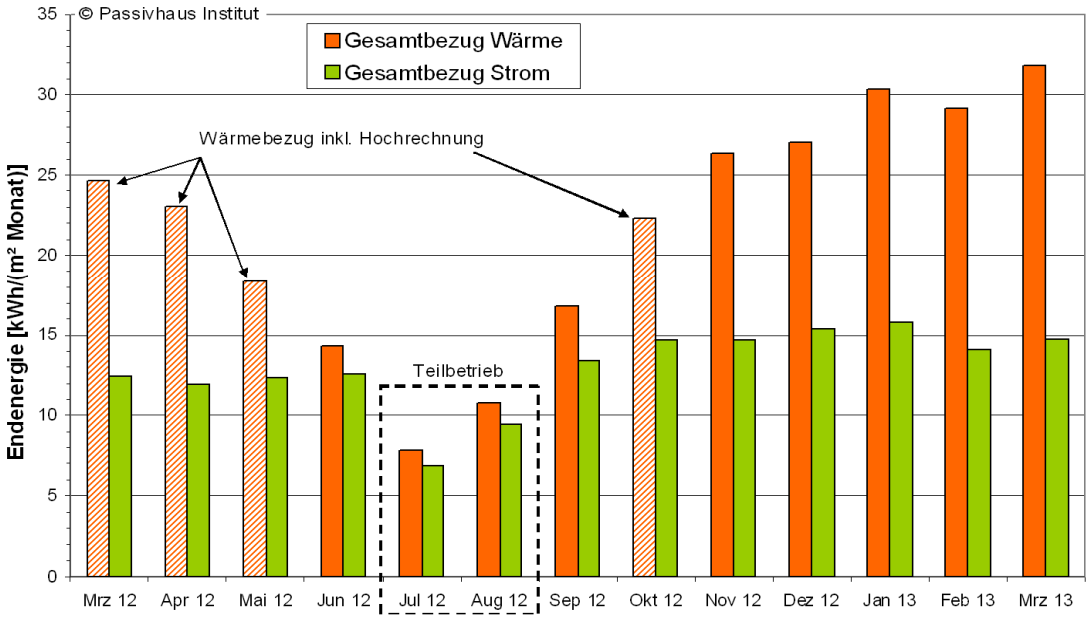

Figure 76: Total specific heat and electricity consumption (final energy) of the indoor pool from March 2012 to March 2013.

If one relates these total annual consumption values to the **Pool area** of 850 m², the following specific consumption values result:

Heat coverage: 1,189 kWh / (m² pool a)

Power consumption: 718 kWh / (m² pool a)

With the consumption values for the total consumption of heat and electricity related to the pool areas, comparisons can be made with other baths. There are only a few published measurements of other baths known to the authors that can be used for a comparison. The range of fluctuation of the few references is very large. The sources used are not individual baths, but rather mean values or ranges of very different baths [ages 2007], [DGfdB R

60.04], [Schlesiger 2001] and [VDI 2089-Blatt 2]. Not every one of these baths will be suitable for comparison individually; for example, leisure pools with slides and wellness areas are represented as well as pure sports pools. In order to get an impression of the consumption figures and to be able to make a first classification of the Lippe bath, the information from the literature was averaged and, as far as possible, its range of fluctuation (maximum and minimum value) was given (Figure

77). Even this first orientation clearly shows that the consumption values in Lünen are already below the mean values of the literature in the first year of operation: in the heating area the measured value is almost 70% below the mean literature value, for electricity it is more than 40%. The first year of operation in the Lippe-Bad was characterized by the regulation of the complex building technology. There is still further optimization potential in operation. Therefore, even lower consumption values can be expected in the future.

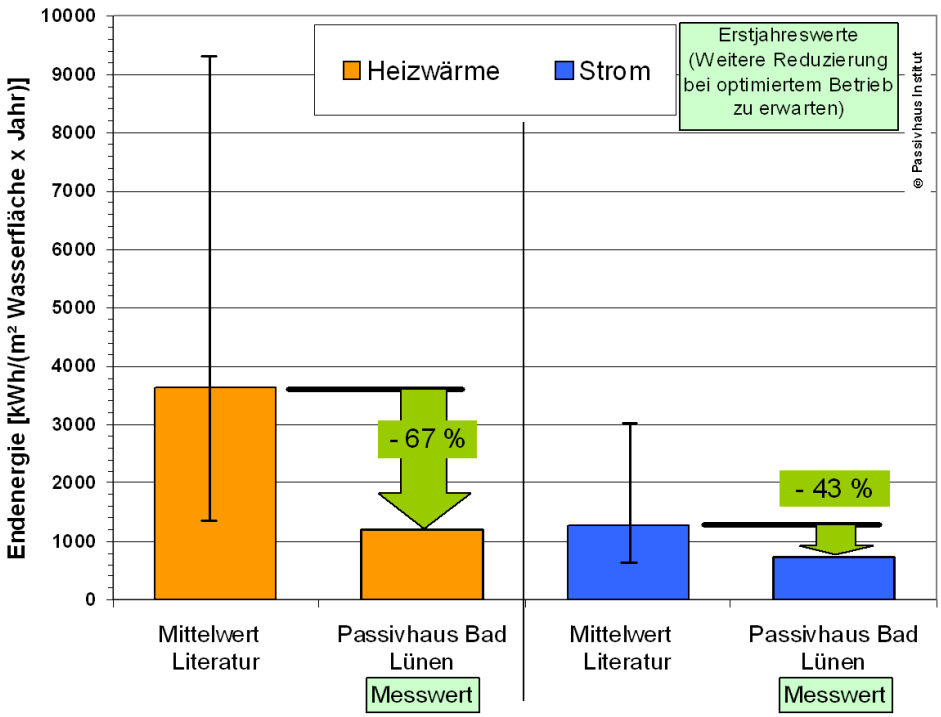

Figure 77: Comparison of the measured consumption values for the entire heat and Electricity consumption (final energy) of the Lünen indoor pool with values from the literature (see text). The range of fluctuation of the literature values is indicated by the maximum and minimum values (black vertical lines).

4.8.1 Heat delivery

The heat supply to the bath is - as described in Section 2.2 - from five different sources. Due to the arrangement of the heat meters, the areas are recorded separately. The direct supply of heat to the biogas CHP will only take place after a renovation in June 2012. The monthly totals of the five areas show the change in the amount of the different energy sources over the course of the year (Figure 78). First, the supply from the district heating network dominates, later the direct supply from the biogas CHP becomes dominant.

The exhaust gas heat exchanger of the biogas CHP plant has a significantly higher share of the supply than that of the natural gas CHP plant.

Table 8: Specific final energy quantities and proportions of heat delivery according to the various sources in the period from April 1, 2010 to March 31, 2013.

	District heating CHP	Exhaust gas heat m exchangers		HT heat CHP biogas	Housing waste heat CHPs (NT circuit)
		Biogas	CHP natural gas		
Final energy [kWh / (m²a)]	41.3	61.9	24.6	87.5	42.8
Proportion of [%]	16.0%	24.0%	9.5%	33.9%	16.6%

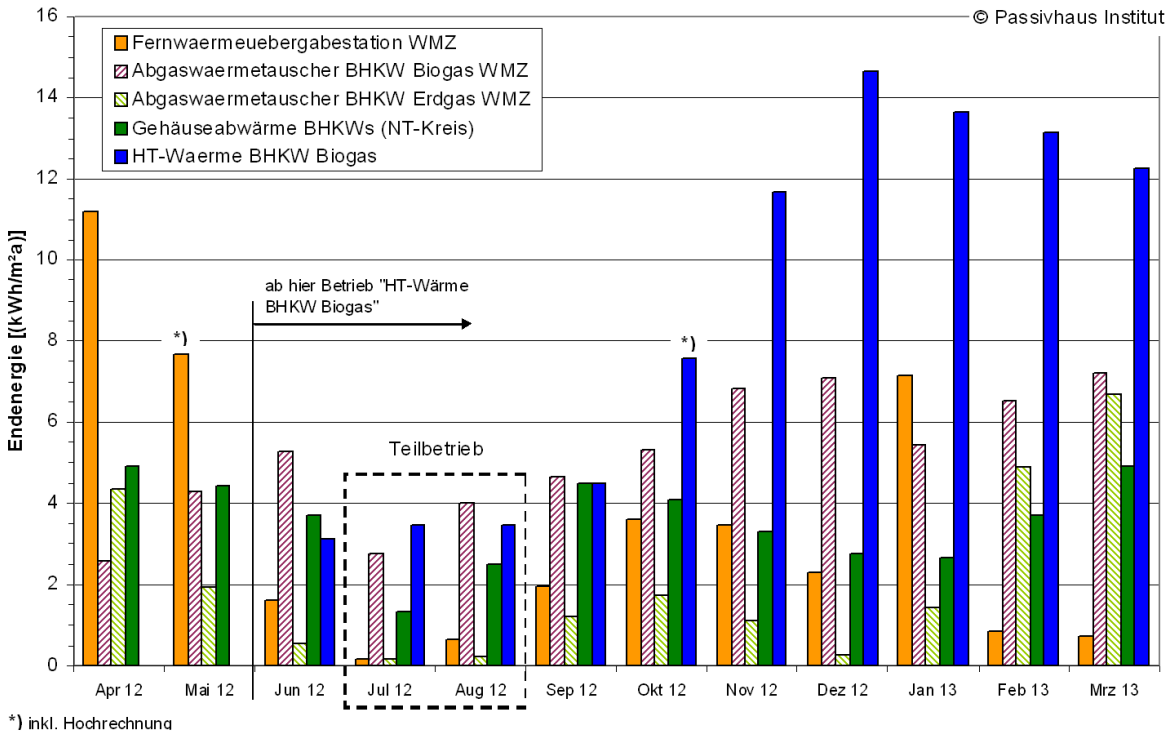

Figure 78: Heat supply from the different sources during the month of April 2012 to March 2013.

4.8.2 Heat consumption

The heat supply for the individual consumers in the indoor pool is organized by the two separate hydraulic supply networks "HT" and "NT" (see. Figure 16 in section 2.2). These two areas must be taken into account in the analysis. The monthly totals of the heat consumption values (delivery) shown in the previous section can be assigned to the different consumption areas due to the arrangement of the meters. A distinction is made between the following three areas:

- Pool water heating (123.4 kWh / (m²a))
- Post-heating ventilation (air heating) (93.7 kWh / (m²a) / including extrapolation)
- Water heating (showering / cleaning) (35.0 kWh / (m²a))

The annual total of energy consumption for air reheating in the ventilation units cannot be determined for August and September 2012, since there was a wire break on the VL sensor of the heat meter on the "adjoining rooms" device. An estimate can be made using the total amount of heat supplied by forming the difference [2nd]

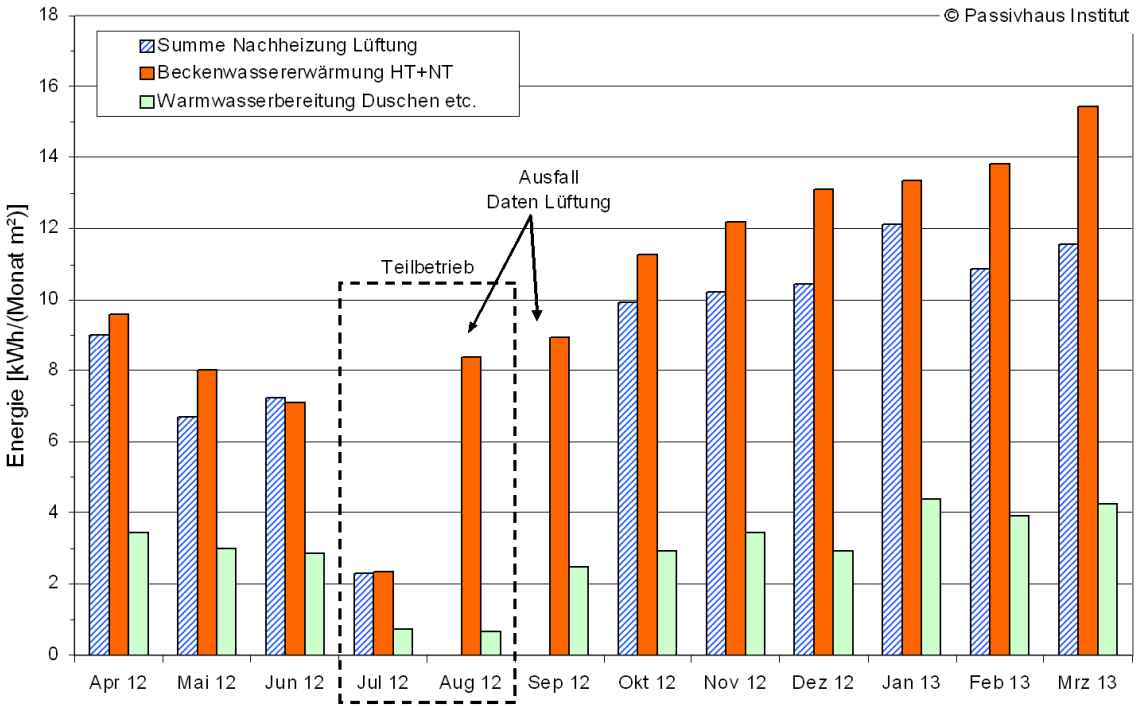

Figure 79: Distribution of heat consumption (final energy) according to the three usage ventilation, pool water and shower water (April 2012 to March 2013).

[2nd] The share of distribution losses in the heat supply compared to the total heat consumers must be taken into account. This is calculated at 2.3% in the next section.

It can be seen that pool water heating has the largest share of heat consumption. If you look at all months (April 2012 to March 2013) without August and September 2012, only the pool water heating accounts for 47% of the total of the three areas. The reheating of the air follows at a short distance with a share of 39%. In contrast, hot water heating for the domestic water (showering / cleaning) only requires 14%.

4.8.2.1 HT network balance

In the HT supply network, the difference between the heat supply to the network and the withdrawal from the network can be calculated based on the meter arrangement. This calculation is used, among other things, to check the heat meters. The correspondence between the two sizes is between 95 and 99% (calculated from daily values), the deviation for winter 2012/2013 is 2.3%. In absolute terms, this corresponds to a difference of 72 kWh / day. This amount of energy results from the measuring accuracy of the heat meters and the heat given off by the pipes to the basement.

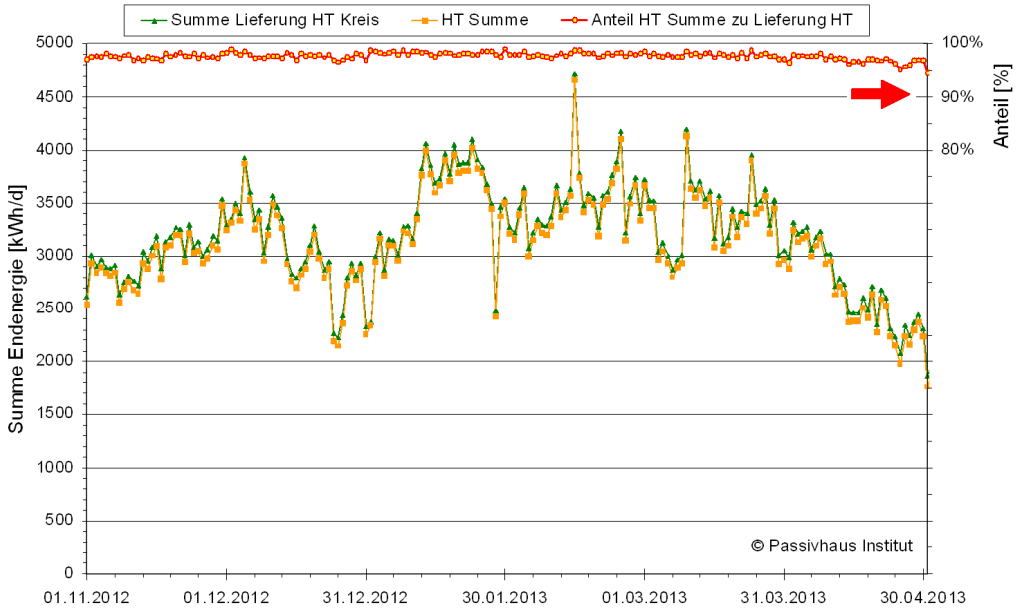

Figure 80: Comparison of the energy supply and the withdrawal of the HT network in winter Period from November 1, 2012 to April 30, 2013 (daily values)

4.8.2.2 Air heating register

Air heating is the only active heat source in the Lünen indoor pool; there was no need for underfloor heating and heating benches. All six ventilation units are equipped with air heating registers for reheating the air. As described, two additional reheaters are installed for reheating the air from the changing area before blowing into the two shower areas. The monthly energy amounts of these eight air

Water registers are shown in Figure 81. Due to the failure of individual heat meters, the data are presented from October 2012.

The first thing that catches the eye is the very high consumption for the reheating of Hall 5 in December 2012 and January 2013. At the same time, the consumption of Hall 4 is correspondingly lower. The reason is an incorrectly changed regulation of the two ventilation systems. As it turned out, the device for hall 5 was operated as the main device for post-heating at this time, the heating register of device 4 was only switched on in addition. The air connection between the two halls had no impact on the hall conditions. The consumption values for the adjoining rooms in October and November 2012 were significantly too high due to control errors.

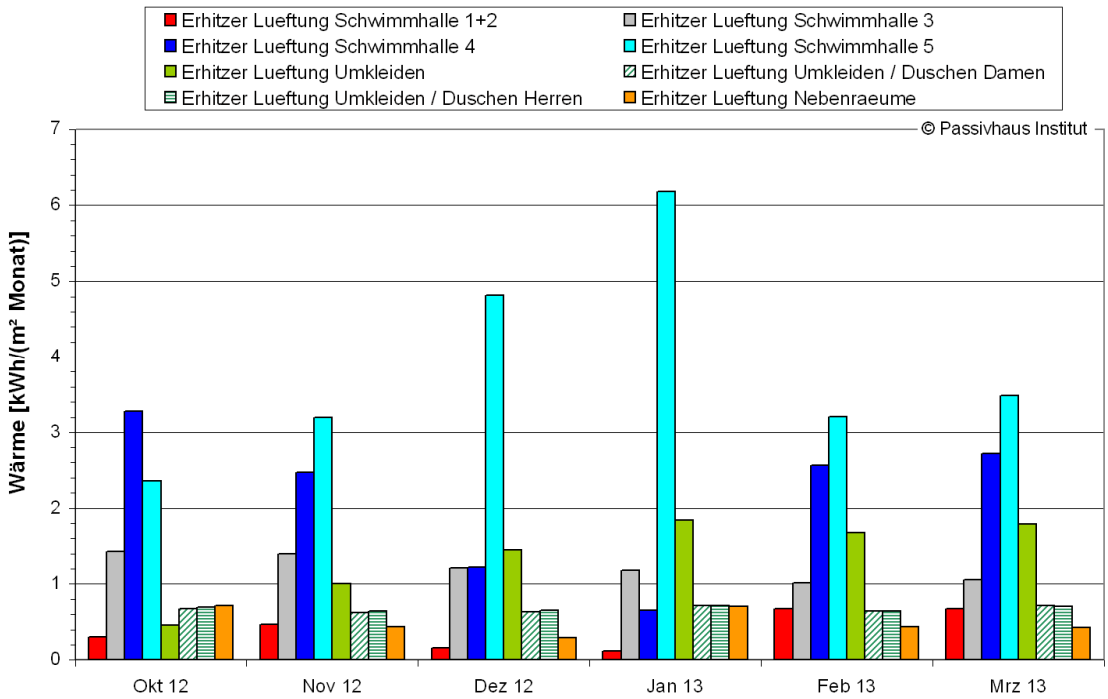

Figure 81: Energy consumption for the air heating register of the ventilation units (monthly totals from October 2012 to March 2013. See text for explanations.

As expected, the heating consumption of the four halls is dominant compared to the lower temperature areas adjacent rooms and changing rooms. The apparently low consumption for heating Hall 1 + 2 is caused by the heat pump's heat input. In the overall balance of the bath, the electricity consumption of the WP is fully taken into account on the electricity side. As in section

4.8.3.1 executed later, the heat input from the operation of the heat pump can be estimated at an average of 220 kWh / day (January 1 to March 30, 2013). Looking at the totals of the individual months - again based on the total energy reference area of the bath - between January and March 2013 between 1.5 and 2.1 kWh / (m² month) heat for hall 1 + 2 must be taken into account

will. The heat consumption values in Hall 1 + 2 thus increase in total from January to March 2013 to values of 2.2 and 2.3 kWh / (m²a). As expected, they are higher than in the smaller hall 3 and slightly lower than in the significantly larger, but somewhat less heated, halls 4 and 5.

Due to the limited period and the adjustment phase, no annual totals can be given. In February and March 2013, post-heating in halls 4 and 5 was correctly set again. If the heat consumption of the halls including the heat input of the heat pump is considered during this time, the following distribution results:

Table 9: Specific final energy quantities and proportions of heat delivery for the air heating Register of the different zones for February and March 2013. In contrast to Figure 81, the heat input by the heat pump is listed separately here. Here too, the reference area is the energy reference area of 3912 m².

Heat	Hall 1 + 2 Air heating register	Hall 1 + 2 Heat pump	Hall 3	Hall 4	Hall 5	Changing rooms	showers	rooms
[kWh / m²] for two months	1.35	3.10	2.07	5.29	6.70	3.46	2.70	0.87
Proportion of [%]	5.3	12.1	8.1	20.7	26.2	13.6	10.6	3.4

From the table, the total heat consumption of all four halls is 72.4% compared to the remaining areas of the bathroom with 27.6%. This means that more than 2/3 of the heating energy of the bathroom was needed for the hall areas in February and March 2013. It can also be seen that the heat input from the heat pump covers the majority of the heating consumption in Hall 1 + 2.

4.8.2.3 Pool and shower water heating

Differentiation of the pool water heating is done by the three HT and the three NT heat meters of the pool water heat exchanger. These are considered here in total for each cycle. In addition, the energy consumption for the hot water preparation of the showers (including cleaning taps) is balanced.

The heat consumption for pools 1 + 2 with its water content of only 230 m³ is clearly dominant. The common cycle for pools 4 and 5 with a total pool volume of 1,231 m³ is significantly lower in consumption. Pool 3 (240 m³) has the lowest heat consumption.

For the assessment of the consumption values, it must be taken into account that the following influencing factors in particular influence heat consumption: water temperature, water quantity, evaporation depending on the hall humidity and temperature as well as the heat sources in the water (people) or in the water cycle (pumps, underwater lighting). The attempt to take into account these different influences and thus the analysis of the consumption values shown is carried out in detail below in section 5.1.1.

The annual totals of the specific consumption values for heating the three pool circuits and warming the shower water are included here, including the revision time in summer. Table 10 shows the sums and the proportions.

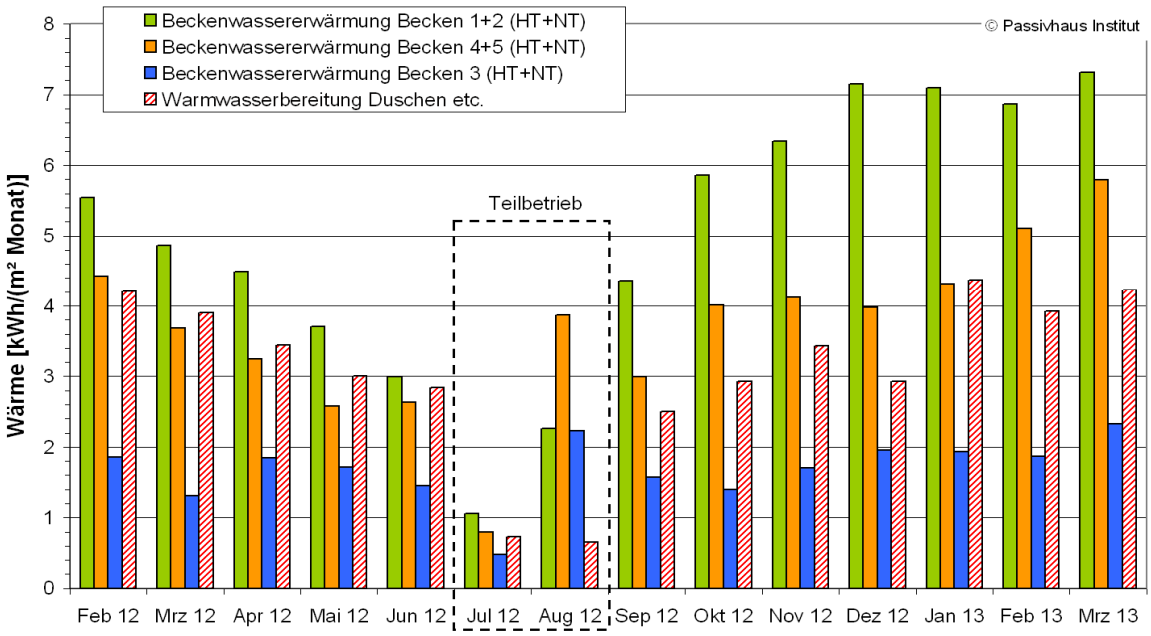

Figure 82: Monthly amounts of heat for pool and shower water heating from February 2012 to March 2013

Table 10: Specific annual final energy quantities and shares in heat consumption for the Pool water heating and hot water preparation (showers etc.) for the period from April 2012 to March 2013. Here too, the reference area is the energy reference area of 3912 m².

