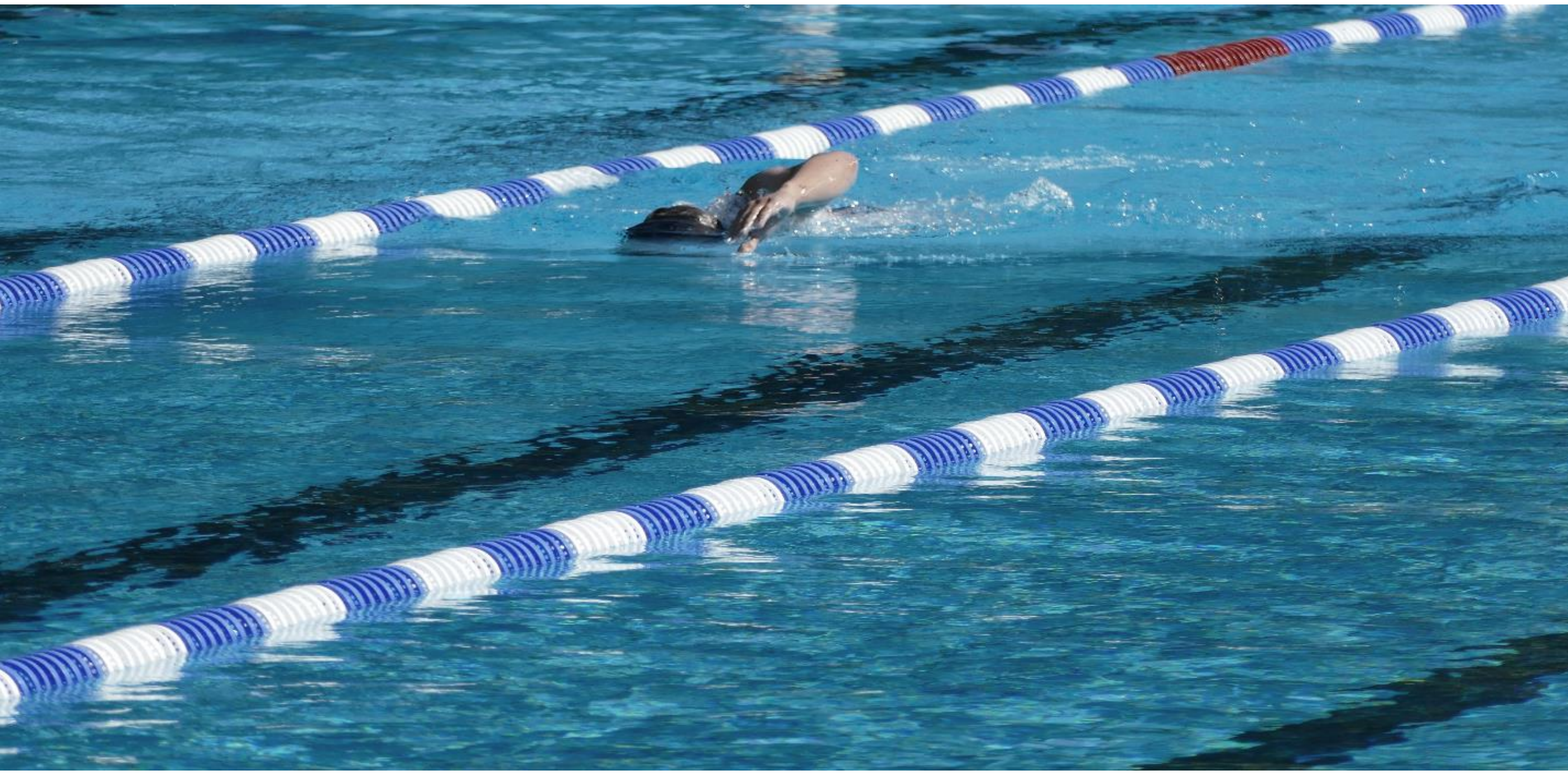
Passive House concept for indoor swimming pools:

Guidelines



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1 Introduction

A growing number of people, political institutions and organisations are becoming aware of the fundamental importance of energy efficiency. Despite this fact, it is still frequently the case that only the investment costs are considered. For example, a municipality wishes to provide a swimming pool for its citizens and decides what kind and size of pool it can afford based on a specific investment amount. The fact that a major share of the costs will be incurred only after the construction is completed, namely for operation of the pool, is not given much attention during this process. By taking into account efficiency measures early on during the planning process, the energy demand of indoor swimming pools can be reduced considerably. This not only contributes to climate protection but also entails savings for the financial resources of a municipality.

The Passive House concept is a comprehensive approach which considers the overall energy consumption of a building. By investing in intelligent planning, in high quality building components and in a tried and tested control strategy, the energy costs for operation of the building can be reduced significantly. This means that although the investment costs might be slightly higher, the operating costs will be reduced.

There are also other advantages apart from lower operating costs:

- Planning certainty for budgets due to less dependence on energy price increases
- A high quality and durability of the building substance, because airtightness and high interior surface temperatures protect against structural damage
- A high level of thermal comfort
- Contribution to the energy revolution and sustainable energy supply structures

On account of the high energy consumption of indoor swimming pools, an increase in energy efficiency has a particularly strong impact. These guidelines provide recommendations for implementing a high level of energy efficiency with regard to planning as well as commissioning and operation management. This document has been prepared by the Passive House Institute within the framework of the research project "Passive House concept for indoor swimming pools: Data evaluation and recommendations". The recommendations are based on theoretical research work and investigations by the Passive House Institute, as well as practical experiences gained from monitored pilot projects.

In addition to these detailed guidelines, a quick reference guide for building owners, operators and other interested parties is available on www.passivehouse.com. Other detailed reports relating to Passive House indoor swimming pools (Bambados and Lippe-Bad) can also be found here (see also Section 9: Conclusion and further information). Note that some of the literature is available only in German.

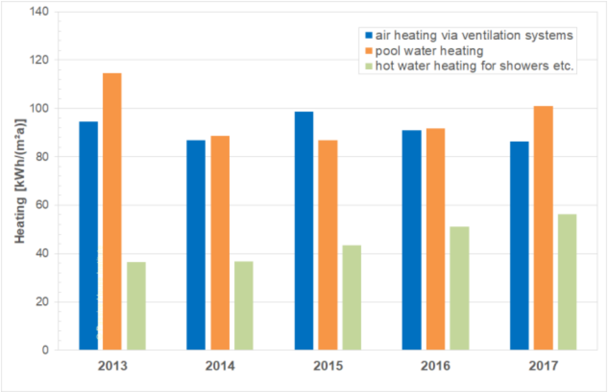


Fig. 1: **Lippe-Bad in Lünen: Measured energy consumption for space and water heating (reference: total heated area of the pool).**

In particular the high quality of the building envelope to the Passive House standard with high surface temperatures enables a new way of thinking compared to conventional planning of swimming pool buildings, thus providing new opportunities for energy relevant optimisation. Fundamental relationships are depicted in the schematic diagram below.