	Basin 1 + 2	pool 3rd	Basin 4 + 5	Hot water showers
Heat consumption [kWh / (m²a)]	59.5	20.5	43.5	35.0
proportion of	37.6% 12.9%	27.4%		22.1%
proportion of	77.9%			22.1%

4.8.3 Power consumption

As described above, the power supply to the bath is ensured by grid connection and solar power. The two additional PV trackers installed outdoors only deliver to the public power grid.

Figure 83 shows the specific monthly electricity consumption values. The monthly values fluctuate in months with full bath operation between just under 12 and almost 16 kWh / (m²a). This corresponds to absolute consumption values between 46,575 and 61,808 kWh / month.

The annual electricity consumption (April 2012 to March 2013) of the entire bath adds up to a total of 155.9 kWh / (m²a), corresponding to an absolute 609,873 kWh / a. In the same period, 18.6 kWh / (m²a) of self-used PV electricity;
1.2 kWh / (m²a) solar electricity was fed into the public grid. The trackers fed in 19,459 kWh / a (based on the energy reference area this corresponds to 5.0 kWh / (m²a)).

The monthly change in PV electricity yield shows the expected low solar power yield in winter ("winter break") and the maximum summer solar power production. The solar power production of the PV system and the tracker is shown separately in Figure 84. The annual totals of electricity consumption and feed-in are shown in Figure 85.

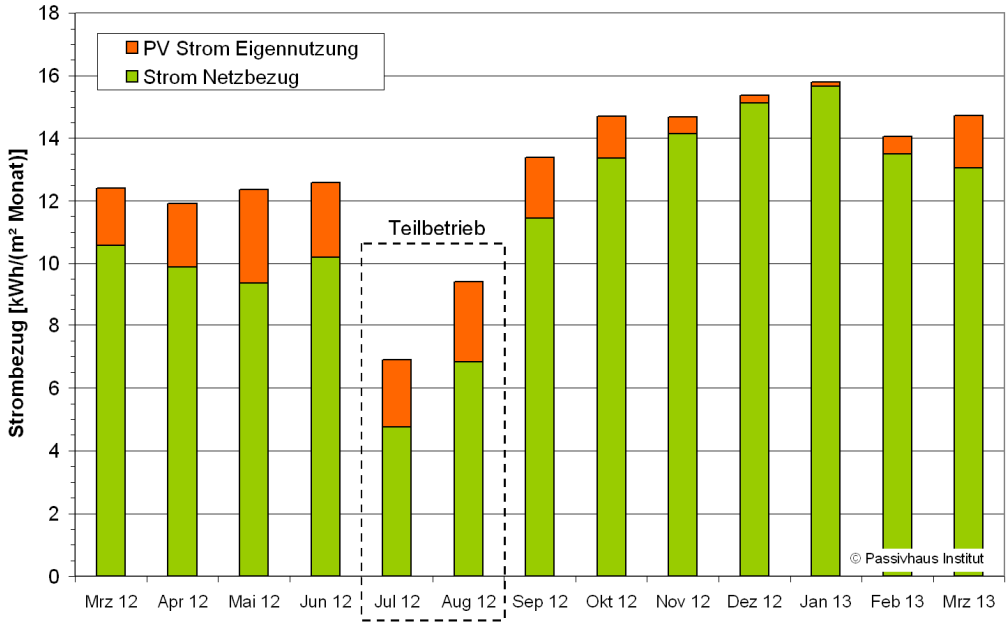

Figure 83: Monthly specific total electricity consumption of the bath from March 2012 to March 2013 according to the origin of electricity (grid and PV)

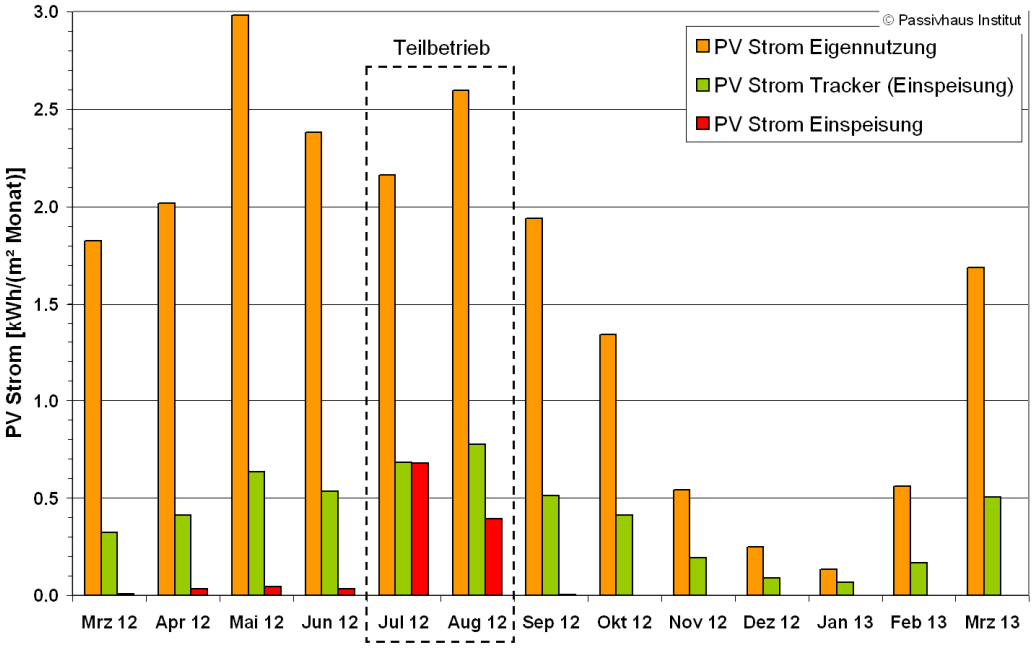

Figure 84: Specific monthly solar power yields broken down by source and Own use or feed-in

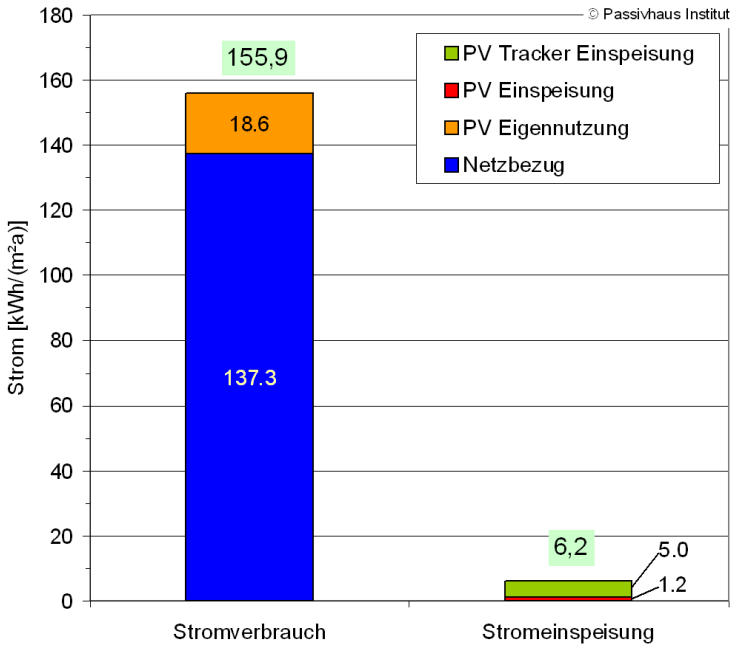

Figure 85: Annual totals of the specific electricity consumption and the feed-in

4.8.3.1 Electricity consumption by sub-area

The individually measured sub-areas of the power consumption measurement are explained above in section 3.4; they are evaluated here.

The data recording of the "Light + sockets" section was only completed in September 2012 (connection to the BMS). Therefore, the measured values for this consumption range from April to June 2012 are supplemented with the mean values of the operating time (Sep. 2012 to March 2013) (Figure 86). Half of the consumption value was assumed during the partial operating hours in July and August 2012.

Due to the changes in the water technology (filter enlargement etc.) as well as in the operation of some ventilation systems, there are significant changes for these sub-areas: The "Diverse" area (swimming pool technology (without circulation pumps) and all other consumers of the bath) grows after the revision period until January clearly; ventilation consumption drops significantly. Due to the changes in the flow rate and the additions or conversions in the water circuits, the electricity used for the circulation pumps of the water circuits also increases significantly, from an average of 2.5 kWh / (m² month)

4.2 kWh / (m² month) after the summer closing.

The lighting has a decisive share in the power consumption for "light + sockets". Only a few sockets are included, which are used for cleaning devices, the lighting control and two clocks and door controls. The potential of the lighting control cannot be exploited in connection with the illuminants used. In part, the lighting

switched manually. The consumption data therefore do not show the hoped-for reduction during the brighter summer months. Overall, there is good daylight utilization during on-site appointments: Hall lighting is not necessary for many hours. The opening times of the bathroom, which are very long (6:15 a.m. to 9:45 p.m.), lead to a higher lighting requirement in comparison. Further measurements would be necessary for details.

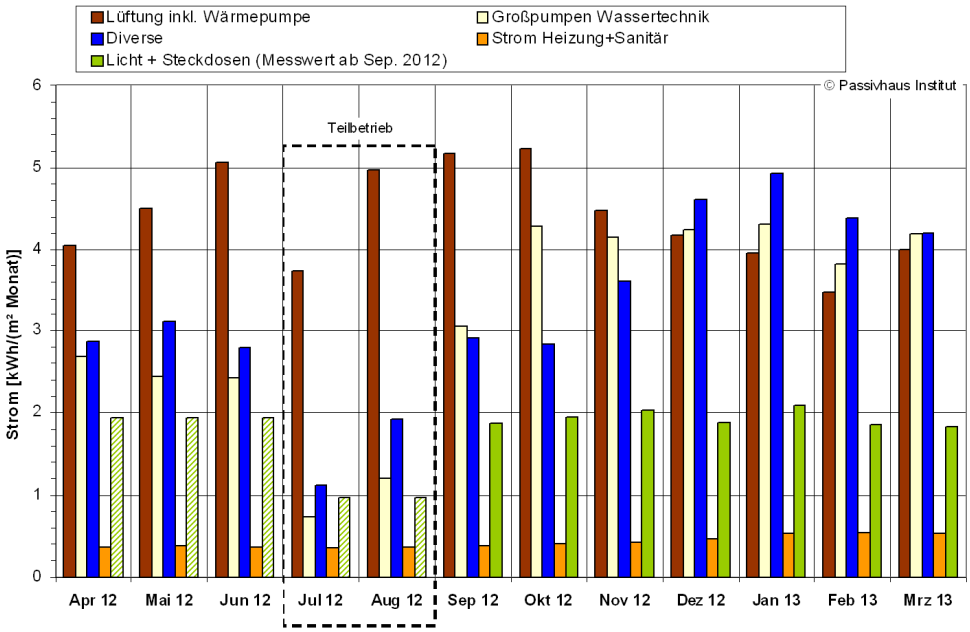

Figure 86: Monthly specific electricity consumption of the sub-areas in the indoor pool (April 2012 to March 2013)

The electricity consumption values for an entire year (April 2012 to March 2013) in Figure 87 show that ventilation technology is by far the largest main electrical consumer (34%). The circulation pumps in water technology also consume a large part of the electrical energy with 24% of the total consumption.

During the calculation from the planning period, the specialist planner for the heating / sanitary area set an expected value of 5.8 kWh / (m²a). With slightly different technology and including reduced consumption during the revision period, the measurement data show a somewhat lower value of 5.1 kWh / (m²a). In contrast, a planning value of 29.7 kWh / (m²a) was used for the six circulation pumps; in real terms, 37.6 kWh / (m²a) was used. With the additional filter technologies in the pool water circuits, the pressure loss and thus the electricity consumption has increased significantly compared to the planning. If the measured pump power consumption of the first three months were extrapolated for the whole year, the planning value would be only 29.6 kWh / (m²a) despite all changes.

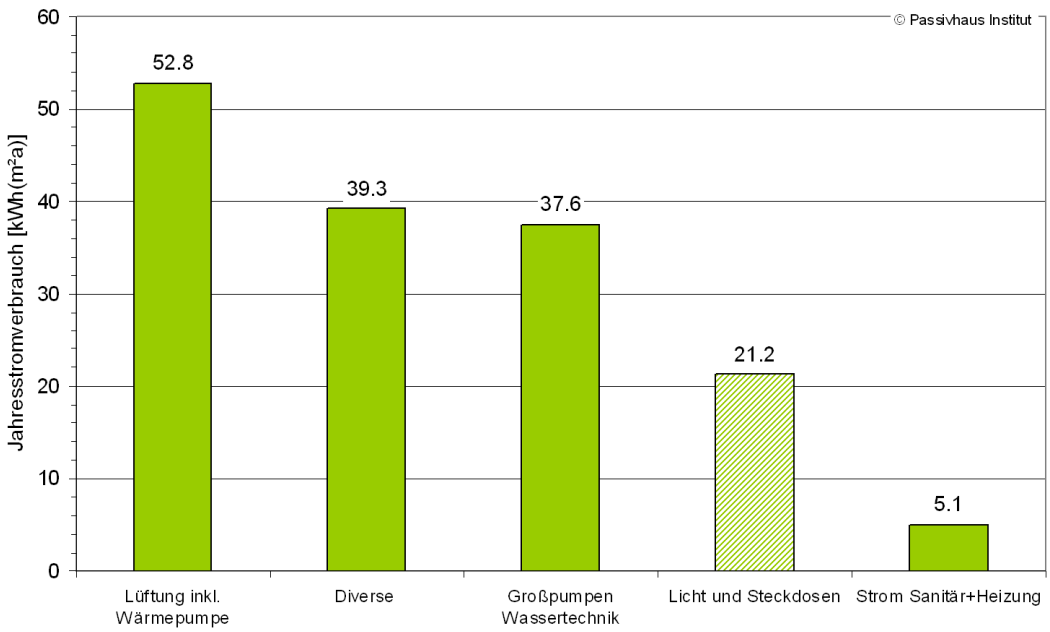

Figure 87: Specific annual electricity consumption values for the five main areas (April 2012 to March 2013). The measurement from the "Light and Sockets" area was supplemented with data for the full year calculation (see Figure 86).

ventilation

The electricity consumption of the six ventilation systems in the bathroom is measured separately for each system. A heat pump is installed in system 1 + 2, which takes energy from the exhaust air (after the heat recovery unit) and transfers it to the supply air volume flow in front of the reheater.

The electricity consumption of the systems is always related to the entire area (EBF = 3,912 m²) of the building for a uniform presentation and a better comparison.

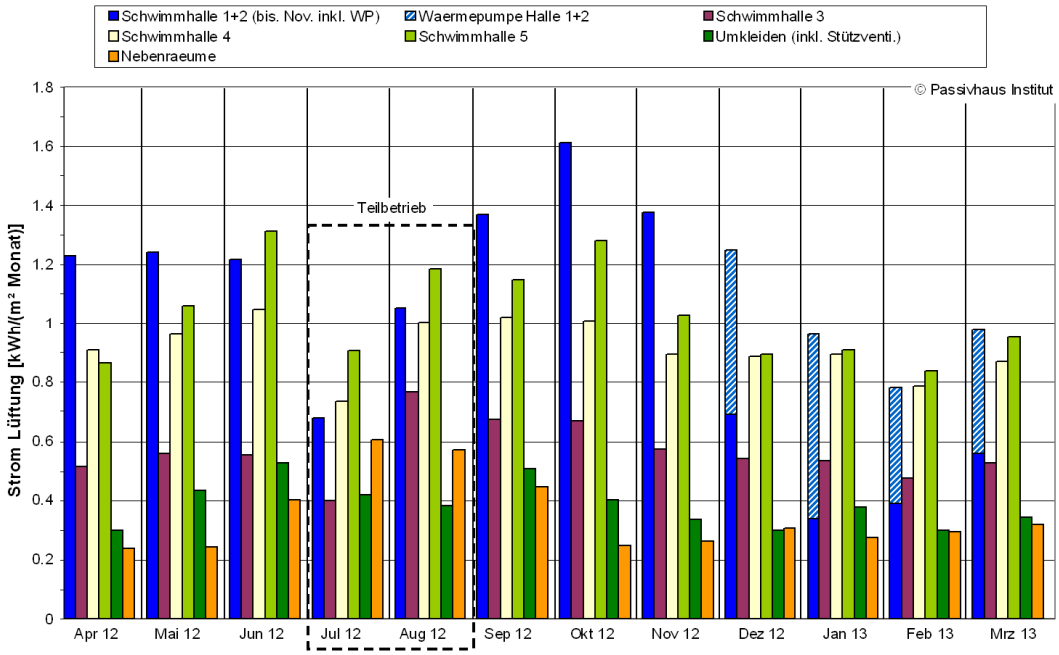

Figure 88: Monthly specific electricity consumption of all six ventilation systems (April 2012 to March 2013)

If you consider the size of the outside air volume flow compared to the circulating air volume flow as the sum of all six ventilation units in the bathroom, the following picture results:

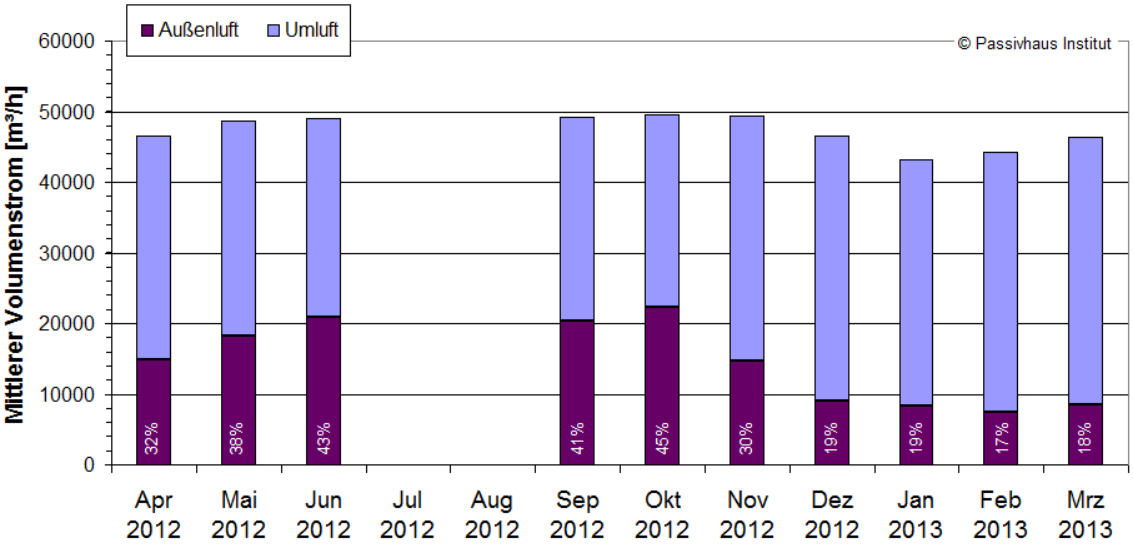

Figure 89: Sum of the measured monthly mean outside and recirculated air volume flows of all six ventilation units. The outside air share is 30% on average, the recirculated air share 70%. There is considerable electricity saving potential here.

In Figure 89 it can be seen that the circulating air volume flow of all devices in the indoor pool is on average around 70%, the outside air volume flow is only 30% of the

Total supply air volume. Only the latter is necessary for the removal of moisture from the halls and for maintaining the air quality. The circulating air volume flow, on the other hand, is neither necessary for the removal of the moisture nor for the removal of the pollutants (eg THM and trichloramine). It should ensure the mixing of the hall air, for which lower air circulation volume flows are sufficient with the corresponding ventilation systems (see evaluation of the fog tests in section

4.5.5). This shows that there is still great potential in saving electricity for the ventilation units. The objective of the passive house concept for indoor swimming pools is to operate completely without recirculating air [Schulz et al. 2009].

Heat pump

Due to the high enthalpy of the exhaust air in a swimming pool ventilation unit, the use of an exhaust air heat pump (WP) for heating the supply air or pool water has high energetic potential (cf. [Schulz et al. 2009]). With low electricity consumption, the exhaust air enthalpy can be “recovered” in this way instead of getting the required heat directly from another source. Whether a HP is energetically advantageous depends on the number of work done and the efficiency of the alternative heating system. The aim is to save primary energy by using a WP. If a heat pump reaches the working number of 5, for example, and a primary energy index of 2.6 is used for electrical power, the alternative heating system would have to have a maximum PE value of 2.6 / 5 = 0.52. That means that at eg

An exhaust air heat pump is integrated in the ventilation unit in Hall 1 + 2 in Lippe-Bad Lünen. The electricity consumption of this heat pump has been recorded separately since November 15, 2012 and has daily consumption values between 36 and 84 kWh / day. Figure 90 shows the dependence of electricity consumption on the outside temperature and the outside air volume flow. On the basis of the available measurement data, however, no reliable calculations of the heat pump's coefficient of performance have yet been able to be made, since the amount of heat generated with the HP cannot be reliably determined under the existing boundary conditions. The first rough estimates were made as part of the monitoring: For this purpose, the heat output to the supply air was calculated using the temperature difference upstream and downstream of the condenser and the measured supply air volume flow. However, since the temperature measurements are subject to uncertainties (incomplete calibration of the sensors in the ventilation unit, malfunction due to radiation from the post-heating register or the condenser, and uneven flow through the ventilation pipe, etc.), the temperature measurement had to be corrected manually in order to obtain a plausible result. The roughly estimated average number of WPs in this way (January to April 2013) is on the order of 3, whereby fluctuations in the daily average occurred between approx. 1 and 6. The expected value of an annual work of the condenser and uneven flow through the ventilation pipe etc.), the temperature measurement had to be corrected manually in order to obtain a plausible result. The roughly estimated average number of WPs in this way is around 3 on average (January to April 2013), with fluctuations in daily averages between approx. 1 and 6 due to the operating mode. The expected value of an annual work of the condenser and uneven flow through the ventilation pipe etc.), the temperature measurement had to be corrected manually in order to obtain a plausible result. The roughly estimated average number of WPs in this way (January to April 2013) is on the order of 3, whereby fluctuations in the daily average occurred between approx. 1 and 6. The expected value of an annual work

the number between 5 and 7 is clearly undercut. More detailed analyzes on the topic are still pending. Initially, test series are to be carried out in order to be able to determine the heat generation of the HP more precisely. If the previous evaluation should be confirmed, potential for improvement must be worked out and implemented in cooperation with the manufacturer so that enthalpy recovery by HP can be carried out more efficiently, both in the Lippe bath and in future projects.

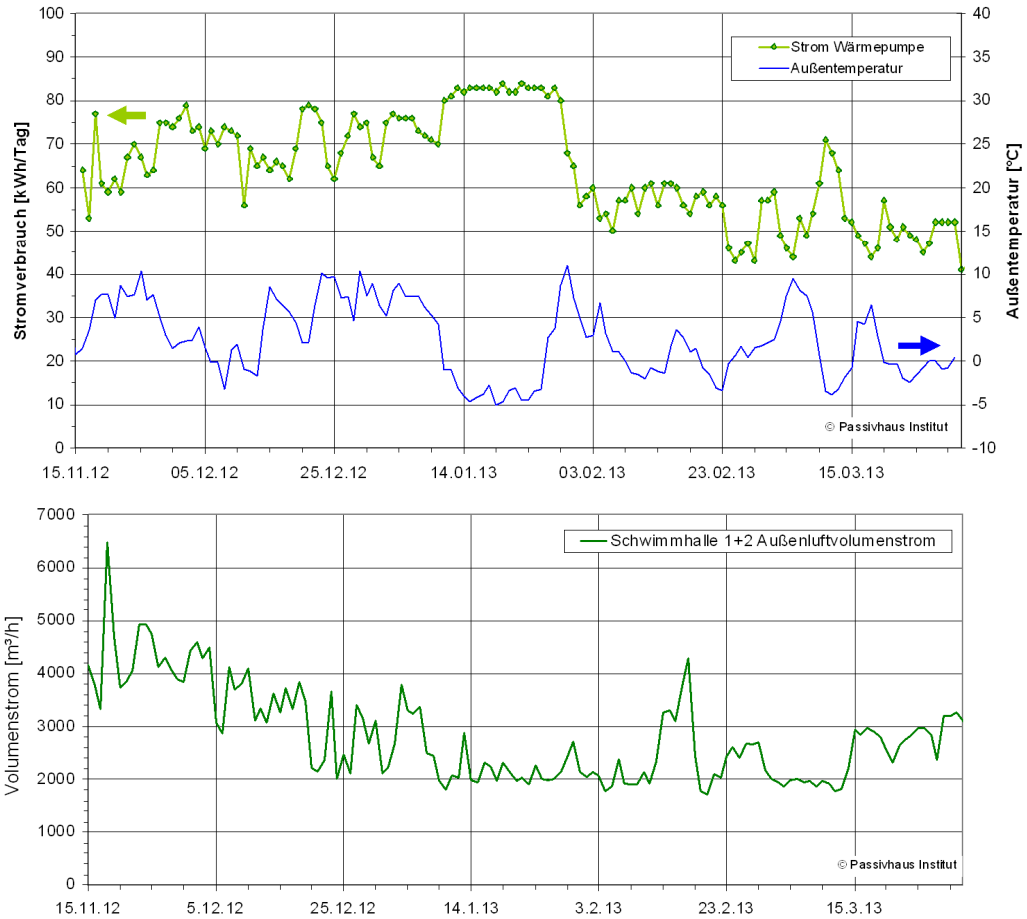

Figure 90: Power consumption of the heat pump in the ventilation unit in hall 1 + 2 and Outside air temperature and (below) the outside air volume flow of the device from November 15, 2012 to March 30, 2013 (daily values)

4.8.4 Electricity consumption and flow in pool water circuits

The six circulation pumps in the pool water circuits are operated continuously. The volume flow is only interrupted regularly for filter backwashing. The operating behavior can be read from the flow measurement of the pool water circuits and you can see when filter backwashing was carried out (Figure 91).

The electrical power consumption for these six circulation pumps is measured separately, as described. It depends on the pressure loss of the system with the pipes and different water filters as well as on the volume

electricity. With the measurement data, the specific electrical expenditure per cubic meter of water for the operation of the circuits can be calculated. Depending on the water cycle and the observation period, the results are between 0.048 and 0.070 kWh / m³ (Table 11). Due to the increased circulation rates compared to the planning with unchanged pump technology, the pumps cannot be operated at the optimal operating point. Therefore, the specific values are not optimal and would be even better if they were re-designed.

Table 11: Specific power consumption [3rd] for pool water circulation in different Periods and volume flow during normal operation (including backwash interruption)

Special power consumption c h Circulation			
[kW per m³ / h]	Basin 1 + 2 basin 3 basin 4 + 5		
03/26/2013	0.067	0.068	0.050
03/27/2013	0.068	0.066	0.051
03/28/2013	0.067	0.068	0.048
24.3. until May 1st, 2013	0.067	0.070	0.049
Volume flow at N O rmal operation (without backwash lung)			
[m³ / h]	124	54	217

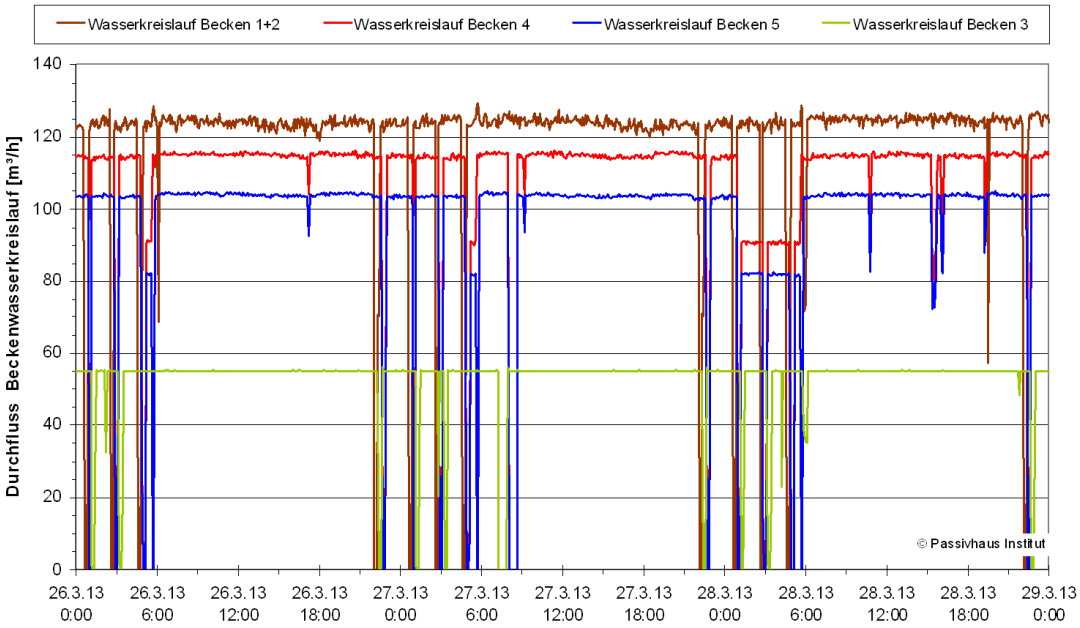

Figure 91: Flow of the 4 water circuits from March 26th to March 28th, 2013 (5 minutes Data)

[3rd] Additional granular carbon filters were retrofitted in the pool water circuits, making additional pressure booster pumps necessary. The power consumption of these booster pumps and the pumps in the bypass flow of the heat exchangers for heating the circuits could not be taken into account in the power consumption.

In order to be able to assess energy efficiency, it makes sense to relate the required energy to the service offered. The service in the field of bath water treatment is the provision of clean water for a 50 m sports pool, for example. For an assessment of energy efficiency, it is helpful to choose a suitable reference variable:

There are different ways to provide clean water. The DIN 19643 standard specifies a specific circulation volume for water purification. The pool type and size are taken into account. In addition, the filter type implemented is included in the calculation of the circulation volume by means of the so-called “k factor”. The k factor 0.5 is assigned to all filter types; the only exception is ultrafiltration (UF) with the k-factor of 1. Since the k-factor is in the denominator in the corresponding formula, only half of the circulation volume is required for the UF. The circulating quantities actually driven in the operation of a bath can deviate from these calculated values. Experience has been gained especially at the UF, which shows that the calculated circulation volume is too low. The k-factor in these systems should rather be 0, 7 than 1. The k factor is explained in the standard [DIN 19643].

In order to be able to compare the electricity consumption values of the circulation pumps of pool water circuits of different baths - regardless of the filter technology and the circulation volume flow actually driven - the PHI suggests the following: The electricity consumption for operating the circulation pumps (or also the total electricity consumption for the hygienically necessary water treatment) should always refer to the circulation volume calculated with the k-factor of 0.5. The determination is therefore quite simple: The power consumption is divided by the number of hours (measuring time) and by the circulation volume flow calculated for the pool with k = 0.5. Comparative values result in the unit kW per m³ / h.

Table 12: Specific power consumption [4th] for pool water circulation on two sample days based on the calculated circulation volume with the k-factor 0.5 in normal operation.

Specific power consumption circulation			
[kW per m³ / h]	**Basin 1 + 2 basin**	**3 basin 4 + 5**	
Reference quantity: calculated circulation volume flow with k-factor = 0.5	130 m³ / h *	75 m³ / h	290 m³ / h
03/26/2013	0.061	0.048	0.036
03/27/2013	0.062	0.046	0.035

*) Without surcharges for attractions and massage jets

[4th] See footnote # 3 on the previous page.

4.9 Final and primary energy

For the final energy assessment of the building, it is necessary to draw up a primary energy balance, ie to take into account the type of heat supply. For this purpose, the final energy requirement is weighted with primary energy factors (PE factors). The PE factors have already been defined for the previous project report [BGL 2011]; they are adopted unchanged. For clarification, a section from the report is cited below:

“There are two combined heat and power plants in the swimming pool building, one of which is operated with biogas and one with natural gas. The CHPs are part of the district heating network of the city of Lünen, for which a very low primary energy factor of 0.17 was determined due to the high proportion of renewable energies (cf. [Wibera 2010]). The bathroom draws part of the heat it needs from the district heating network.

Since there is a high demand for low-temperature heat in the bathroom, both condensation heat from the CHP plants (condensing boiler use) and waste heat from the installation room of the CHP plants can be used. This waste heat can only be used in conjunction with the bathroom. Therefore, the primary energy factor for this waste heat is set to zero. The primary energy factor for electricity is included in the regulations of the current Energy Saving Ordinance (EnEV)

2.6 accepted. "

Since the necessary electrical auxiliary energy for, for example, the pumps of the NT circuit was not taken into account in this calculation of the PE factor, the energy is accounted for in this evaluation with the total power consumption. If the total annual electricity and heat consumption is summed up, the final energy consumption of the indoor pool is 414.0 kWh / (m²a) (Figure 92). Due to the extremely favorable PE factors, the heat consumption is reduced to a minimum (21.9 kWh PE / (m²a)). The dominant is the power consumption, which is based on the final energy value

155.9 kWh End/(m²a) on primary energy 405.3 kWh PE / (m²a) increases. All of the electricity consumed in the building is accounted for - regardless of its origin. Overall, this results in a primary energy consumption of **427.2 kWh PE / (m²a)** for the indoor pool. During the planning, a primary energy requirement of 391 kWh PE / (m²a) - but without the recirculated air mode of the ventilation systems - estimated (see [BGL 2011] page 104). The approaches during planning differed in many points from the technical equipment implemented and in particular the mode of operation. Therefore, at the time of primary energy

requirement and primary energy consumption NOT directly comparable to each other. There is still potential to further reduce energy consumption by further optimizing the mode of operation (comments in the report).

The PV electricity produced on the site of the indoor swimming pool can be fully offset against the electricity consumed: The PV electricity produced on the house or property displaces conventional electricity from the grid. Not that

According to [Gemis], the renewable share of solar power is credited with a PE factor of 0.3. One way of taking primary energy into account for the electricity displaced in the grid is to calculate the creditable PE factor for the generated PV current as follows: 2.6 - 0.3 = 2.3. According to Figure 93, the total generated 24.8 kWh End/(m²a) PV electricity with primary energy

56.9 kWh PE / (m²a). This amount can be deducted from the total primary energy consumption. This is reduced to 427.2 - 56.9 =

370.3 kWh / (m²a).

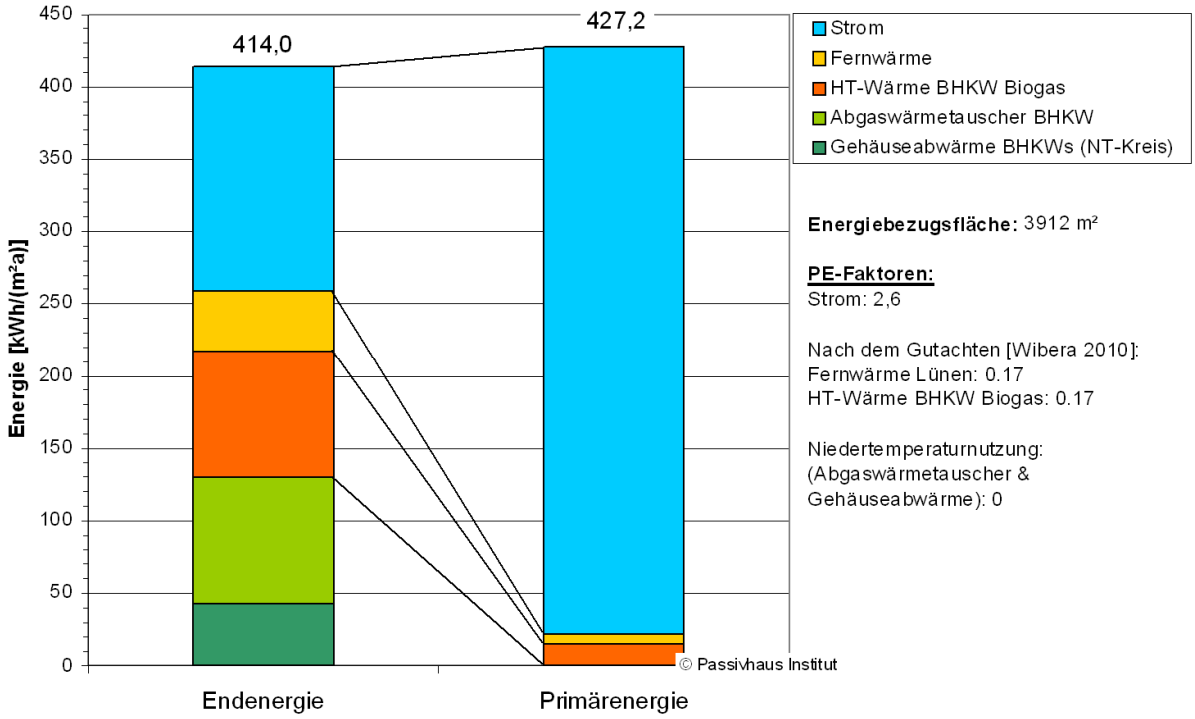

Figure 92: Final energy consumption and the primary energy consumption of all calculated from it Energy expenditure of the Lippe bath in the balance year April 2012 to March 2013. Information on the PE factors can be found in the text. The generated PV electricity is in this Consumption representation not considered.

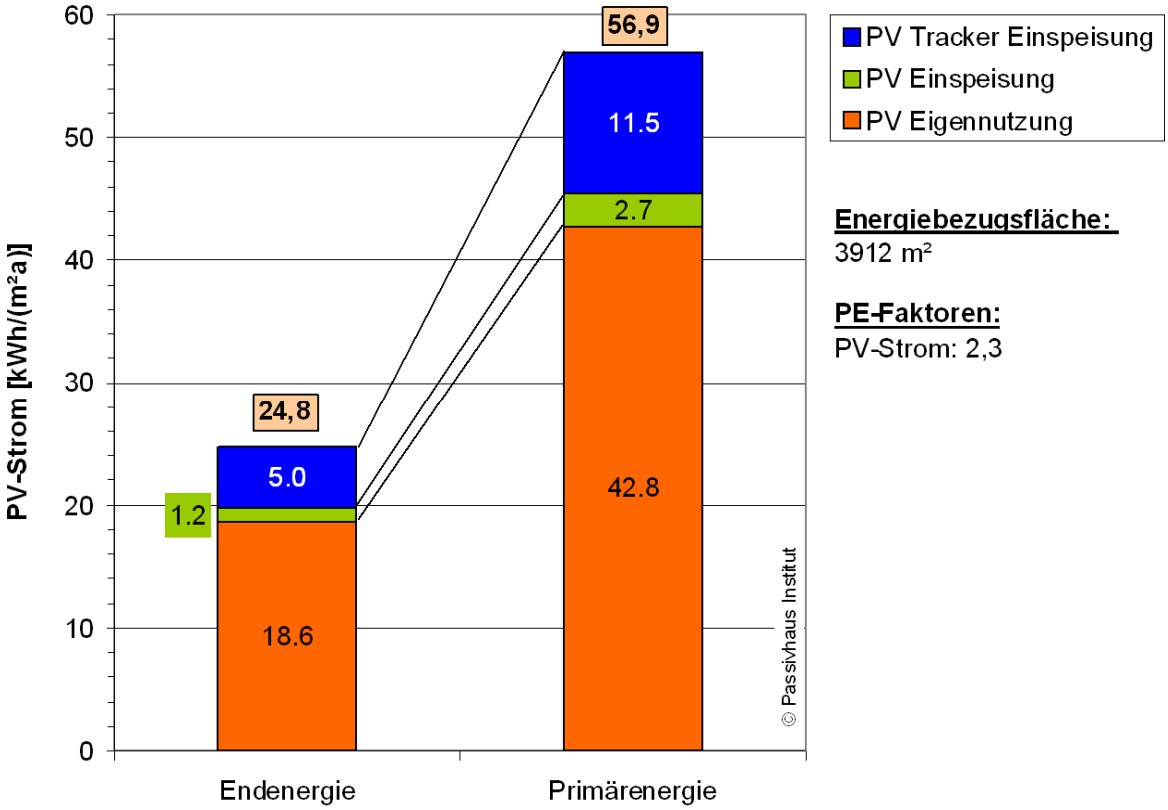

Figure 93: Annual solar power production on the building or with the PV trackers

the site (accounting year April 2012 to March 2013). For comparability, the values are again related to the energy reference area of the indoor pool.

5 Optimization through energy balancing

The ability to reliably predict the energy requirements of a building during the planning phase is a basic prerequisite for achieving high energy efficiency. It enables the optimization of individual components as well as the holistic building concept. Due to many interactions and regulations, the energy flows in an indoor pool are very complex and therefore difficult to detect. In order to be able to assess and improve energy efficiency, an essential part of the research and consulting services during the planning of the Lippe bath was the preparation of an energy requirement calculation (cf. [Schulz et al. 2009] and [BGL 2011]). To this end, the Passive House Projecting Gun Package (PHPP) for the energy flows in a bathroom was essentially adapted and expanded, including several temperature zones, various ventilation strategies and pool and hot water heating. The calculations of this stationary energy balance on a monthly basis were compared and supplemented for specific questions with dynamic simulations on an hourly basis. The software specially developed by the PHI [D YNBIL]. Dynamic simulations are time-consuming and often prone to errors due to the many input parameters. In principle, they enable a detailed statement to be made about the thermal and hygric behavior and energy parameters of buildings, but given their complexity, they are not very suitable for the everyday planning and optimization process. In the case of the Lippe bath, the results of the dynamic simulation and the adapted PHPP are in good agreement, which means that the simplified stationary calculation method is in principle

for the calculation of energy requirements even of complex ones Swimming pools qualified. However, further validation and processing of the data entry are necessary for the untrained user before the tool can be used widely.

The PHPP is essentially a stationary energy balance on a monthly basis in which monthly adjusted boundary conditions (outside climate) are applied. The data entry is as simplified as possible, so that parameters for which a monthly breakdown is not necessary are assumed to be constant with mean values (e.g. the internal heat sources and the air exchange). In the specially developed swimming pool PHPP, the calculations were expanded and a procedure developed with which the relationships in the swimming pool can be better represented. Depending on the outside humidity and moisture sources in the room, an average air change for dehumidification is calculated. A distinction can also be made between different modes of operation during and outside opening hours. Further additions were carried out in the PHPP in order to be able to calculate the pool water heating under the boundary conditions entered. It is assumed that only one operating mode is implemented in the bathroom throughout the year.

All calculations of the Lippe bath published in [BGL 2011] are based on assumptions for different sub-areas. Estimates had to be made for some aspects, as not all planning details had been determined at the time of publication (e.g. electricity requirements for swimming pool technology). In other aspects, however, precise parameter determination was simply only possible to a limited extent, since there were no reliable measured values from other projects (eg the evaporation quantities and enthalpy losses to be expected). A detailed comparison of the consumption data from the monitoring with the energy balance now enables a review and thus confirmation / specification of the assumptions made.

5.1 Comparison: measurement data and calculated final energy requirement

The energy flows in an indoor pool depend heavily on the operating mode. An energy-saving use was assumed for the project planning of the bathroom, which up to now could only be partially implemented for various reasons. A match of the energy parameters predicted and achieved in [BGL 2011] is therefore not to be expected. However, the direct comparison is of interest because it shows where deviations have occurred. The total energy consumption (heat + electricity) calculated in advance was 550 kWh / (m² EBF a) accounted for. The measurements of the first year show a consumption value of only 412 kWh / (m²) despite different (tending to be less favorable) operating conditions EBF a). The balanced and measured values (March 2012 to April 2013 inclusive) are shown in a comparison in Figure 94, divided into three sub-areas - space heating, water heating and electricity. The biggest difference is unmistakable in the area of water heating, while the consumption values for space heating and electricity consumers fit well with the projected values.

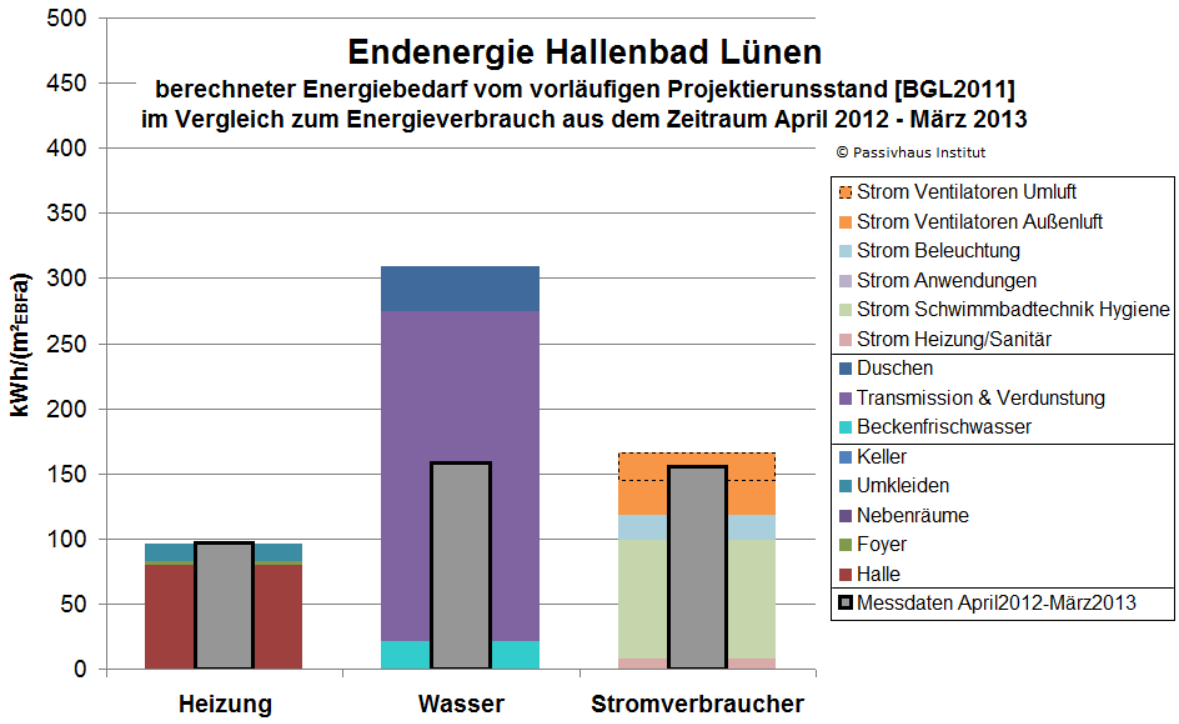

Figure 94: The calculated final energy from the original energy balance of the Lippe Bades (as of September 2011. Source: [BGL 2011]) in direct comparison with the measured values (differing operating conditions) from the period April 2012 to March 2013 inclusive. These are specific values with reference to the energy reference area.

Since the operation of the Lippe bath was not constant during the monitoring, a comparison of the calculated and measured annual values is not useful for a further analysis of the deviations. Instead, sub-areas were selected from periods with reliable data and constant mode of operation and the corresponding measured boundary conditions were updated in the energy balance. The corresponding evaluation of the measurement data and the resulting knowledge are explained in detail in the following text sections for the sub-areas of pool water heating, space heating, electricity and domestic hot water.

5.1.1 Pool water heating

According to the needs calculations during the planning phase of the bath, the heating of the pool water is the largest final energy consumer (please refer Figure 94). This forecast was confirmed by the monitoring (see section 4.8.2 on the measured energy consumption of the various sub-areas) for the distribution of the measured heat consumption), if not to the same extent The measured values are significantly lower than expected, so a close look at the energy flows for pool water heating is of particular interest.

The pool water heating is determined by the following factors:

- Heating of the required **Fresh water make-up:**
  30 liters per bath guest Hygienic requirements according to the standard or water loss due to necessary filter backwashing and other water discharges, eg through evaporation or wet bathers

- Reheating the **Net heat loss:**
  Heat loss through eg evaporation, transmission and convection
  less Heat gains through eg floats, pump technology and transmission and convection

The individual factors of the corresponding energy balance contain many uncertainties that have a significant impact on the calculated heating demand. In particular, the heat losses due to evaporation and the heat gains from people and swimming pool technology are difficult to estimate. Both parameters strongly depend on the user behavior and the mode of operation of the bath (bathing time, swimming style, pool water and indoor air conditions etc.), which can only be partially recorded by monitoring. For some important influencing factors there is uncertainty regarding the assumptions to be made, for example for the evaporation quantities and the corresponding heat loss attributable to the water. The typical average heat release by swimmers or bathers to the water is also not exactly known.

From the monitoring, the fresh water quantities and the heating energy consumption per pool circuit are known, as well as water temperatures at different points in the respective circuits, the circulation quantities and the fresh water temperature at the entrance to the building. The water volume of the filter rinse water treatment is also recorded separately for the water balance. An evaluation of this data should, as far as possible, provide information about the suitability of the assumptions made in the energy balance.

The **Fresh water requirement** (Make-up during bath operation) is usually dominated by the amount of water required for regular filter rinsing. A comparatively small additional requirement arises from water losses such as
eg evaporation or discharge by bathers. In order to reduce the amount of water required in bath operation and at the same time to save on heating requirements, a treatment of the filter rinse water was planned in the Lippe bath, with which approx. 70% of the required filter rinse water is retained in the pool circuit and only approx. 30% is replenished with cold fresh water Need to become. According to [VDI 2089], an average of 30 liters of fresh water per bathing guest must be made available for hygienic reasons - filter water treatment only brings an energetic advantage as long as this value is not undercut. Figure 95 shows the measured monthly fresh water quantities compared to the projected values. The planned filter rinse water **processing** was off in the period under review

not in operation for technical reasons. The agreement of the monthly fresh water quantities up to June 2012 with the demand assessment without filter water treatment is acceptable (the consumption is approx. 19% higher on average). During the temporary partial closure for revision purposes in July and August, the values decrease understandably. According to this, the fresh water consumption for all three circuits is higher than before and is now on average 76% higher than expected. The increase is due to a retrofit of the filter technology, in which, among other things, the filter technology was adapted and the filter areas enlarged. It is planned to optimize the filter technology in the future and also to put the filter rinse water treatment into operation. Based on the original project planning, the savings potential is approx. 1,700 m³ / month, So 80% reduction compared to the current consumption values. Reduced amounts of fresh water are not only desirable in terms of saving water, but also because of the accompanying reduction in heating energy for heating up to pool water temperature.

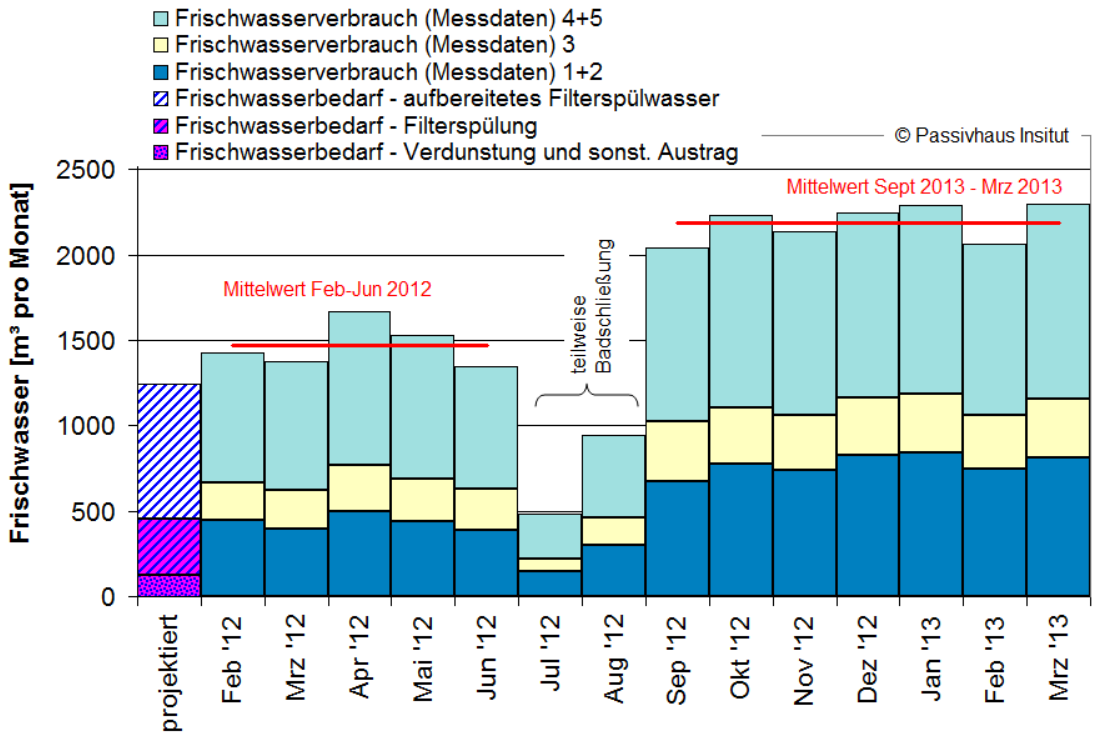

Figure 95: Fresh water volume - the set demand value for the sum of all circuit sales compared to the measured monthly consumption of the three circuits since February 2012.

According to expectations, with a real increase in water consumption, the **Heating energy consumption** higher lie, however, this is not the case Observations. As can be seen in Figure 96, the average heat consumption during the measurement period is significantly lower than originally planned. The consumption shares of the pool circuits in the total heating consumption are also different than expected. Despite the highest fresh water consumption and the largest water surfaces, the heating energy consumption for the two sports pools (4 + 5) is lower than in practice

for the much smaller and warmer parent-child pool (1 + 2). The numbers shown here are **Not** directly comparable, as the temperatures and humidity levels in the hall did not meet the planned boundary conditions. For a closer look at the heating energy for pool water heating and analysis of the causes of the deviations between the projected and measured values, the various influencing factors were given a closer look under given boundary conditions.

Note: Reliable data for the temperature of the fresh water will only be available from mid-August 2012. Temperatures for the remaining months of the evaluated year were estimated by adapting a sine curve to the existing measurement data. This results in a mean annual temperature of 13.3 ° C, i.e. approx. 3 ° C above the fresh water temperature of the project planning for the reference climate.

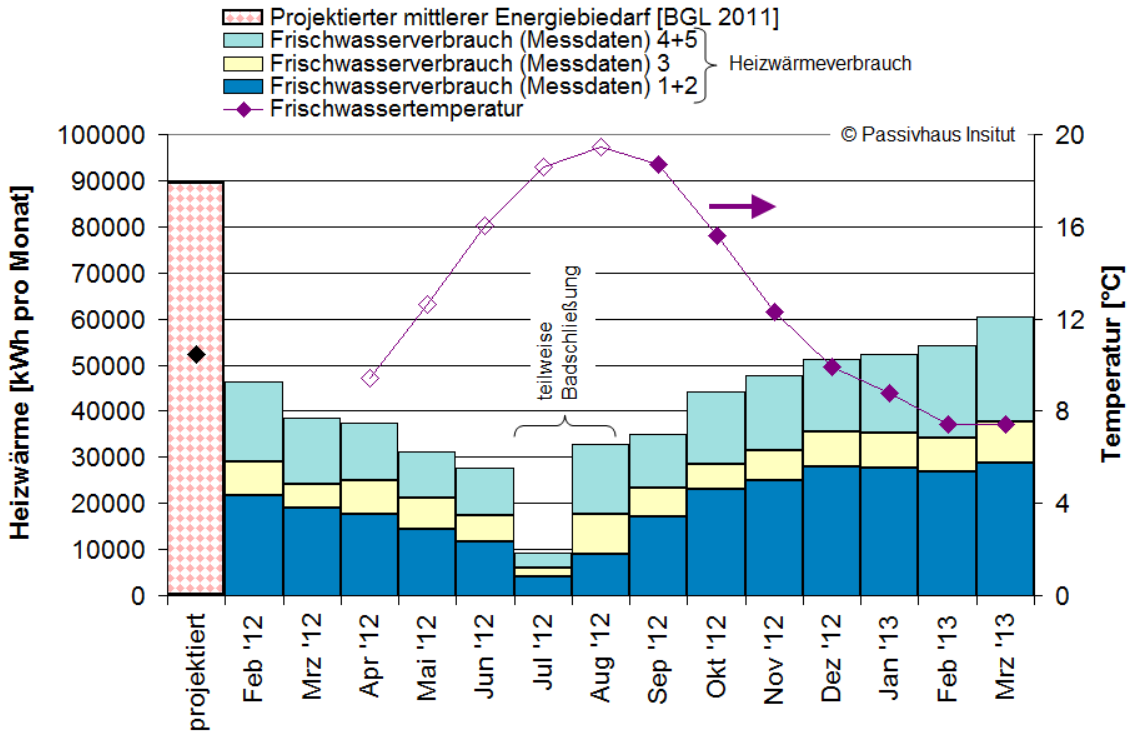

Figure 96: Monthly heating demand and consumption for the three pool circuits, as well as the fresh water temperature measured every month (empty diamonds = extrapolation). Consumption is significantly lower than expected in spite of higher fresh water consumption. However, there are other boundary conditions than in the project planning.

5.1.1.1 Evaporation

As expected, heat loss through evaporation accounts for the majority of the pool water heating required. The amount of evaporation to be expected

$M_{BD/bu}$ in kg / h corresponds to [VDI 2089]:

$$M_{BD/bu} = \frac{\beta}{R_D \cdot \bar{T}} \cdot (p_{WD} - p_{LD}) \cdot A_B$$

β	Mass transfer coefficient [m / h]
R_D	specific gas constant for water vapor [J / (kgK)]
$\bar{T}$	Average pool water and air temperature [K]
p_{WD}	Saturation pressure at pool water temperature [Pa]
p_{LD}	Indoor air vapor pressure [Pa]
A_B	Pool water surface [m²]

The level of the actual evaporation is determined by the mass transfer β determines which, however, is fraught with great uncertainties. For the design of the ventilation devices (peak load), mass transfer coefficients were used in the energy balance during the planning phase based on the [VDI 2089]. These parameters were adopted in the original energy balance, even if these are peak values, not average values in bathroom operation - the calculations are on the safe side. As already in [Schulz et al. 2009] (page 23), average evaporation quantities of approx. 50% of the value calculated according to VDI can be expected in practice. Based on the measurement data, these parameters can now be checked for each pool and adjusted in the energy balance. A direct measurement of the evaporation from the pool water is not possible during operation. However, the order of magnitude can be calculated from the dehumidification performance of the hall ventilation: If the interior humidity is constant, the difference between the supplied moisture (supply air) and the extracted moisture (exhaust air) corresponds to the sources of moisture in the room. It is initially assumed that the total calculated dehumidification performance has its origin in the evaporation of pool water. For the energy balance, it is also assumed that the corresponding enthalpy of evaporation is taken 100% from the pool water and not from the hall air. In practice, part of the evaporation certainly occurs outside the pool, e.g. from water drops / puddles that form on the floor due to water discharge by the bathers, through evaporation on the skin of wet guests or from towels, swimming equipment, etc. Especially with strong water movement and droplet formation it can also be assumed that the required enthalpy of evaporation is taken from the surrounding air instead of the pool water. Further uncertainties arise from moisture in and out in the respective

Hall, for example, during floor cleaning or when exchanging air with other rooms (door openings) as well as by regulating the amount of air that is not for the Dehumidification is required (e.g. regular calibration of the ventilation units, in which 100% outside air is briefly introduced into the hall). The uncertainties in the measurement itself can also lead to a shift in the results at this point [5]. In order to be able to take into account the effect that not all of the dehumidification performance calculated from the ventilation data has its origin in the pool water evaporation, the calculation value per pool is reduced with a flat-rate correction factor. How high the actual proportion is in practice cannot be determined exactly and can vary from hall to hall. As an assumption, reduction factors between 0.5 and 1 were used in the comparative calculations for pool water heating (see 5.1.1.5). For the remaining part of the evaporation, which is not counted towards the pool water, the necessary enthalpy of evaporation must have its origin elsewhere

eg the indoor air. This effect should be reflected in the measurement data for the heating energy of the individual halls. The corresponding analysis is carried out in Chapter 5.1.2.

Table 13 compares the values used in the original energy balance with the mean mass transfer coefficients calculated from the monitoring. During the rest periods, the measured values are in the range of 60 to 100% of the values according to the approach based on the VDI, i.e. in reasonable agreement in view of the uncertainty of the calculation. During the day, the calculated evaporation rate corresponds to an average of 20 to 40% of the design, depending on the pool. The calculated mass transfers are between 7 and 11 m / h. The correlation of the VDI of greater evaporation in deeper pools cannot be confirmed with the available data. Fluctuations in mass transfer can be caused by a wide variety of influencing factors, in particular by using the pool, Indoor humidity and the temperature level (indoor air to pool water). Figure 97 shows an example of the calculated hourly dehumidification performance during the day compared to the pool occupancy. Additional graphics with the calculated dehumidification performance over time are listed in Section 8 (Appendix).

For a better understanding, the data of periods with the most constant possible boundary conditions (hall humidity, air and pool water temperature) were evaluated for all pools and the influence on evaporation was examined. The calculated mean mass transfers of all pools as well as the calculated specific dehumidification performance (= evaporation) per square meter of pool surface under different boundary conditions are shown in Figure 98 and Figure 99. The calculated dehumidification performance ranges from 0.07 to

[5] At this point, data from standard sensors of the manufacturers in the ventilation unit are used, which were checked for plausibility by the PHI, but not finally calibrated. Such a calibration is planned to continue the measurement.

0.19 kg / (m² Pool area H). As expected, a decrease can be seen in the case of higher temperature differences between the indoor air and pool water, as well as with higher indoor humidity.

Table 13: Overview of the mass transfer coefficients ß [m / h] for the calculation of the Evaporation. The values according to the ventilation design of VDI 2089 are compared with the values that result from the monitoring on average.

Mass transfer coefficient β [m / h]	Energy balance planning phase		Calculation from average dehumidification performance over the hall ventilation	
	Bathing operation	night	Bathing operation	night
Parent-child & warm pool	40	6.3	9.7 [24%]	5.7 [92%]
Training pool (with lifting floor)	28	6.3	7.6 [27%]	4.0 [64%]
Sports pool 4 (non-swimmers)	34.5	6.3	7.0 [20%]	4.7 [74%]
Sports pool 5 (old building)	28	6.3	11 [39%]	6.4 [101%]

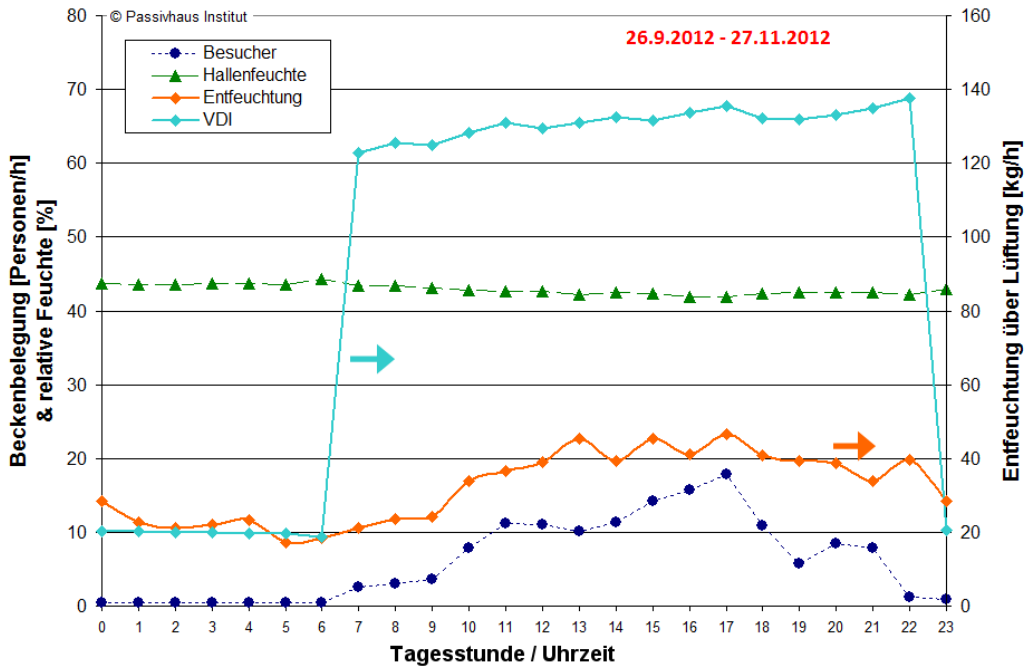

Figure 97: Average daily profile of the pool occupancy (LASE scanner) and the results Dehumidification performance via ventilation in hall 1 + 2 over approx. 8 weeks. As expected, the dehumidification performance tends to increase with higher pool use. Outside of opening hours, the dehumidification is of a similar magnitude as planned, but significantly lower during the day.

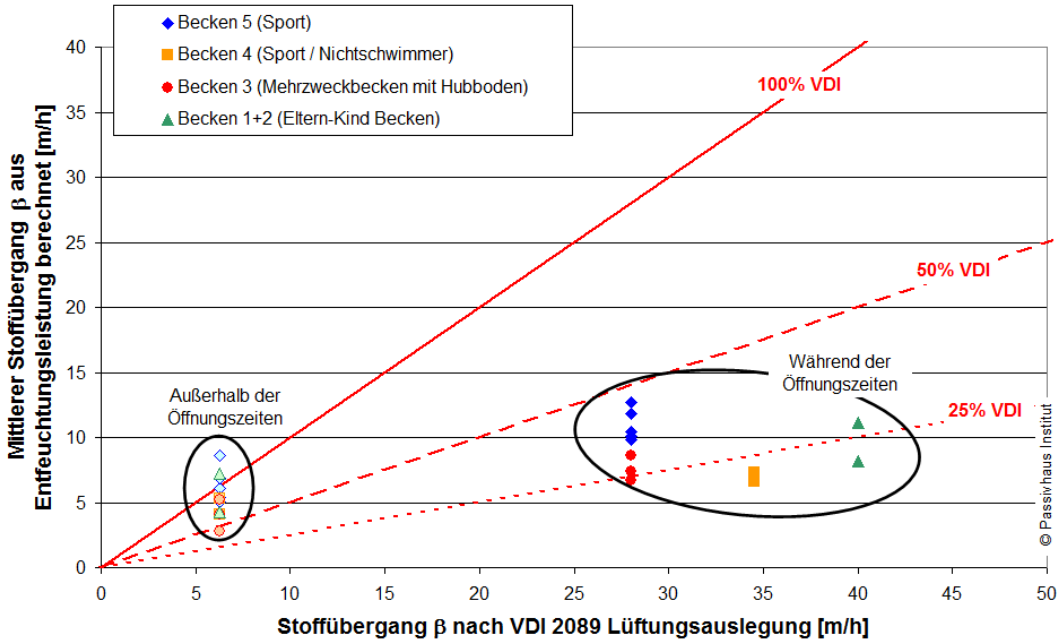

Figure 98: The mass transfers calculated from the dehumidification performance for the Evaporation of the individual pools from several representative periods with different boundary conditions. During the opening times, the mean values are always below 50% of the characteristic values for the peak load design of the ventilation according to [VDI 2089].

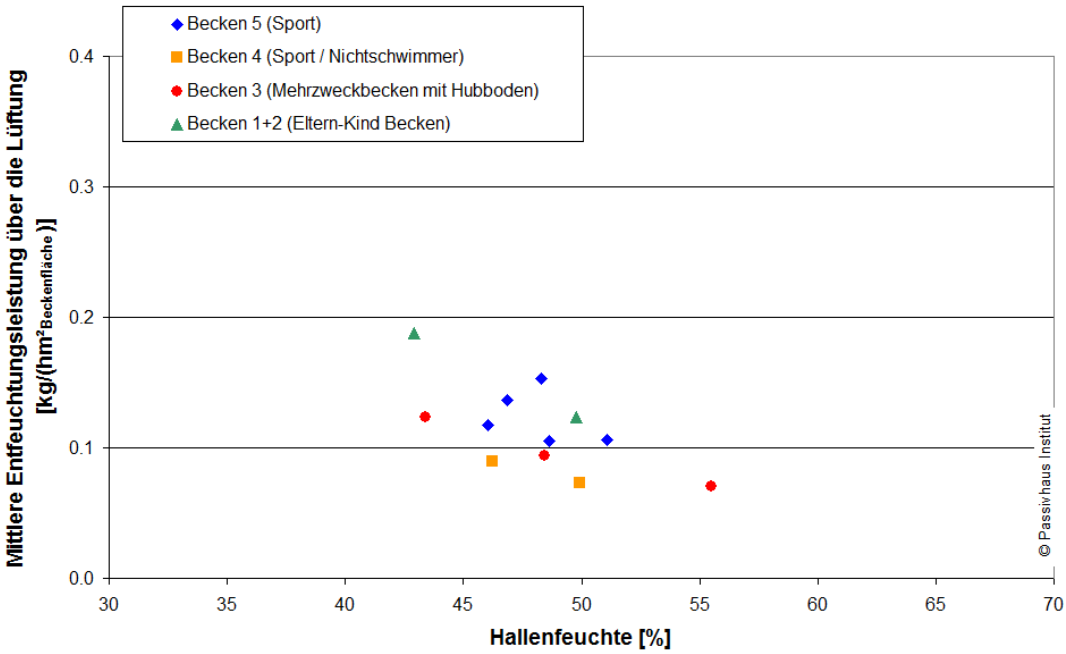

Figure 99: The calculated average dehumidification performance of the individual halls several representative periods with constant boundary conditions, shown at the respective hall humidity. The expectation of reduced evaporation with increased air humidity tends to be confirmed.

5.1.1.2 Fresh water heating

In addition to the necessary reheating of the heat losses due to the enthalpy of evaporation to maintain the desired pool water temperature, the heating of the replenished fresh water makes up a significant part of the heating requirements of the pool water. Theoretically, this heating energy requirement for fresh water heating can easily be calculated from the amount of water, the specific heat capacity of the water and the temperature rise (fresh water to pool water temperature). All three parameters are known from monitoring.

However, uncertainties arise from the fact that the pool water is constantly circulated through the pool, the overflow channels, the splash water tank, the pipes and filters etc. in the warm cellar. The required fresh water is replenished in the respective splash water tank, where it immediately mixes with the already warm water. Before it is actively heated on the supply line to the pool via the HT and NT heat exchangers, there is a heat exchange with the basement. How much heat the fresh / pool water mixture draws from the cellar and therefore no longer needs to be actively reheated is difficult to estimate and difficult to understand using measurement technology. In an additional experiment, the temperatures were measured at various points in the individual pool circuits over several hours. Due to the high flow rates,

Heat absorption from the basement could be estimated. Different variants are examined in the comparative calculations of calculated energy demand and measured energy consumption under the same boundary conditions. It is based on the assumption that the fresh water does not warm up to basement temperature or up to 30% (see 5.1.1.5).

The intended heat recovery from the filter rinsing wastewater for passive preheating of the fresh water has not yet been put into operation and must therefore not be taken into account when tracking the energy balance.

5.1.1.3 Heat sources in water

Heat sources in the pool water circuit help to heat the water and therefore reduce the need for post-heating. Two major heat sources are taken into account in the energy balance. Potential solar gains are neglected in the energy balance.

(a) Swimming pool technology (SBT): The water volumes are controlled by circulation pumps kept permanently in motion, further SBT ensures water hygiene. The electricity required for this circulation and water treatment is considerable; Much of this energy ultimately benefits the water in the form of heat. The current consumption of the circulation pumps of the individual pool circuits was recorded individually in the course of the monitoring, while the remaining elements of the SBT in the pool circuit that could be relevant as a heat source (e.g. pool lighting, chlorine electrolysis, UV disinfection) were not permanently measured separately. For the comparative calculations, 70 to 100% of the measured electricity consumption of the circulating pumps plus the average predicted electricity consumption of the additional main SBT consumers per pool circuit (approx. 18 kW in total for all pool circuits) was taken into account as the heat source for the water. This range is considered to be a plausible heat source for the pool water based on previous data analysis and experience. Further studies in this area are still pending.

(b) People: Depending on the activity and ambient temperature, people give warmth to the environment. Typical parameters for the heat emission in air are 80 W for a seated and 100 W for a standing, slightly active person. However, other boundary conditions apply to swimmers, since most of them are under water. In view of the physically higher heat transfer to water than air and the mostly athletic activity of bathers, it can be assumed that the heat output tends to be higher when bathing than during a typical stay in the room, but the authors do not know any reliable parameters. In [Mareés 2003] 11.5 W per kg body weight at a swimming speed of 3 km / h (25 m in 30 seconds) are cited. This

corresponds to approx. 570 W for 50 kg body weight, around 900 W. for 80 kg. Mareés also writes that the energy consumption is strongly influenced by various influences, such as swimming style and speed, the level of training of the individual swimmer and also gender . The authors' estimate of the body's heat release from typical average calorie consumption values when swimming leads to outputs between approx. 400 and 700 W / person. Sport swimmers produce more warmth than bathers with a calm swimming style. These values do not apply to non-swimmers, such as children playing in the warm pool or guests who practice swimming gymnastics. For the original energy balance, an average of 100 W / person was taken on the safe side. Up to 500 W / person were used as the mean for comparing the consumption values. In addition to the uncertainty of the average heat output per person, the occupancy is not known for all pools. As a very simple assumption, it was assumed that the visitors were evenly distributed over the four pools and each spent an hour in the water on average. With a number of 220,000 visitors a year, this would correspond to an average of 9.4 bathers per pool during opening hours. The occupancy data for pools 1 + 2 are available by evaluating the automatic counting with a pool scanner. These data show that the original estimate fits very well, at least for this one. The difference in dehumidification performance for the individual halls, during the opening times compared to at night,

5.1.1.4 Pool walls & water surface

Heat is exchanged with the surroundings on all water surfaces. The transmission through the pool walls and floors can be calculated on the basis of the component U values. It should be noted that due to the properties of water, the heat transfer resistance on surfaces is almost zero

is. The

Heat transfer at the water surface was initially not sufficiently taken into account in the original energy balance. As the following comparative calculations show, this factor can have an impact on the end result. The heat transfer resistance to be applied according to [DIN EN ISO 6946] in interior rooms with downward heat flow of 0.17 m²K / W can be used as a guideline, which corresponds to a heat transfer of 5.88 W / (m²K). If the mass transfer coefficient ß of evaporation is known, the heat transfer can α based on the analogy between heat and mass transfer on the evaporating surface with the help of the Lewis number **Le**

and the heat capacity of the moist air c_{Lm} can be easily calculated:

$\alpha = \beta \cdot Le \cdot c_{Lm}$. Le applies to evaporating water ≈ 1 [Dubbel 1997]. Table 14

gives an overview of heat transfer coefficients under a range of boundary conditions typical for indoor swimming pools.

Table 14: Overview of the heat transfer coefficients calculated on the basis of the Lewis Relation.

Mass transfer β [m / h]	Air temperature [° C]	Relative humidity	Heat transfer coefficient α [W / (m²K)]
7	32	48% / 64%	2.31 / 2.32
	28	48% / 64%	2.34 / 2.36
15	32	48% / 64%	4.95 / 4.98
	28	48% / 64%	5.02 / 5.05
28	32	48% / 64%	9.24 / 9.30
	28	48% / 64%	9.37 / 9.42
40	32	48% / 64%	13.21 / 13.29
	28	48% / 64%	13.38 / 13.46

5.1.1.5 Energy balance for pool water heating

As described in the previous sections, the energy balance for pool water heating is fraught with many uncertainties. In November 2012, the boundary conditions in all pools / halls were relatively constant. This month is therefore used as the basis for the comparison of monthly consumption and the calculated energy requirement under different assumptions. The results for the three pelvic circuits are shown graphically in Figure 100 to Figure 102 (note: different scales). The corresponding monthly mean values were used as a boundary condition for temperatures (pool water and indoor air) and the indoor humidity. The measurement data for the fresh water consumption and the pump current were also included in the calculation.

To explain the eight calculated variants with gradually adjusted parameters:

- Calculation of the enthalpy of evaporation as in the original energy balance based on the mass transfer coefficients β following the [VDI 2089]
- Evaporation enthalpy corresponding to 100% of the calculated dehumidification performance via the ventilation in November (see chapter 5.1.1.1)

- Assumption that only 75% of the calculated dehumidification performance can be attributed to the pool water as evaporation enthalpy (see Chapter 5.1.1.1)

- Assumption that the fresh water to be heated already warms up to 30% to basement temperature before it is actively reheated (see Chapter 5.1.1.2)

- Increased heat output by the swimmers of an average of 500 W / person (see chapter 5.1.1.3)

- Assumption that 100% of the current consumption of the circulation pumps and SBH main consumers is transferred to the corresponding pool circuit (see chapter 5.1.1.3)

- Adjusted pool allocation based on people counting in pools 1 + 2

- 5.88 W / (m²K) heat transfer coefficient on the water surface, according to the information for downward heat flow in the interior according to [DIN EN ISO 6946] (see Chapter 5.1.1.4)

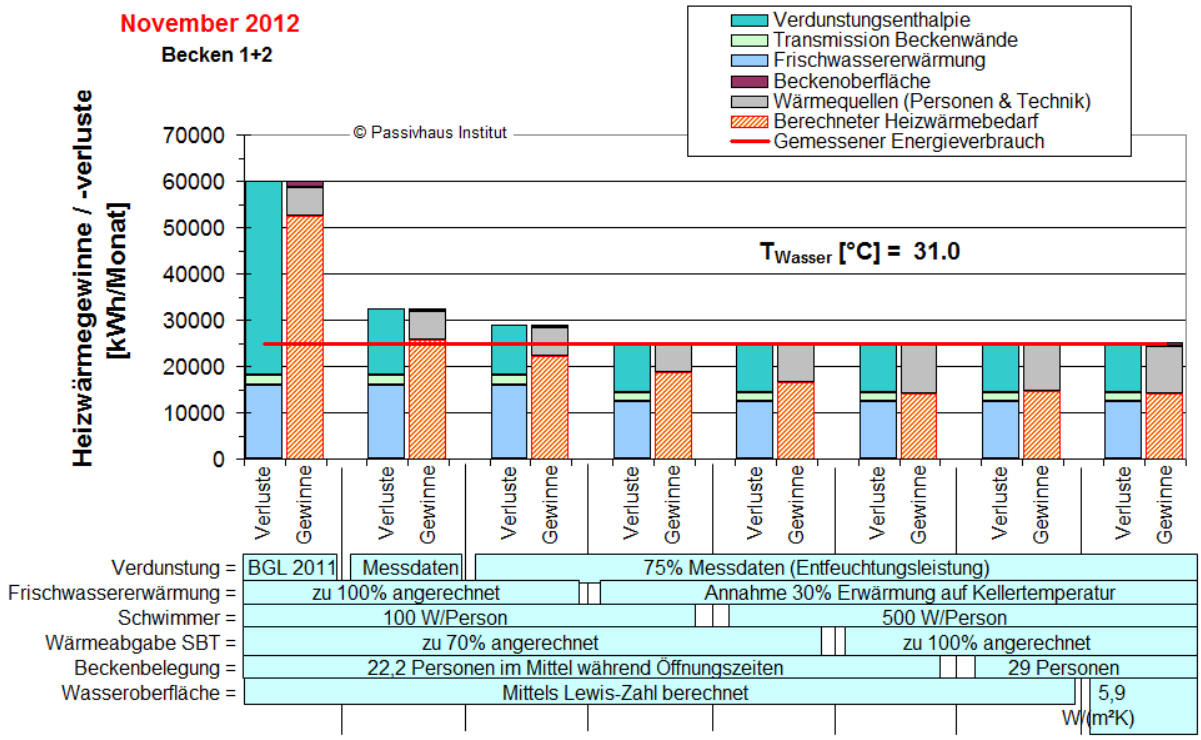

Figure 100: The measured heating consumption for pools 1 + 2 in November 2012 in Comparison to the calculated energy requirement under various incrementally adjusted assumptions.

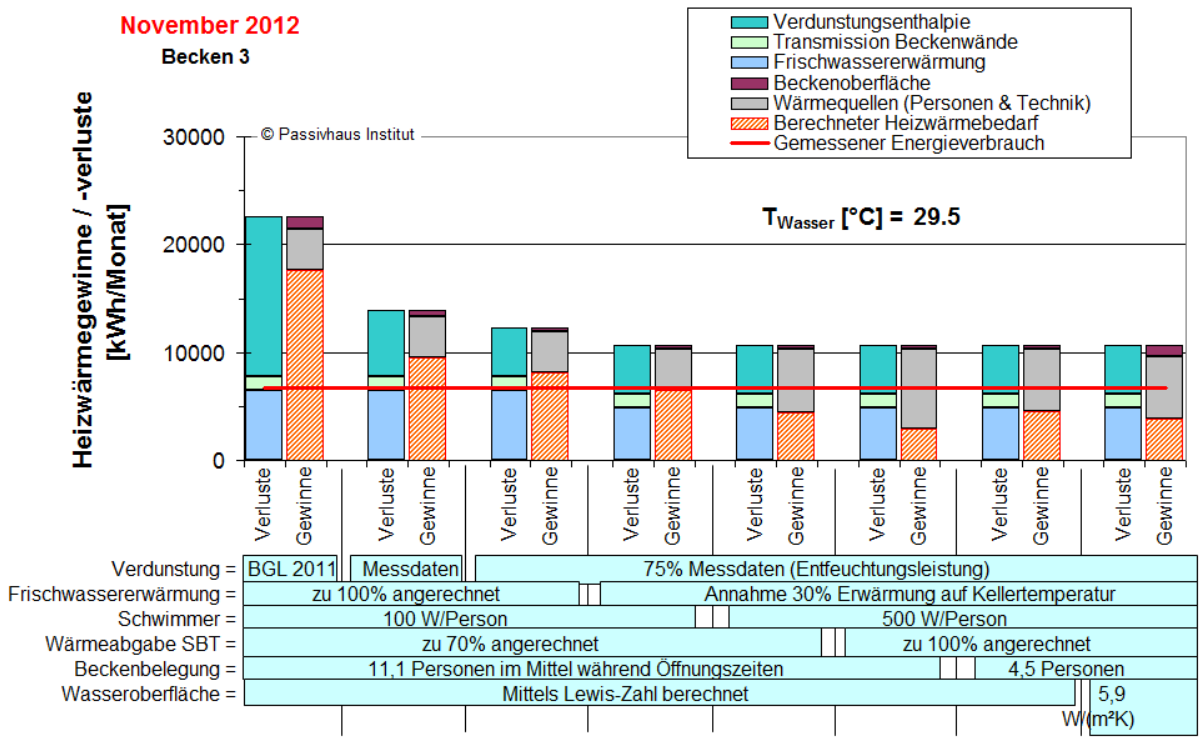

Figure 101: The measured heating consumption for pool 3 in November 2012 in

Comparison to the calculated energy requirement under various incrementally adjusted assumptions.

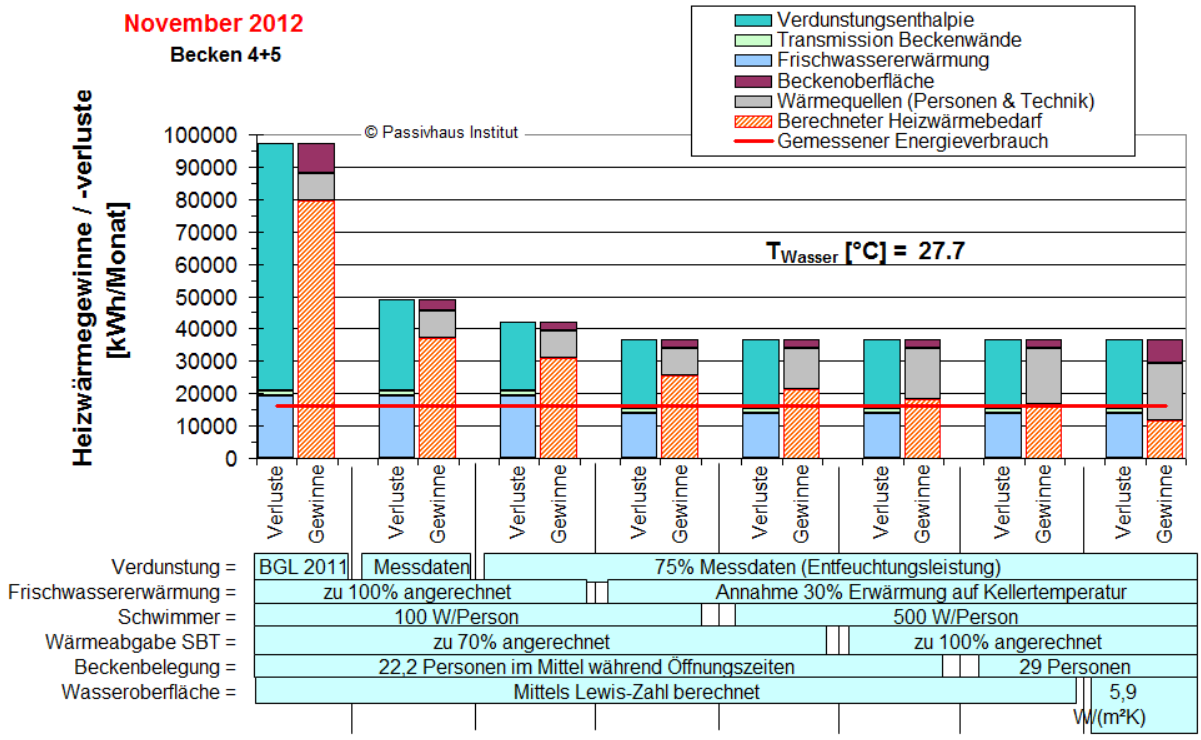

Figure 102: The measured heating consumption for pools 4 + 5 in November 2012 in

Comparison to the calculated energy requirement under various different incrementally adjusted assumptions.

By varying the assumptions, an agreement with the measured value can be achieved for all circuits. It is striking that both in the training pool (3) and in the sports pool circuit (4 + 5) the measured energy consumption is roughly the order of magnitude of the calculated energy requirement for the amount of fresh water alone. Accordingly, there must be significant heat sources in these pool circuits that help to reduce the heating requirement. In the sports pools in particular, the energy requirement is significantly lower than expected - the exact relationships should be examined in more detail in the future.

In Figure 103, the projected energy requirements for pool water heating over the course of the year are compared to the measurement data and the energy requirements of the updated energy balance. This comparison shows that the original energy balance was clearly too pessimistic. The measured values from winter 2012/2013 (temperatures, evaporation volume, fresh water consumption) were used as a boundary condition for the following calculation. On average, the results are in relatively good agreement with the measurement data. As can be seen in the graphic, the annual cycle of heating consumption is not reflected in the results of the energy balance due to the different fresh water temperatures per month. The monthly differences are not relevant for the annual heating demand,

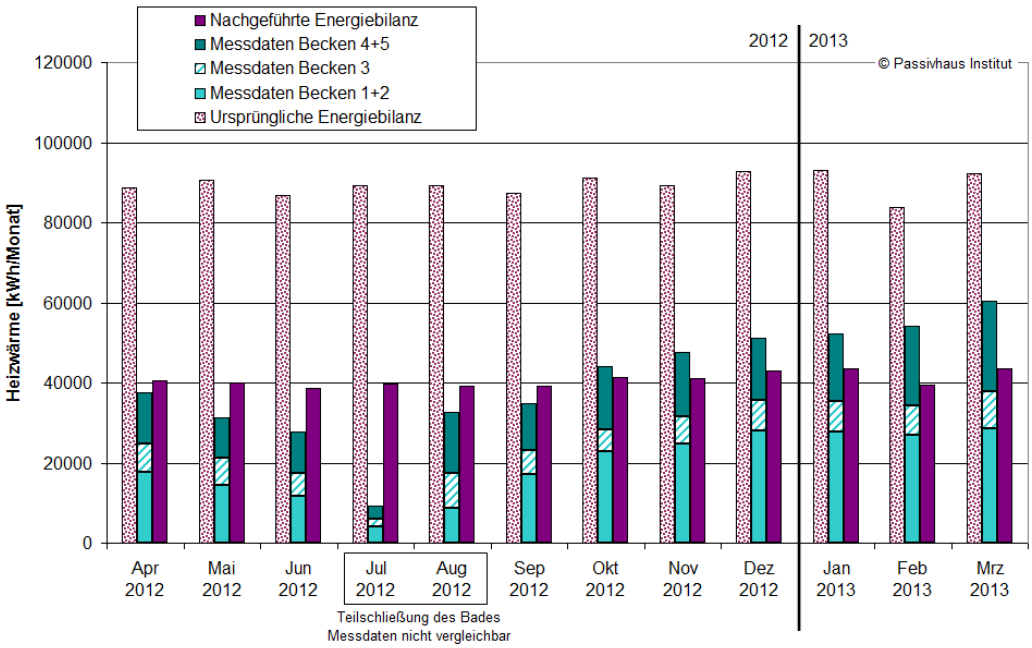

Figure 103: Comparison of the monthly energy requirements for pool water heating from Planning status [BGL 2011] with the measured heating energy consumption and the demand values of the updated energy balance in the course of the year.

It is important to recognize that, contrary to the assumption of the original energy balance for pool water heating, evaporation is not dominant. The energy requirement of fresh water heating makes up a comparable proportion in all circuits compared to evaporation. It is therefore energetically worthwhile to reduce the amount of fresh water, although of course the pool water hygiene must be taken into account. The analyzes also show that it is of great relevance for the energy balance to also take a closer look at the heat sources in the pool water.

No further restrictions or indications for generally suitable assumptions and characteristic values for the balancing of indoor swimming pools could be created within the scope of the investigations carried out so far. The interrelationships would have to be examined in more detail with controlled and deliberately different boundary conditions. This may be possible in a follow-up project.

5.1.2 Space heating

The second largest consumer of heat after pool water heating is space heating (see 4.8.2). To check and, if necessary, improve the energy balance in this important sub-area, the corresponding measurement data are analyzed and compared with the calculated values. The heating energy requirement of the room air is influenced by various factors. The following measured parameters from the monitoring were updated in the energy balance to determine whether the measured heating energy consumption of the individual areas can be tracked using the swimming pool PHPP calculation method:

- Outdoor conditions: temperature, solar radiation and relative humidity (see section 4.2)
- Average values of the measured room temperatures as a temperature requirement of the different temperature zones in the energy balance
- Air volumes: Average outside air and recirculated air volume flow
- Reduction of the internal heat sources in the side rooms from flat rate 3.5 W / m² to 2.1 W / m²

The quality of the building envelope (apart from the airtightness) was not adjusted in the energy balance. The transmission losses and solar gains change compared to the original energy balance only according to the adjusted indoor and outdoor temperatures. With the high air volumes, the ventilation heat losses play a significant role in the overall energy balance. The efficiency of the heat exchangers and the heat recovery achieved are crucial for this. Based on the existing measurement

at the time of this publication, no reliable evaluation of the efficiency of the heat exchangers could be made in the ventilation devices. Compared to the normal case in residential or office buildings, the calculation is considerably more complex due to the high exhaust air humidity with the formation of condensate in the exhaust air and deliberate disbalance (for component protection) of the air volumes. The first evaluations confirm that the efficiency is in the range of the expected parameters (70 to 80% depending on the device), but more detailed analyzes on this topic are still pending.

5.1.2.1 Swimming pools

Since the outdoor air exchange in the swimming pool depends on the dehumidification requirement, the swimming pool PHPP is adapted so that no volume flows are specified by the user at this point (as is usual), but are calculated from the set boundary conditions. According to the moisture sources in the halls, the required outside air change and the corresponding ventilation heat losses are calculated by the PHPP on a monthly basis. In order not to intervene in the algorithms, but instead to check whether the calculation calculates correctly under given boundary conditions, the measured amount of outside air was not taken over when the energy balance was updated, but rather the mean evaporation amount resulting from the monitoring. Figure 104 shows the monthly mean dehumidification performance calculated from the measured values (= estimate of the moisture sources / evaporation in the hall, see Section 5.1.1.1) of the individual hall devices. The energy balance assumes constant operation throughout the year, and the average value from November 2012 to February 2013 was used for the tracked energy balance (period with reliable and relatively stable operating conditions). Figure 105 shows the monthly average outside air volume flows compared to the outside air requirement calculated with the PHPP based on the specified evaporation quantities. Before December 2012, the measured volume flows are significantly higher than those calculated with the PHPP, which can be explained by the fact that the actual moisture sources in these months are higher than the energy balance. Even in the following months, the calculated outside air quantities are slightly lower (approx. 10 to 15%) than the realized ones. If the outside air volume is calculated too low, the ventilation heat losses are also underestimated with the energy balance. The most likely cause for this deviation are control engineering influences, which in practice lead to higher air changes, such as the regular calibration of the devices. This observation should continue to be observed in the constant operating conditions of the bath in order to decide in the future whether an adjustment of the energy balance is necessary at this point. Even in the following months, the calculated outside air quantities are slightly lower (approx. 10 to 15%) than the realized ones. If the outside air volume is calculated too low, the ventilation heat losses are also underestimated with the energy balance. The most likely cause for this deviation are control engineering influences, which in practice lead to higher air changes, such as the regular calibration of the devices. This observation should continue to be observed in the constant operating conditions of the bath in order to decide in the future whether an adjustment of the energy balance is necessary at this point. Even in the following months, the calculated outside air quantities are slightly lower (approx. 10 to 15%) than the realized ones. If the outside air volume is calculated too low, the ventilation heat losses are also underestimated with the energy balance. The most likely cause for this deviation are control engineering influences, which in practice lead to higher air changes, such as the regular calibration of the devices. This observation should continue to be observed in the constant operating conditions of the bath in order to decide in the future whether an adjustment of the energy balance is necessary at this point. The most likely cause for this deviation are control engineering influences, which in practice lead to higher air changes, such as the regular calibration of the devices. This observation should continue to be observed in the constant operating conditions of the bath in order to decide in the future whether an adjustment of the energy balance is necessary at this point. The most likely cause for this deviation are control engineering influences, which in practice lead to higher air changes, such as the regular calibration of the devices. This observation should continue to be observed in the constant operating conditions of the bath in order to decide in the future whether an adjustment of the energy balance is necessary at this point.

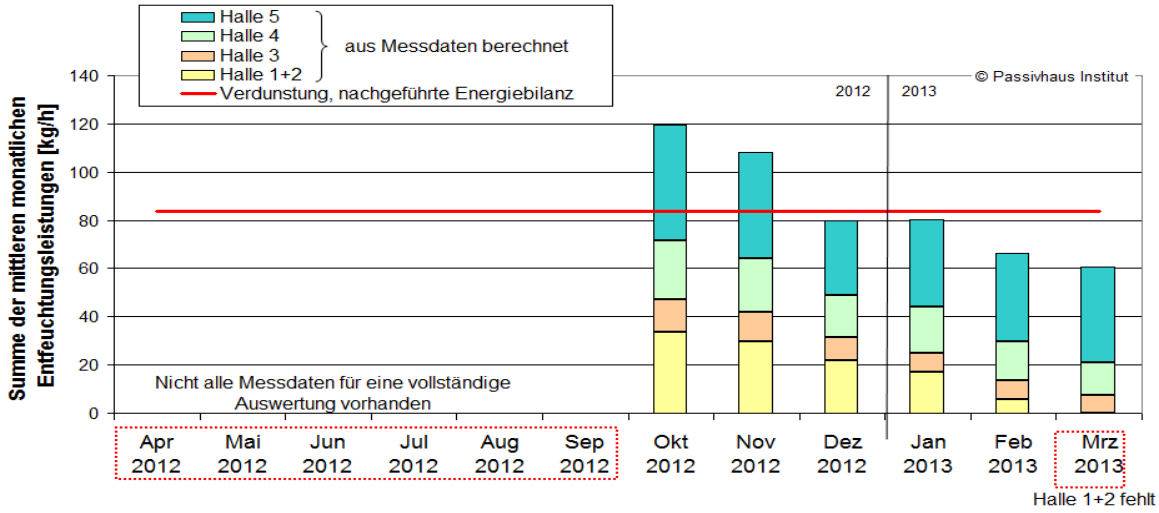

Figure 104: Dehumidification performance calculated from the measurement data via the ventilation in the monthly average for the individual halls. The average value from October 2012 to February 2013 was used for the tracked energy balance.

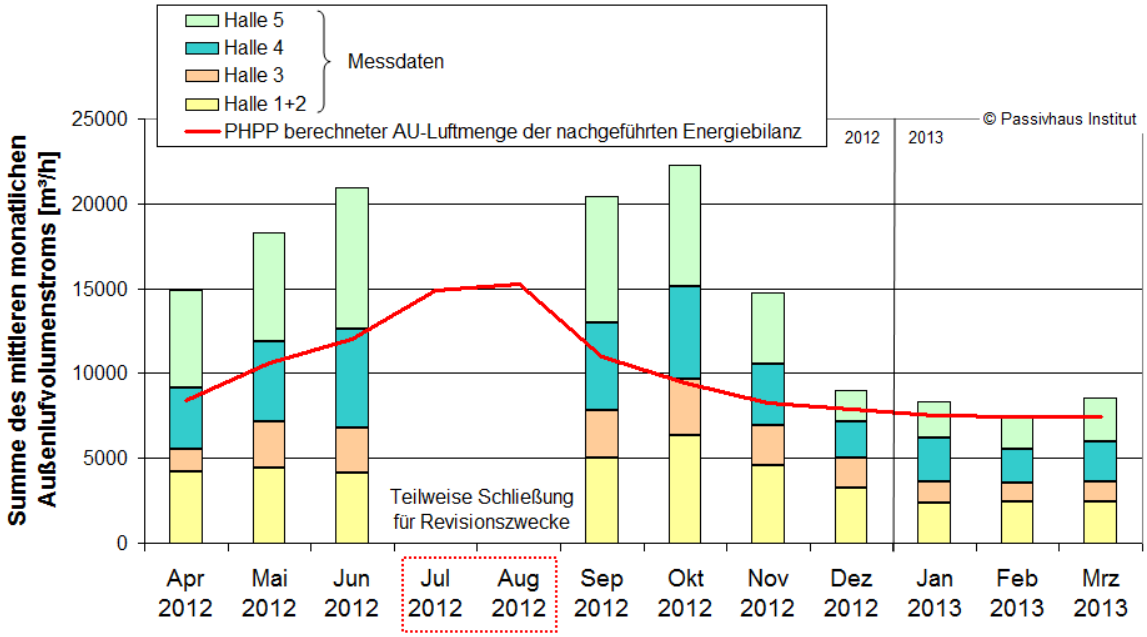

Figure 105: The measured mean monthly outside air volume flow of the individual Halls (totaled) compared to the calculated outside air requirement from the tracked energy balance. Even in the months with less evaporation than calculated (from December 2012, see Figure 104), the amounts of outside air calculated with the PHPP are slightly lower than those realized. In the months with higher evaporation (before Dec 2012) the measured volume flows are significantly higher than calculated.

Figure 106 shows the monthly measured energy consumption of the individual halls in comparison to the energy balance (status [BGL 2011]) and the following calculation. (Note: In this comparison, the enthalpy recovery via the heat pump is also shown as heating energy consumption, since the heat pump is in the energy balance model **Not**) The order of magnitude of the measured and calculated values is in good agreement; However, the calculated values are lower than the measured heating consumption in all months. The cause could not be finally clarified, there are various explanations such as

eg higher ventilation heat losses due to higher amounts of outside air or poorer efficiency of heat recovery, or other heat losses that are not fully taken into account, e.g. due to evaporation in the hall air. As described in Section 5.1.1.1 on the subject of evaporation of the pool water, it is quite possible that part of the enthalpy of evaporation comes from the hall air and must therefore be reheated via the ventilation units. An additional bar is shown in Figure 106, which quantifies the possible increase in heating demand, assuming that 20% of the enthalpy of evaporation is to be counted as heat sinks in the halls.

For a closer examination, a comparison with the dynamic simulation would be helpful, in which the halls are shown individually.

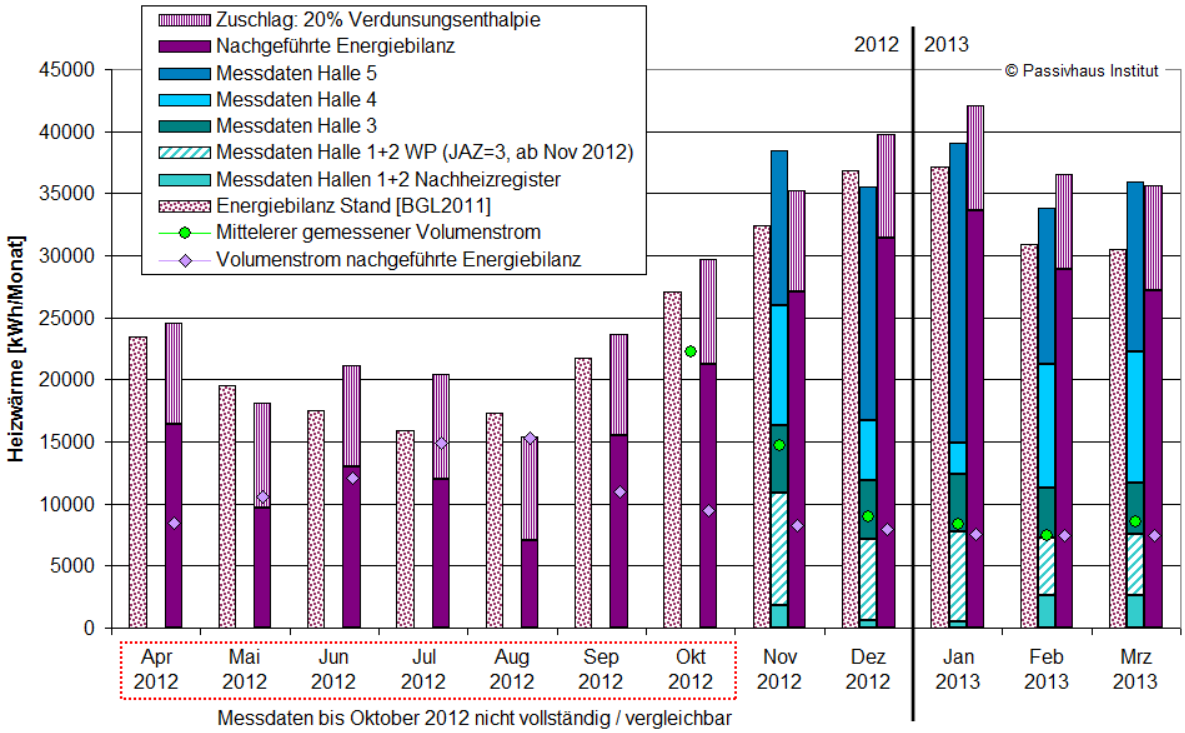

Figure 106: Comparison of the monthly energy demand from the planning status [BGL 2011] with the measured heating energy consumption (including enthalpy recovery via the WP) and the required values of the updated energy balance for the swimming pools.

5.1.2.2 Changing / showering

In the original energy balance, the target temperature was 26 ° C for the changing area and 28 ° C for the showers. The temperatures in the changing rooms were about 1 K lower than planned in winter 2012/2013, but about 1 K higher in the shower rooms. The temperatures in the calculation have been set at 25.2 ° C and 29.4 ° C according to the mean values since October 2012.

The PHPP does not provide for post-heating, as occurs in this zone between the changing rooms and the shower zone, and had to be entered manually into the energy balance. In principle, there are different options for this with different advantages and disadvantages. The selected method from the planning phase resulted in low heating requirements and was therefore revised.

In addition to the target temperatures and calculation methods for reheating, the air change was also updated compared to the energy balance from the planning. As described in section 2.4, the air volume is regulated according to the humidity in the shower rooms, resulting in an average volume flow of 4,885 m³ / h (6,000 m³ / h during opening hours) in the winter months. This value is significantly lower than the assumptions from the planning phase, which were deliberately on the safe side. Since the regulation had not yet been finally clarified at the time of publication [BGL 2011], it was assumed at that time that the device continuously transported the nominal volume flow of 10,000 m³ / h during opening hours. The ventilation heat losses that were set too high at the time partially compensated for the previously described overly optimistic assumptions for post-heating of shower air. As a result, the energy balance according to the planning status and the updated version lead to similar results in the annual heating demand.

Figure 107 shows the measured heat consumption for the evaluated measurement year in comparison to the energy requirement as of [BGL 2011] and the updated energy balance with the boundary conditions from the monitoring. The values before October 2012 are not reliable due to different boundary conditions in the calculation and in practice. The values of the current energy balance from October 2012 are on average 25% below the measured values. This discrepancy corresponds to approximately 2,500 kWh / month or 0.6 kWh / (m² in the winter months EBF Month) and is therefore not decisive for the overall energy balance. The causes of the deviations have not yet been finally clarified. Possible reasons are a poorer effective degree of heat supply of the ventilation system, fewer internal heat sources or higher heat sinks (evaporation).

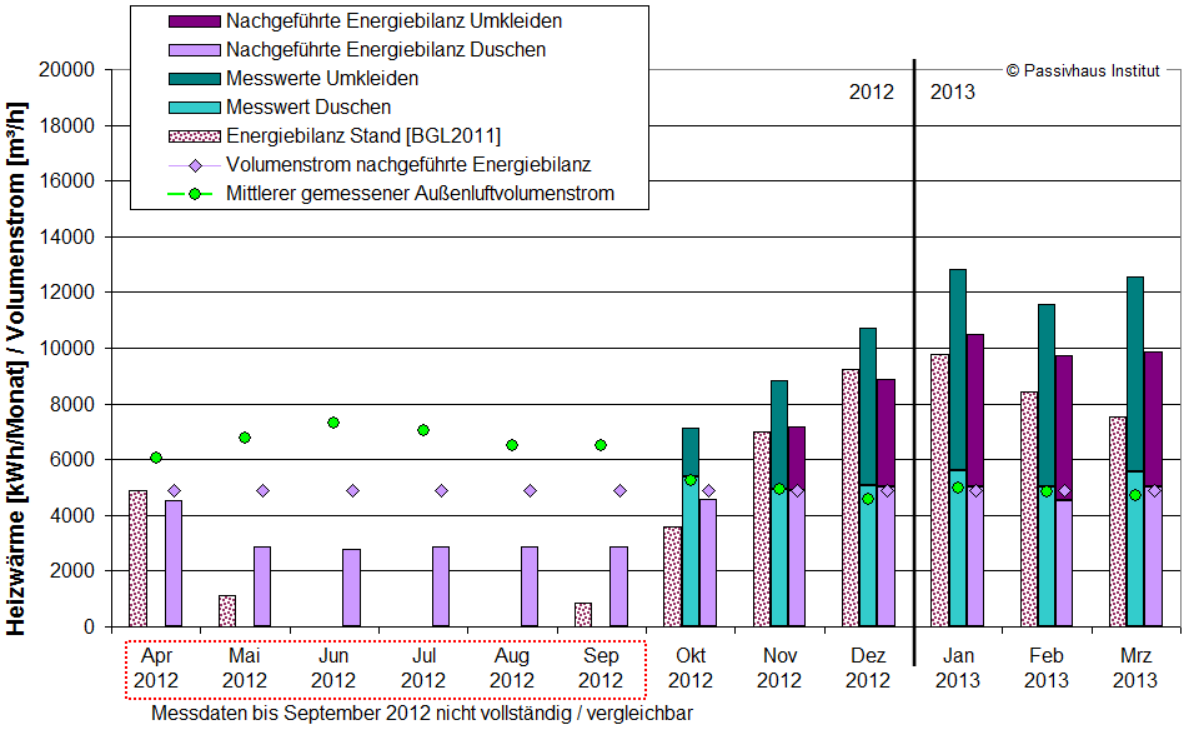

Figure 107: Comparison of the monthly energy demand from the planning status [BGL 2011] with the measured energy consumption and the demand values of the tracked energy balance for the changing rooms and shower areas. The energy balance with adjusted boundary conditions continues to lead to results that are on average approx. 25% below the measured values.

5.1.2.3 Foyer, basement and adjoining rooms

The heating requirement or consumption of the adjoining rooms makes up the smallest share of the total space heating. The various areas in the indoor pool, all of which are supplied by the "auxiliary rooms" ventilation unit, were represented in the energy balance as three different temperature zones: foyer, basement and other auxiliary rooms. The rooms are arranged in different areas of the bathroom with differently warm secondary rooms, therefore different temperatures can be expected despite the shared air supply and have also been measured.

In the energy balance (status [BGL 2011]) from the planning phase, a target temperature of 22 ° C was expected. Most rooms have higher temperatures, but they are all surrounded by warmer zones. In winter 2012/2013, lower values of up to 18.8 ° C occurred in the foyer and in the staff rooms in the basement. The setpoint for the heating balance was reduced to 19.2 ° C in accordance with the average value from December 2012 to March 2013. In addition, the mean volume flow was adjusted to the measured mean from October 2012 to January 2013.

The measurement and calculation results are shown in Figure 108. In this area too, the measured values are higher than the calculated demand values. As in

There are various possible causes for this in the sections described above. The heating of the secondary zones is irrelevant to the overall energy balance of the bath, so the agreement achieved is sufficient.

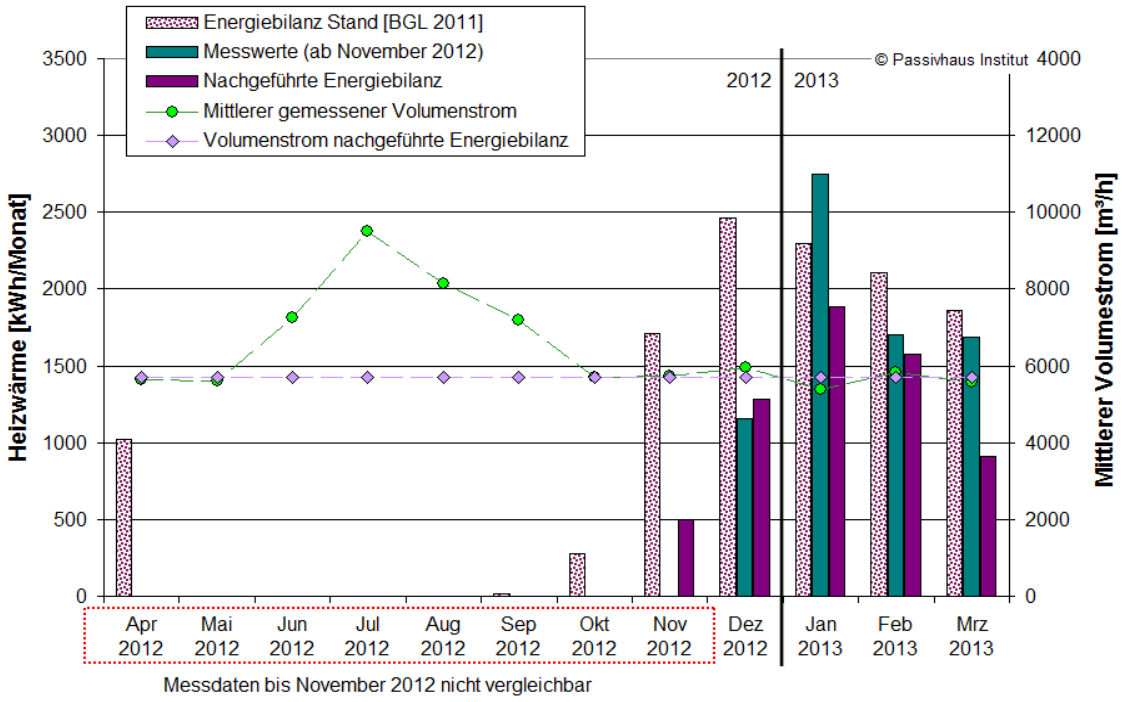

Figure 108: Comparison of the monthly energy requirements from the planning status [BGL 2011] with the measured energy consumption and the required values of the updated energy balance for the foyer, the basement and other adjoining rooms. From May to September there is no need for heating according to the energy balance.

5.1.3 Domestic hot water

The third part of the heating energy is made up of domestic hot water heating. The energy requirement for heating the domestic hot water (showers etc.) is calculated in the energy balance based on the assumed number of people per month, the respective shower water requirement per person and the temperature rise from the average annual cold water temperature to a shower temperature of 40 ° C. The storage and distribution losses are calculated separately and added to the energy required for DHW heating. No distribution losses are included in the original energy balance (as of [BGL 2011]), as there was insufficient information available at the time of this publication.

In the energy balance, 18 liters / person at 40 ° C (shower temperature) are used to calculate the energy requirement, calculated from three minutes of shower time with a flow of 6 liters / minute of the water-saving shower heads. The measured

Hot water consumption in the evaluated measurement period is on average
15.6 liters / person at 45 ° C (temperature when tapping the DHW tank). The equivalent hot water consumption at the shower temperature of 40 ° C is calculated at approx. 18.5 liters / person and is therefore only slightly higher than the assumption of the energy balance (+ 3%). This evaluation indicates the good quality of the selected water-saving fittings, as there are no significantly longer shower times despite the reduced flow rate. The fittings have thus effectively contributed to water and energy savings.

In comparison, the measured heating consumption in the evaluation period April 2012 to March 2013 for DHW preparation with 136,800 kWh / year is in very good agreement with the originally planned value of 136,138 kWh / year (deviation <1%). On closer inspection, however, it becomes clear that different effects compensate each other and thus lead to a matching result - because the energy consumption corresponds to the project planning, despite the lower number of visitors and higher average fresh water temperature. In order to be able to narrow down the cause of the deviations between the measurement and the energy requirement calculation, the energy requirement calculation for the TWW was adjusted with the known parameters from the monitoring (monthly fresh water temperatures and number of visitors). **under** the consumption values. As a result, the original assumptions for calculating energy requirements were somewhat too optimistic - either with regard to shower water consumption per bathing guest or with regard to heat losses. No further analyzes were carried out at this point for the present report. The energy requirement for the DHW and the identified deviations between measurement and energy balance are a comparatively small proportion of the total energy flows in the bath. Optimization is therefore not a major priority. With a general increase in the assumption for the shower time per bath guest by half a minute, the calculations are in better agreement with the measurement data.

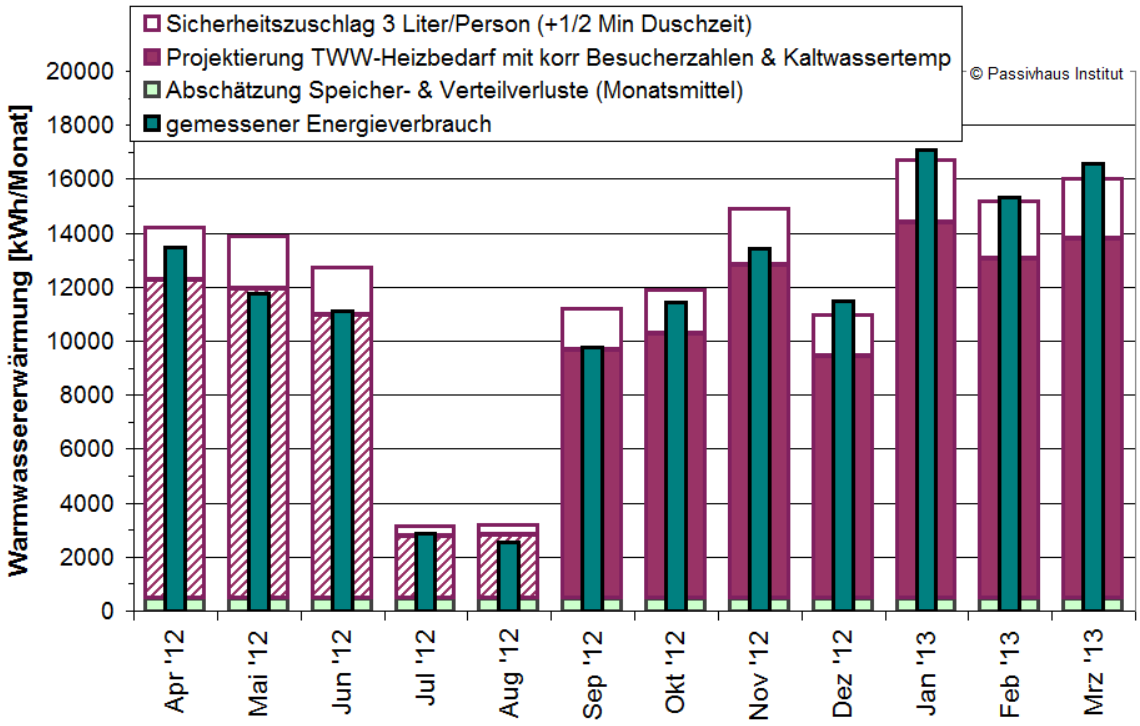

Figure 109: The monthly measured heating energy consumption for DHW heating in the right to the needs calculation after adjusting the number of visitors and fresh water temperatures. (Note: The hatched bars are based on extrapolations of the fresh water temperature.) The project design assumptions tend to be too optimistic, so a safety surcharge for shower water consumption per person is added to the updated / updated energy balance.

Information about memory and distribution losses

The calculated storage and distribution losses in the updated energy balance of the Lippe bath make up a very small proportion of the heating requirements for DHW heating. In the Lippe bath, water hygiene is ensured by an ultrafiltration and chlorine dioxide system directly at the entrance to the main drinking water connection (see [BGL 2011], p.72 ff), so that hot water storage and distribution can take place at a lower temperature level. The monitoring shows storage temperatures between 40 ° C and 45 ° C. This optimization leads to a saving of approx. 50% of the storage and distribution losses compared to a conventional approach with heating the DHW to 60 ° C. During the planning, care was also taken to avoid permanent circulation in order to reduce distribution losses.

5.1.4 Electricity

The determination of the electricity requirement is not the primary component of the PHPP, especially in the context of the very special consumers of a swimming pool. Individual areas can be calculated very precisely with this tool, such as the electricity requirement for ventilation and lighting. The annual total electricity demand of the remaining consumers is entered in the energy balance. With such a special building use, this annual electricity requirement is determined independently of the PHPP. Against the background of the significant share in the energy efficiency of a bathroom, it is strongly recommended that subsequent calculations be carried out as accurately as possible. This list can serve as a basis for identifying optimization potential and exploiting it as far as possible. It is recommended, for example list all pumps and estimate their annual power requirements based on expected runtimes and power consumption at the operating point. In any case, the most efficient devices should be selected.

The measurement data (see section 4.8.3.1) show that the main electricity consumers in the Lünen indoor pool are the ventilation units, followed by the circulation pumps of the three pool circuits ("large pumps") and the sum of all remaining consumers ("Diverse"), as well as light and sockets. A similar weighting was predicted with the energy balance from the planning phase (however, the circulation pumps of the pool circuits were not listed separately from the rest of the swimming pool technology at the time). A comparison of the electricity demand data in the original energy balance with the consumption values is only possible to a limited extent, since the implementation differs from the planning at various points. Nevertheless, Figure 110 shows a comparison of the originally applied electricity demand with the measured electricity consumption for the various sub-areas. In view of the different boundary conditions, the agreement between the individual areas is better than expected. The measured power consumption for ventilation is slightly higher than the expected demand. This is plausible because the measured value also contains the heat pump's electricity consumption, which is not explicitly shown in the energy balance. At the time of publication of the report [BGL 2011], relatively little information was known in the field of swimming pool technology, so these calculations were deliberately on the safe side. Against this background, it is understandable that the measured values are of a similar order of magnitude, despite the increased circulation volumes. For the remaining areas (light, sockets, sanitary and heating), the agreement is very good within the scope of the possible accuracy.

There are still potential savings in this area of final energy consumption in Lünen compared to the current operation, which are partly

balance from the planning phase could be identified. As an an example is

Particularly worth mentioning is the electricity demand for ventilation, which is strongly influenced by the amount of circulating air that is realized.

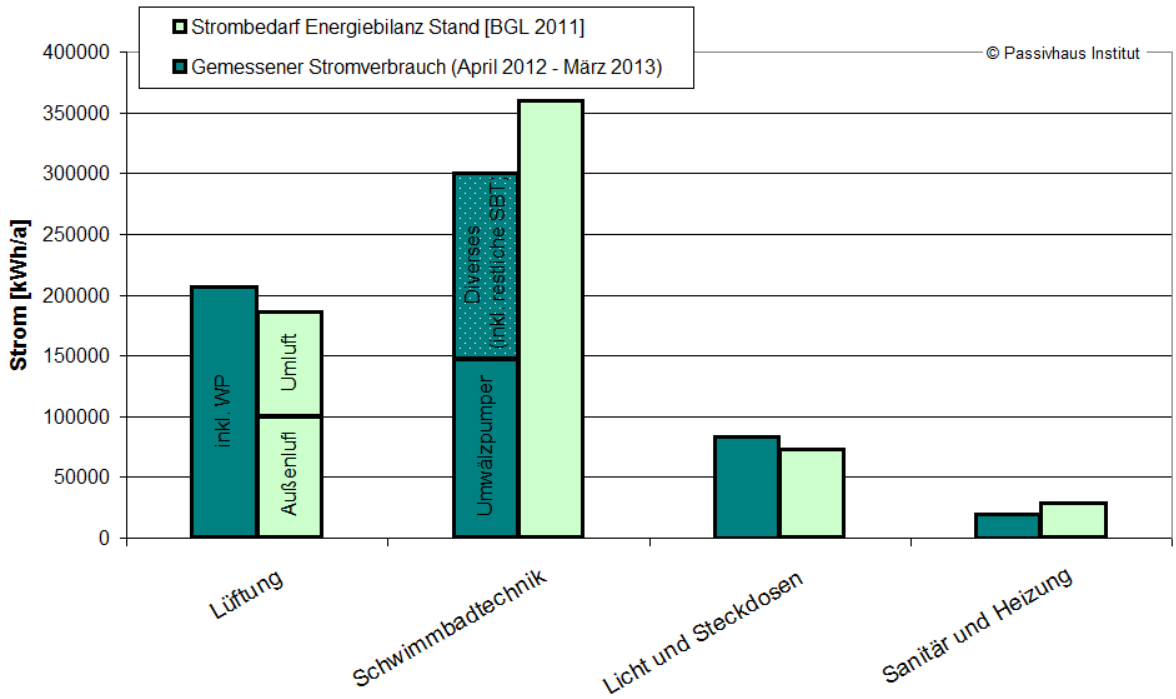

Figure 110: Comparison of the projected electricity requirements during the planning phase with the measurement data from April 2012 - March 2013 according to different sub-areas.

5.2 Energy balance: summary & prospects

The comparisons in this chapter between the measured energy consumption in the Lünen indoor pool and the calculated demand values of the individual areas provide an insight into the complexity of the energy balance of a swimming pool. Despite the inevitable challenges and uncertainties, it was successfully shown that the specially developed multi-zone PHPP for indoor pools is very well suited for the project planning and optimization of main energy consumers.

The tool was adapted during the planning phase of the bathroom to meet the requirements and is still in the development phase. The available measurement data from the monitoring were used to check and further improve the assumptions, approaches and calculation methods of the energy balance. Only a major adjustment of the calculation assumptions was necessary, specifically in the area of pool water heating (cf.

Section 5.1.1). At this point, the measurement data was significantly below the forecast values. The main reason for this deviation was the fact that the evaporation quantities were deliberately set too high during the planning phase, since no reliable data were available for a plausible assessment. Since evaporation has a major impact on the overall energy balance of the bath (post-heating of the evaporation heat losses and the amount of outside air required for dehumidification), determining this size as precisely as possible is particularly important. The magnitude of the evaporation could be determined from the available data, but more detailed analyzes are still pending. Confirm the presented measurement data, that the average mass transfer coefficients for evaporation in practice during the hours of use are significantly lower than specified in [VDI 2089] for the design of the ventilation units (peak load). The determined order of magnitude lies between approx. 20% and 40% of the VDI design, depending on the pelvic cycle under consideration and the given boundary conditions. The monitoring also showed that there are other influencing factors that influence the heating requirements of the pool circuits and could not be sufficiently taken into account in the planning phase, such as the waste heat of the swimmers and heat transfer at the water surface. depending on the pelvic cycle under consideration and given boundary conditions. The monitoring also showed that there are other influencing factors that influence the heating requirements of the pool circuits and could not be sufficiently taken into account in the planning phase, such as the waste heat of the swimmers and heat transfer at the water surface. depending on the pelvic cycle under consideration and given boundary conditions. The monitoring also showed that there are other influencing factors that influence the heating requirements of the pool circuits and could not be sufficiently taken into account in the planning phase, such as the waste heat of the swimmers and heat transfer at the water surface.

Apart from heating the pool water, the calculation results of the energy balance tend to be lower than the measured consumption. The course of the year for space heating requirements in the various temperature zones as well as the magnitude of the individual main consumers (space heating, water heating and electricity) are correctly represented. Since the measurement data relate to a period in which the bath was still adjusted in different areas and different operating modes were implemented, the annual consumption cannot be fully compared with the calculated demand values. Figure 111 nevertheless shows a comparison of the tracked energy balance, adjusted with the described findings from monitoring and the actual measured values. The agreement is good, which confirms the calculation approach.

Despite the typical adjustment period, the indoor pool achieved a very good energy value in the first measurement year. The planning measures have achieved the intended success. As analyzed at various points in this report, the energetic optimization with regard to the operating mode is still not exhausted. Figure 112 shows an updated energy balance for the bathroom under the desired boundary conditions (e.g. 64% hall humidity, reduced circulating air volume flows, 70% filter rinse water treatment). Since the assumptions are still unclear in some areas, this is also one

orienting Calculation. At this point, the measured values from the monitoring were adopted for the electricity requirements of swimming pool technology (SBT), lighting and other consumers. The electricity consumption of the ventilation was calculated with the PHPP. Compared to the measurement results from April 2012 to March

According to this estimate, a further reduction of the final energy requirement by approx. 100 kWh / (m²a) is possible in 2013. The biggest part here is the savings from filter rinse water treatment. The electricity requirement can also be significantly reduced by reducing the amount of circulating air, which is of great relevance when considering primary energy.

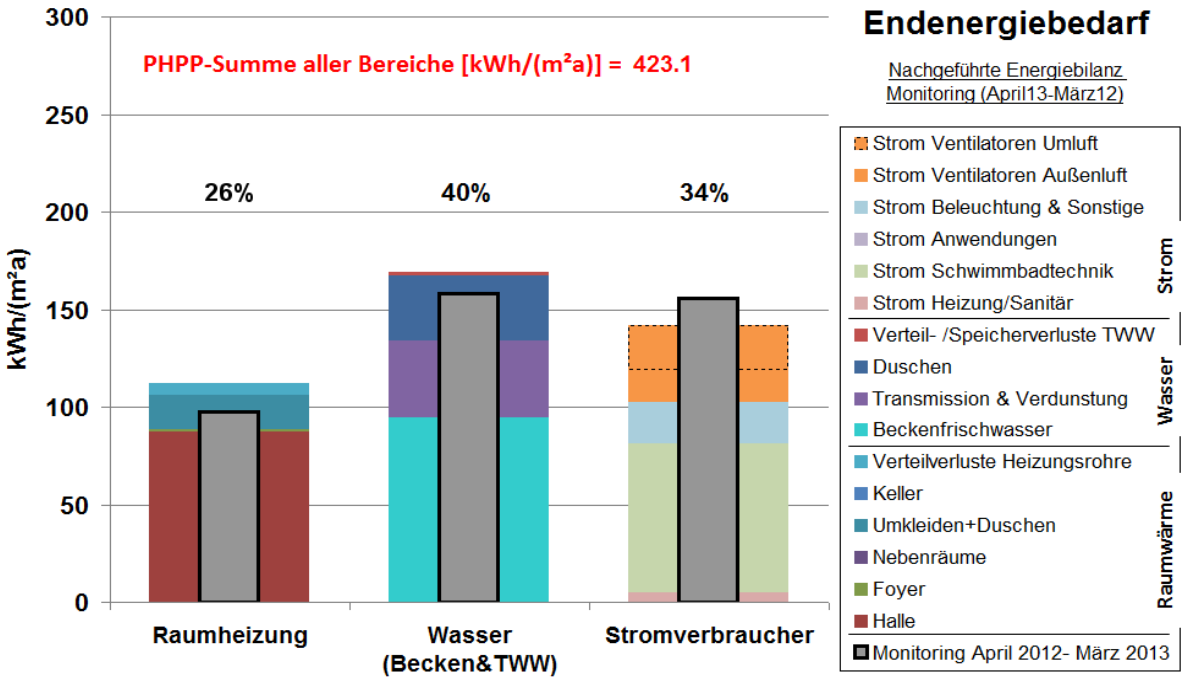

Figure 111: Tracked energy balance under the measured boundary conditions of the Winters 2012/2013 and other measurement data from April 2012 to March 2013. A more exact match with the measurement data is not to be expected due to the inconsistent operation and the remaining uncertainties of some assumptions. The orders of magnitude are calculated correctly. These are specific values related to the energy reference area.

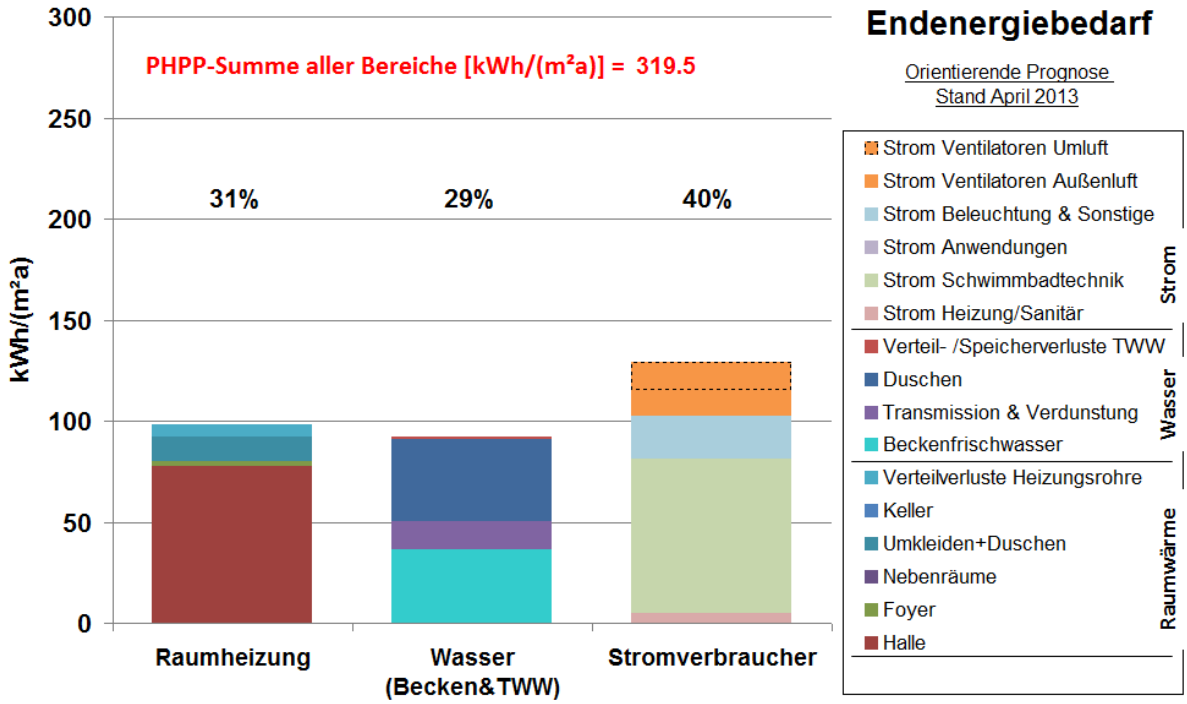

Figure 112: Forecast of the energy balance with the recommended operating mode (future Business). Compared to the current mode of operation, there is further savings potential of approx. 100 kWh / (m² EBF a), mainly caused by the recommissioning of the filter rinse water treatment.

Primary energy balance

As already described in section 4.9, the primary energy requirement is of interest for a final energetic assessment. The final energy balance described in detail in this section is the basis for this. As a further step, the energy producers for the various consumers and the corresponding primary energy factors must be set up. The fact that there was a shift in the focus on electricity compared to heating energy was recognized and emphasized in the planning phase (cf. [Schulz et. Al. 2009] and [BGL 2011]). The greatest uncertainty regarding a calculation of primary energy demand is to predict how much energy will be provided by the different energy providers. For this purpose, estimates were made in the planning phase, which are reflected in the measurement data.

6 Perspectives

The Lippe bath in Lünen is one of the first two pilot projects to implement the passive house concept for indoor swimming pools. Up to the present point of view, the basics of the energy concept were developed in joint work, then applied in the planning process and finally implemented step by step in the ongoing bathroom operation. As shown in this report, the first major milestones have been reached and important insights into the operation of an energy-optimized indoor pool have been gained.

The extensive measurement data from the investigation period were evaluated in detail in order to consider basic questions. Further research needs could be identified at some points. The potential of the pool's energy optimization measures has not yet been fully exploited after this first monitoring period. Due to the existing extensive measurement technology, the good understanding of the complex building technology and their control, the Lippe bath now offers ideal conditions for the systematic clarification of further questions regarding the operation of energy-saving indoor swimming pools. Future test series offer a high potential to advance further perspectives of energy efficiency in indoor swimming pools. Some exemplary projects for tests and further analyzes in the Lippe bath are:

- Permanent implementation of the reduced supply air volume flows for the hall areas to reduce electricity consumption. Test for night operation of the ventilation systems only for moisture protection (increased humidity / reduced temperature).
- Investigation of the energetic influence of the alternative ventilation control strategy "dehumidification via recirculation with HP" for the halls.
- Continuation of the systematic investigations on evaporation (e.g. influence of the hall humidity, the swimmers etc.)
- Development of optimization recommendations for the ventilation of the showers and changing rooms.

- Further analysis and optimization options when using a heat pump to use the exhaust air enthalpy.
- Potentials by optimizing the circulation of the pool water (e.g. night cooling, circulation under water) - influence on the evaporation and the power consumption of the pumps.

- Further considerations on the energy balance of the pool water circuits (e.g. heat dissipation by the swimmers, heat transfer on the water surface). The various influencing parameters were explained in the context of this report, but could not be specified.

- Further development of the Passive House Planning Package (PHPP) for future energy balancing when planning indoor swimming pools. Such a tool is not yet available and is essential for assessing energy saving measures. The PHPP multi-zone version is currently in the development phase.

- Air quality: Continuation of the investigation into the effects of different ventilation strategies on air quality (disinfection by-products).
- Examination of the hot water consumption at the taps (shower heads) to evaluate and optimize the heat losses and utilization of the shower areas. As already described above, a further reduction in the final energy requirement of around 100 kWh / (m²a) is possible compared to the current measurement results of this investigation. This corresponds to a potential reduction of around 25% of the final energy now balanced.

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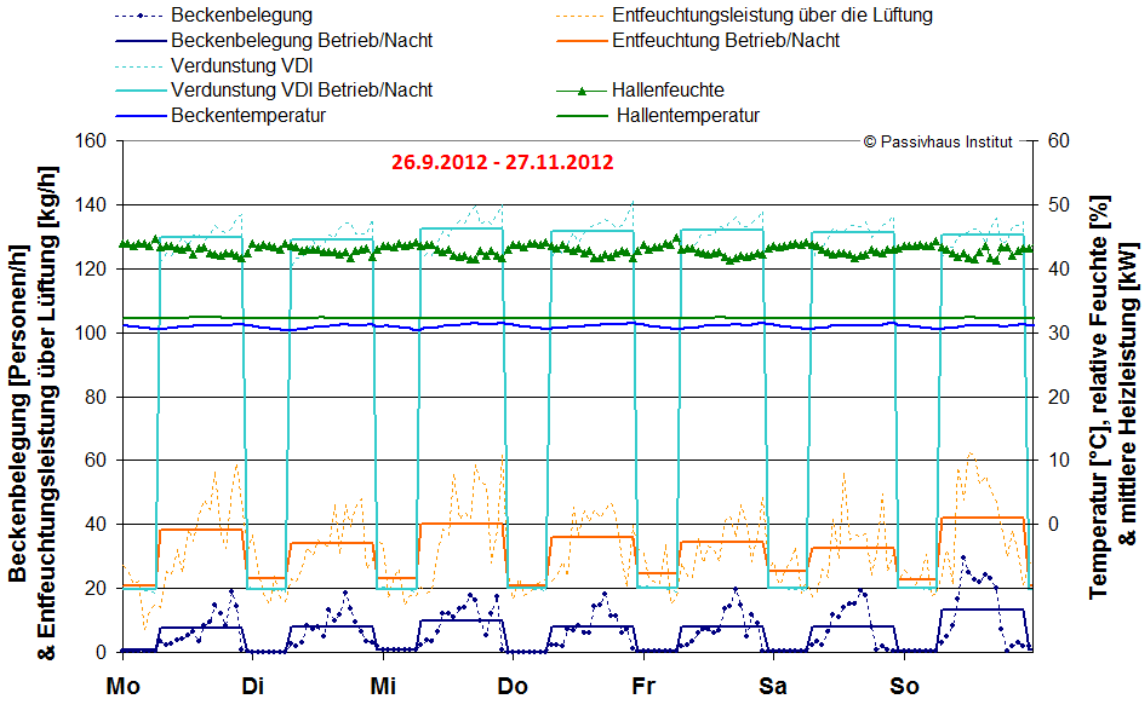
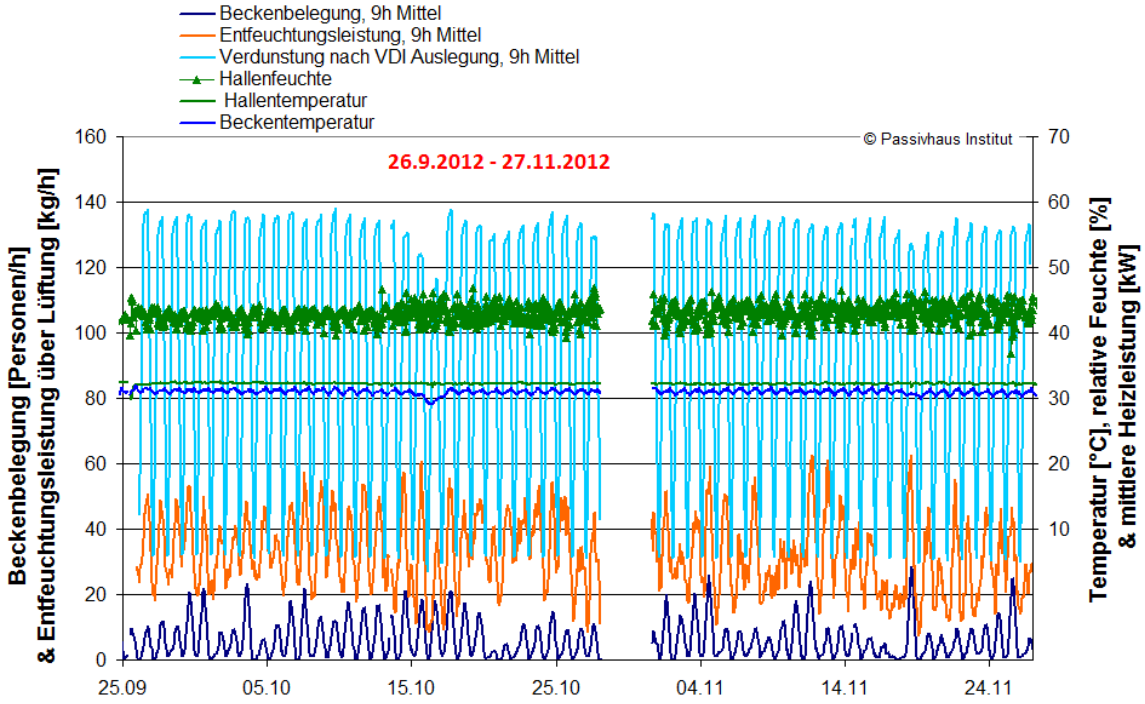
Spray seal in the parent-child pool

8th Appendix: Dehumidification performance during the course

In the following diagrams, two periods are shown for each hall, each with different boundary conditions (hall humidity, temperatures) as average values for the weekly hours (average values of all measured values of one size per weekday and hour) and over time (hourly data). This enables a comparison between the dehumidification performance (calculated from measurement data) and the maximum evaporation quantities according to VDI 2089.

Hall 1 + 2





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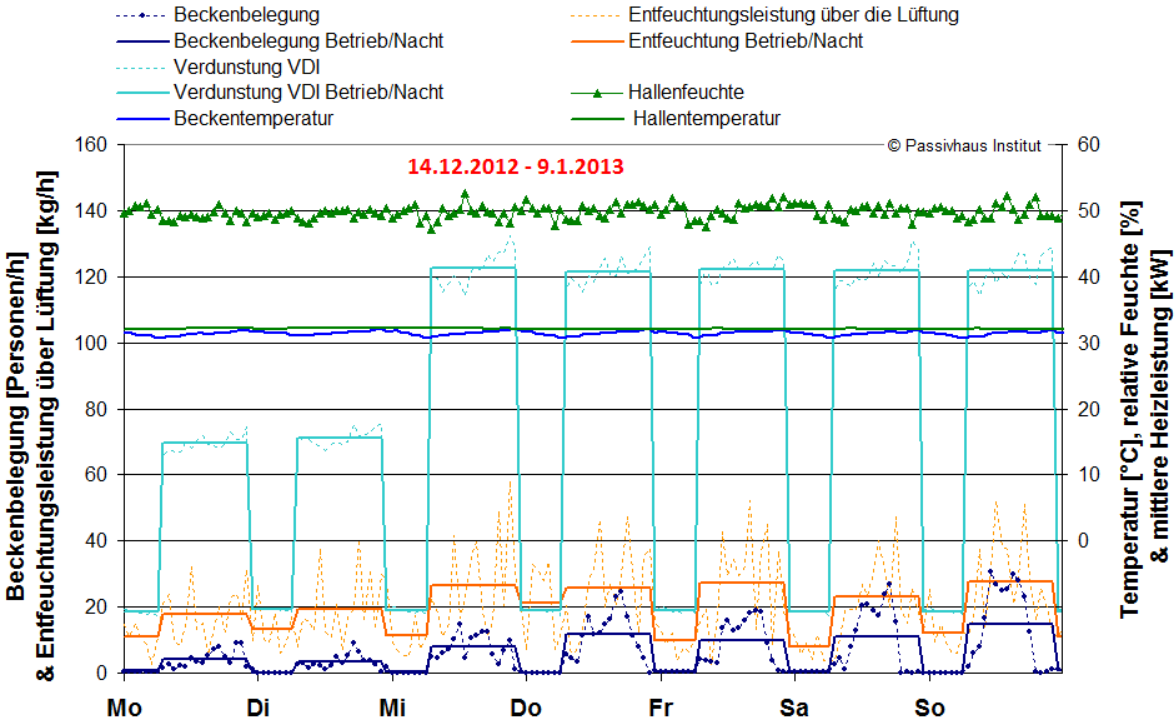

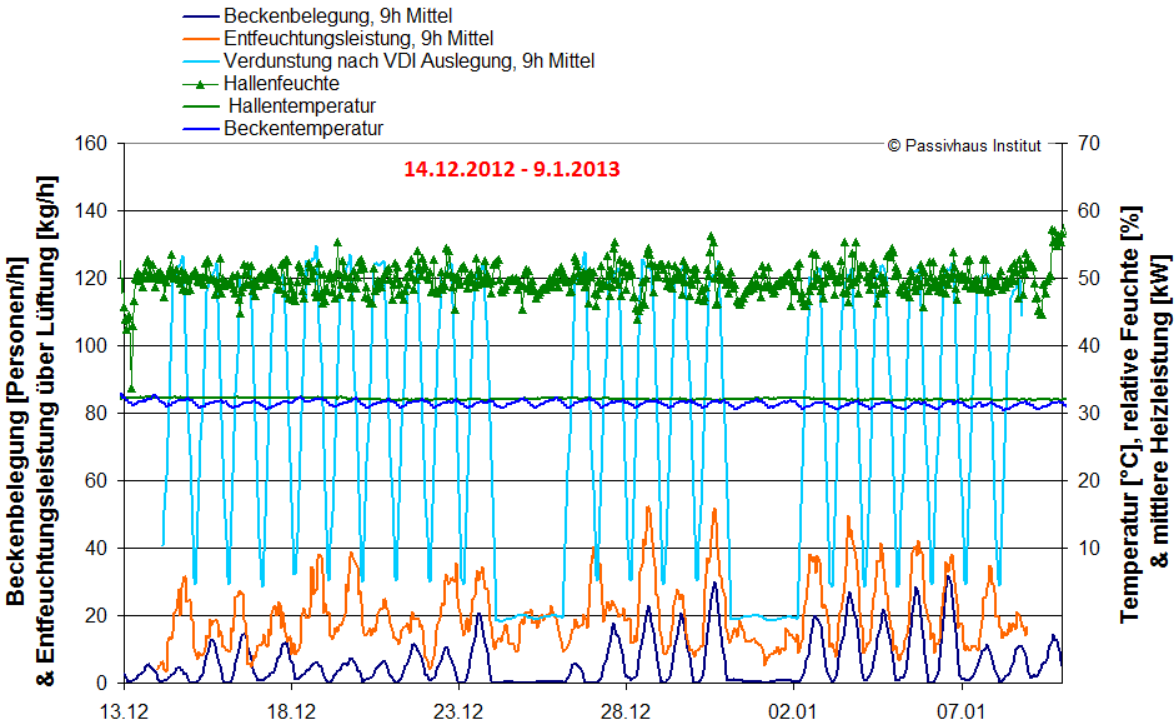

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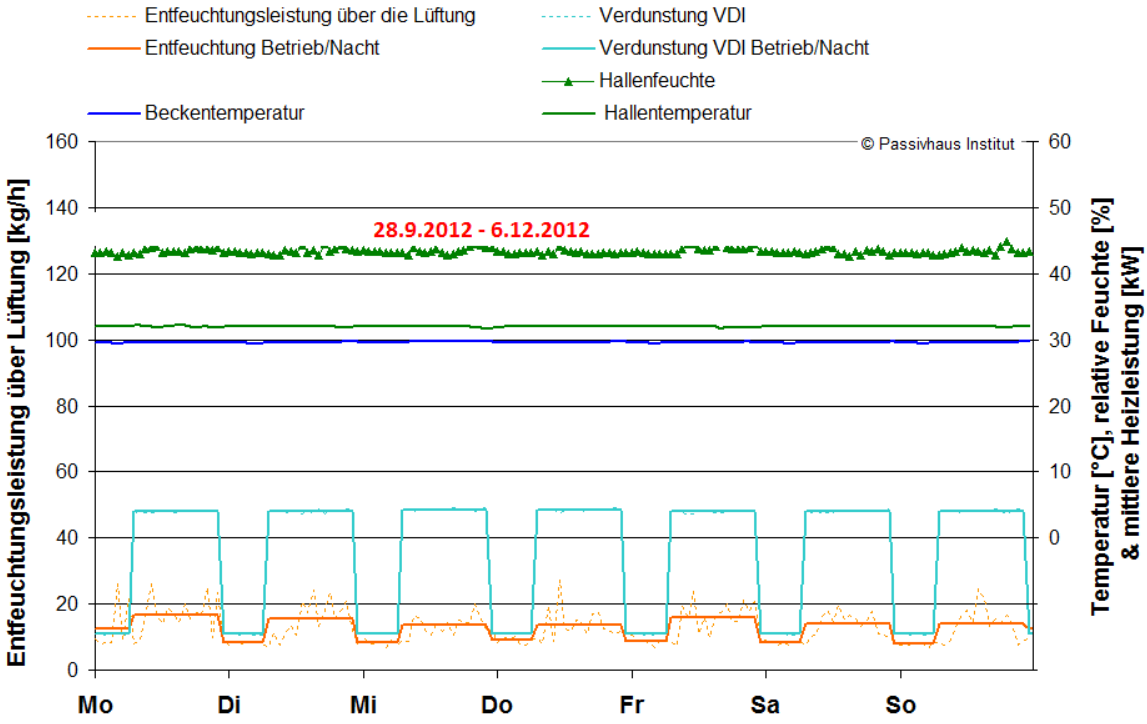
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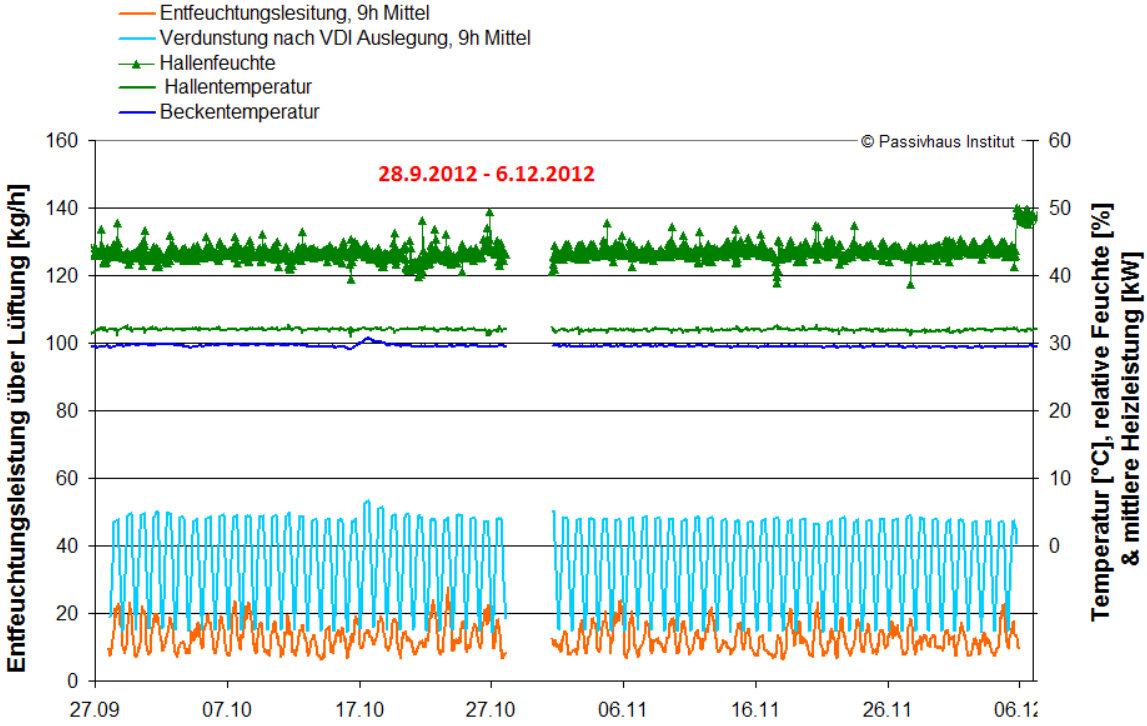
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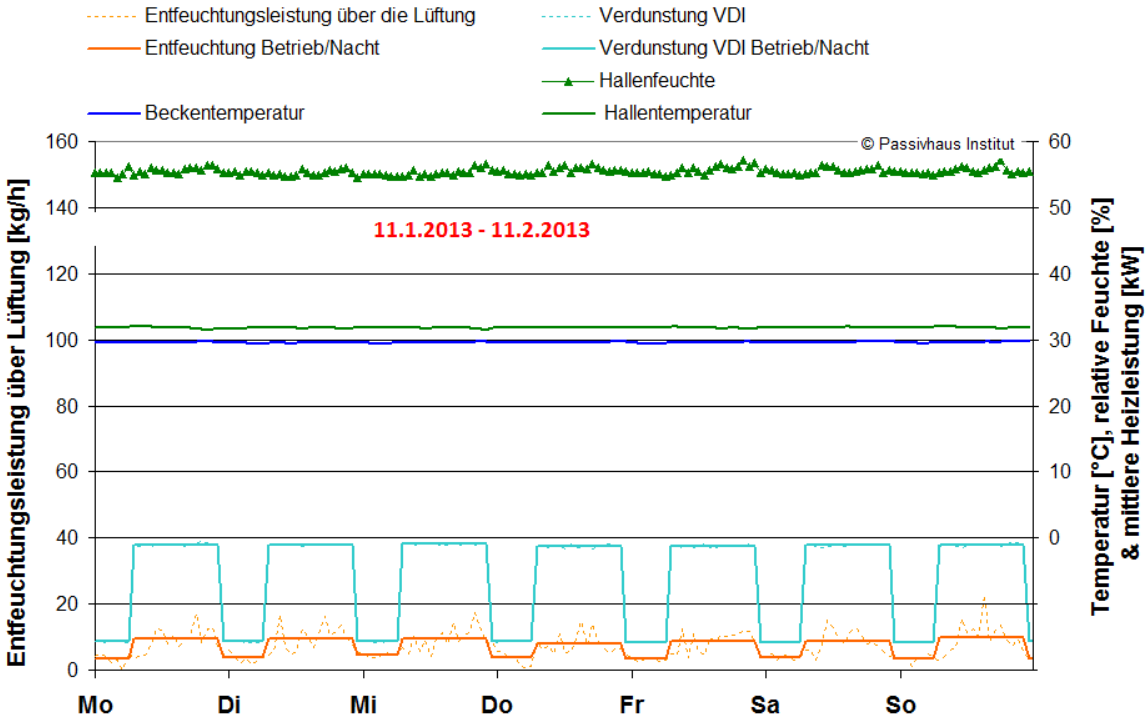

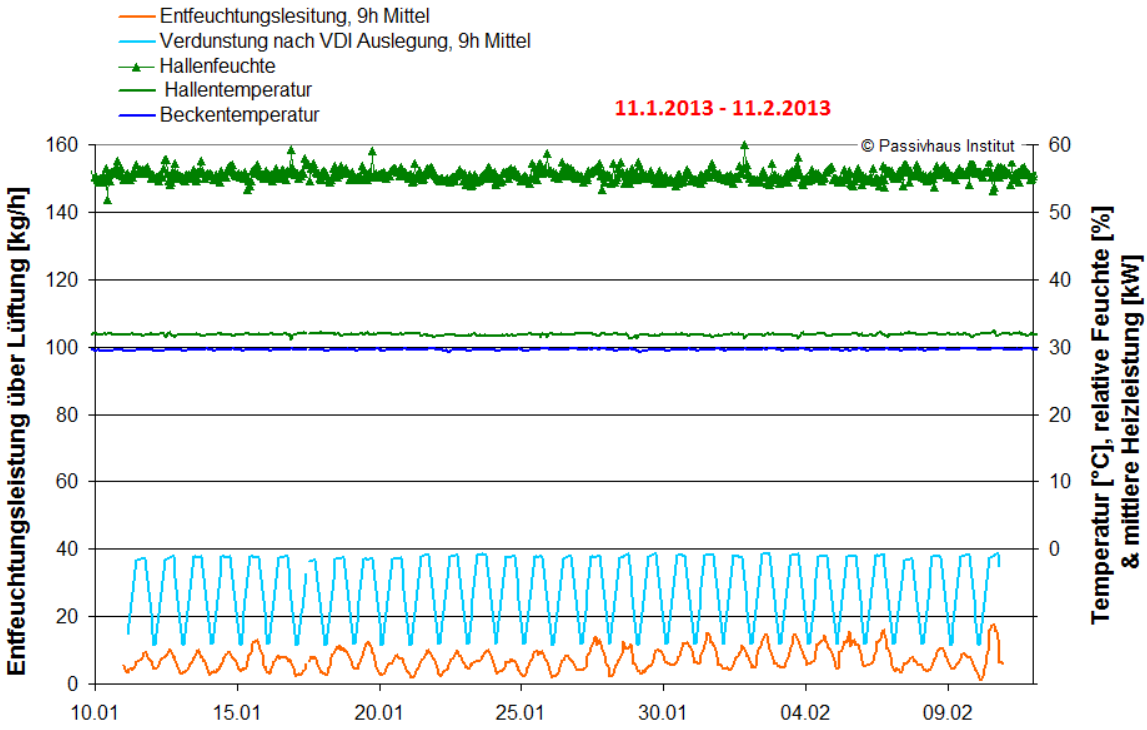

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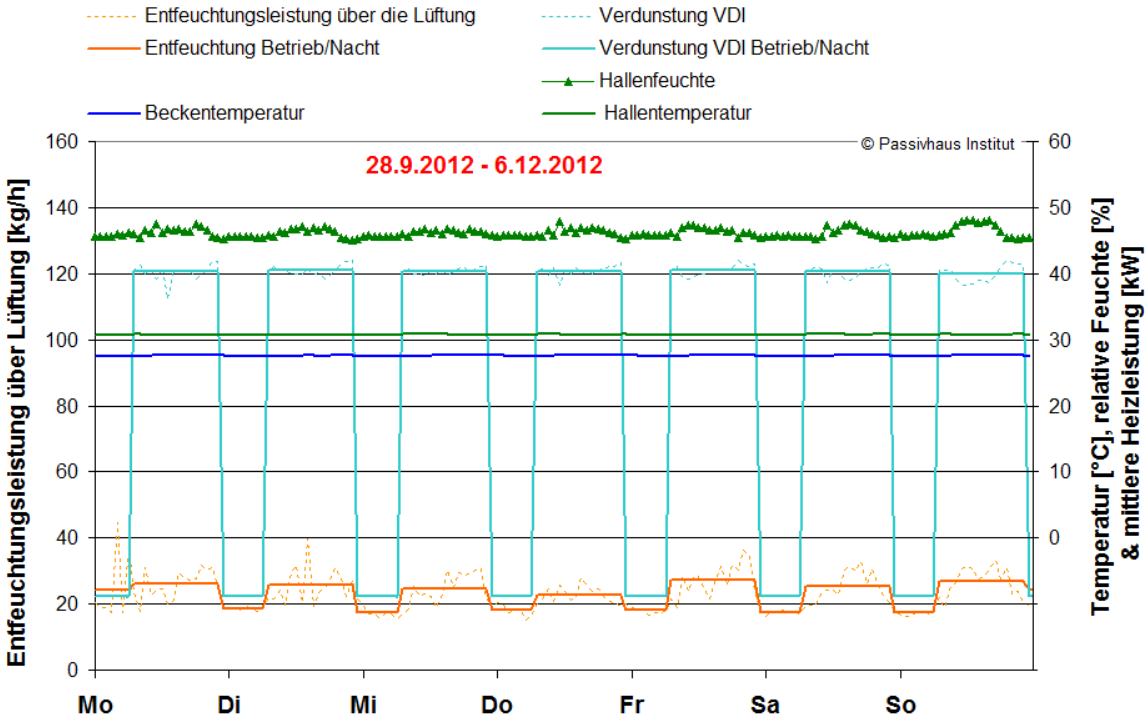
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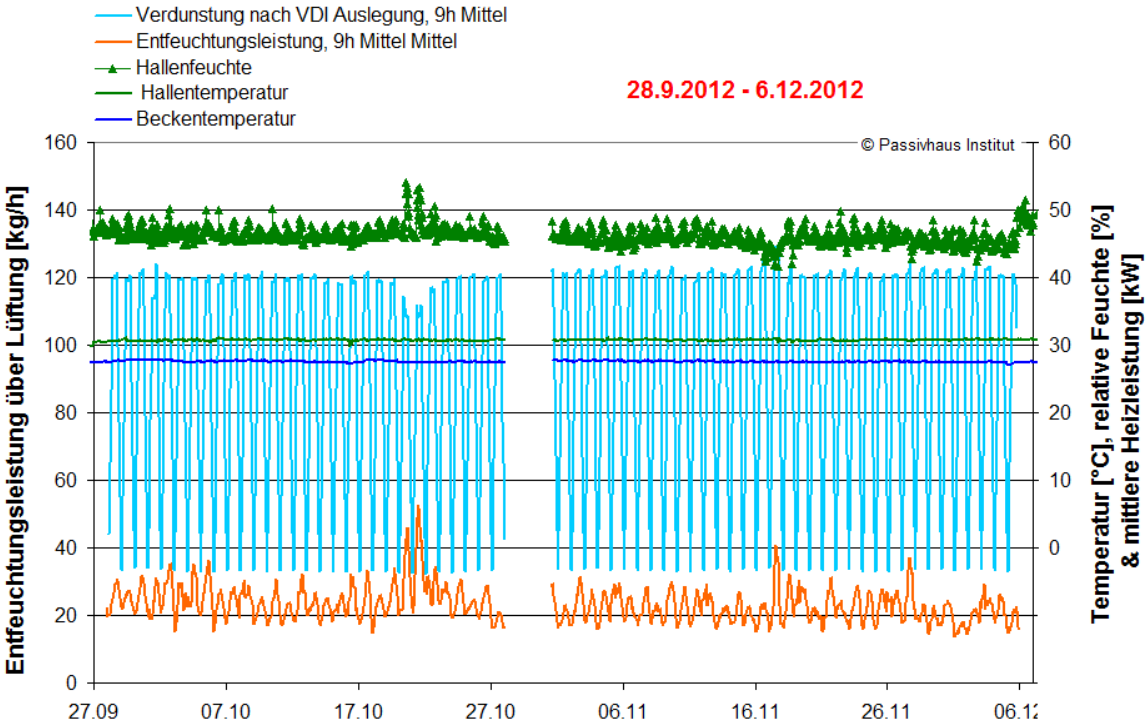
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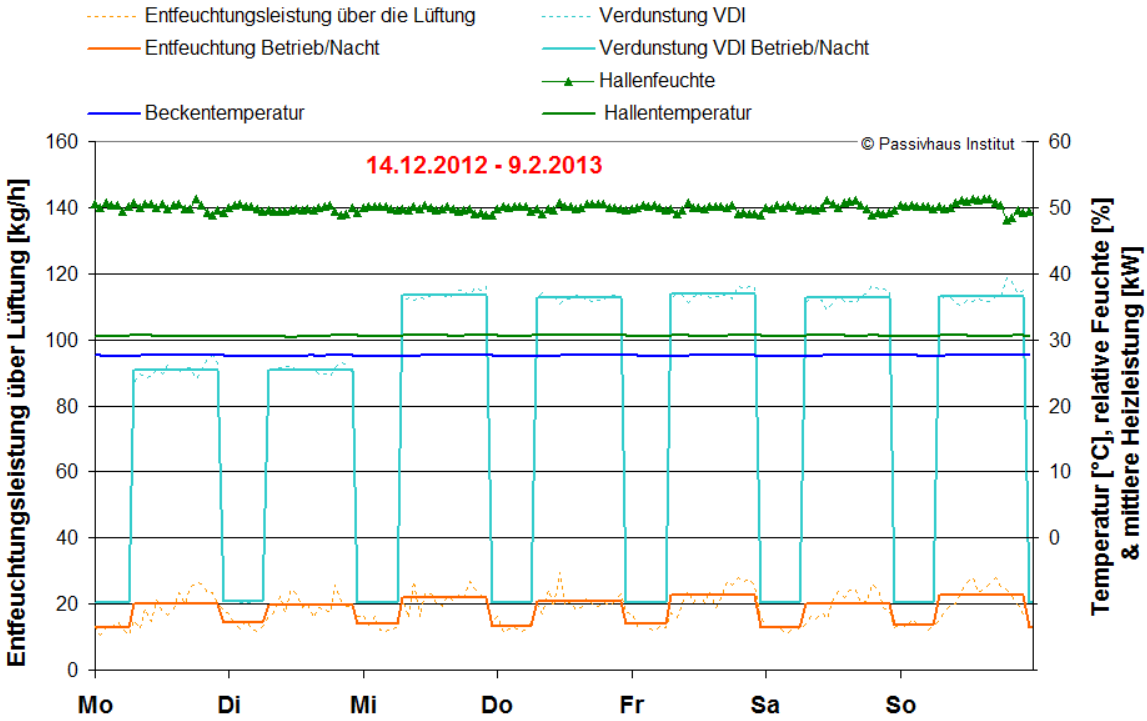
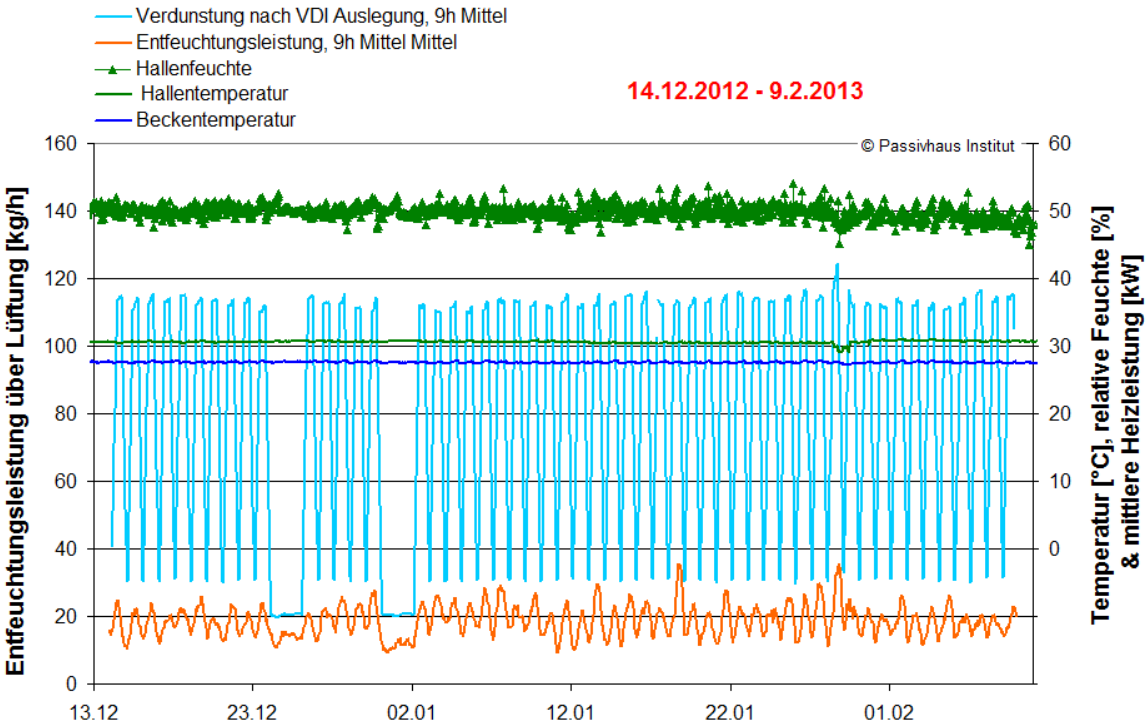
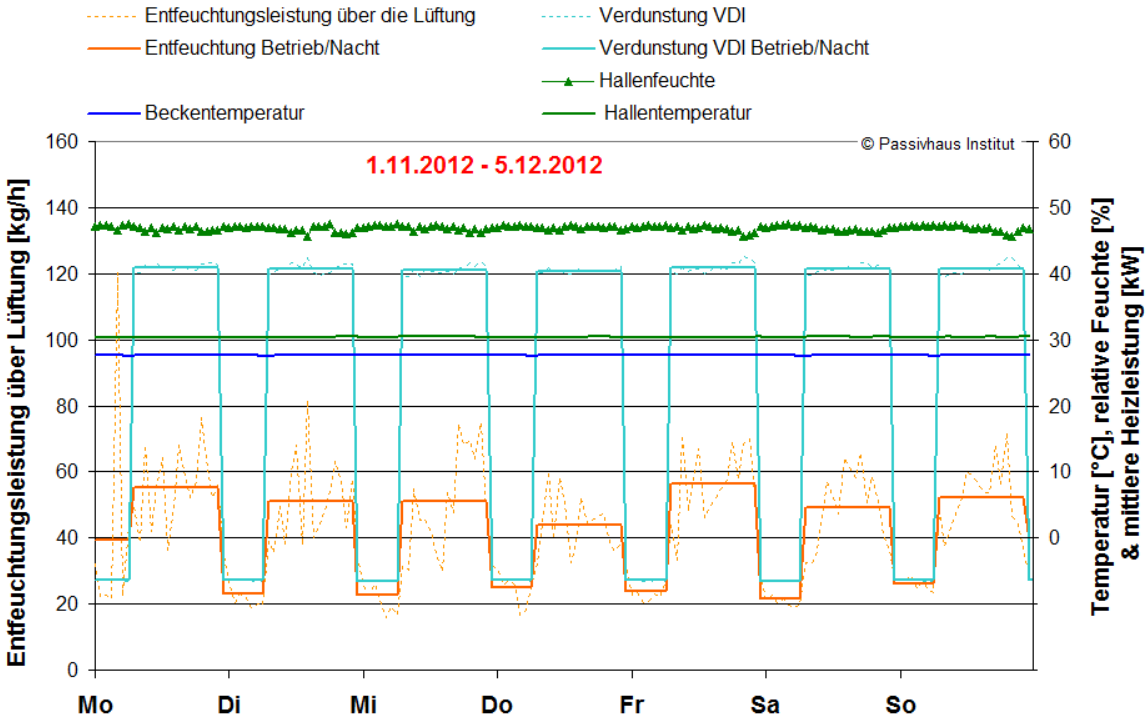




Hall 5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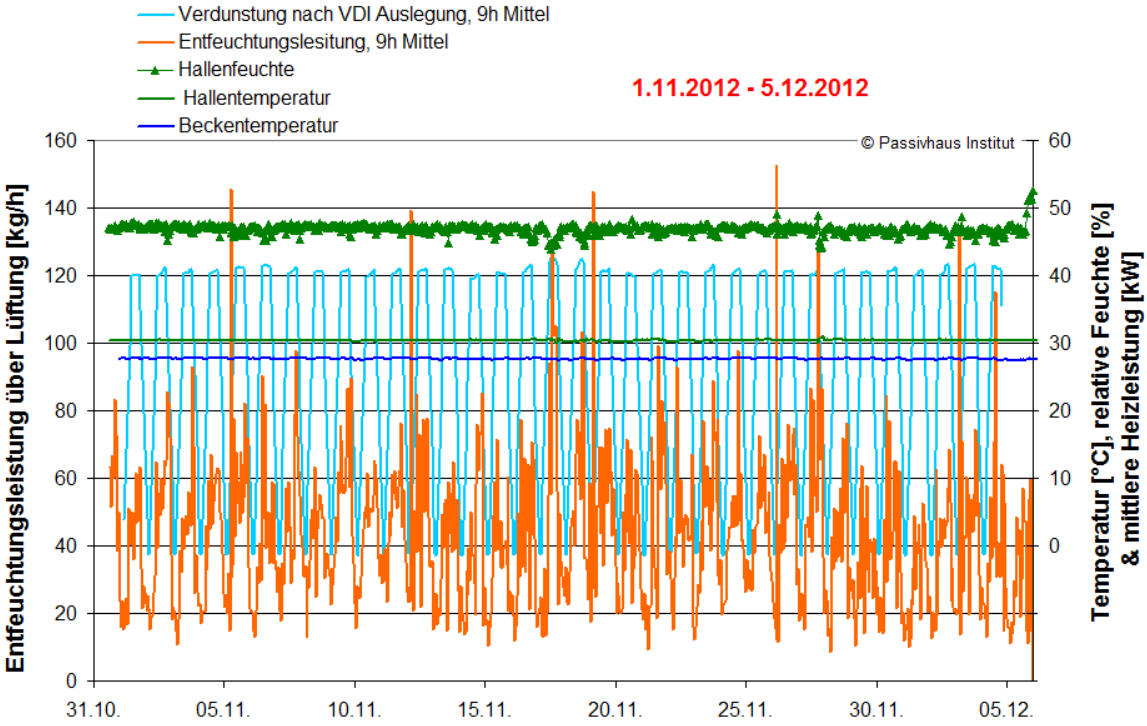
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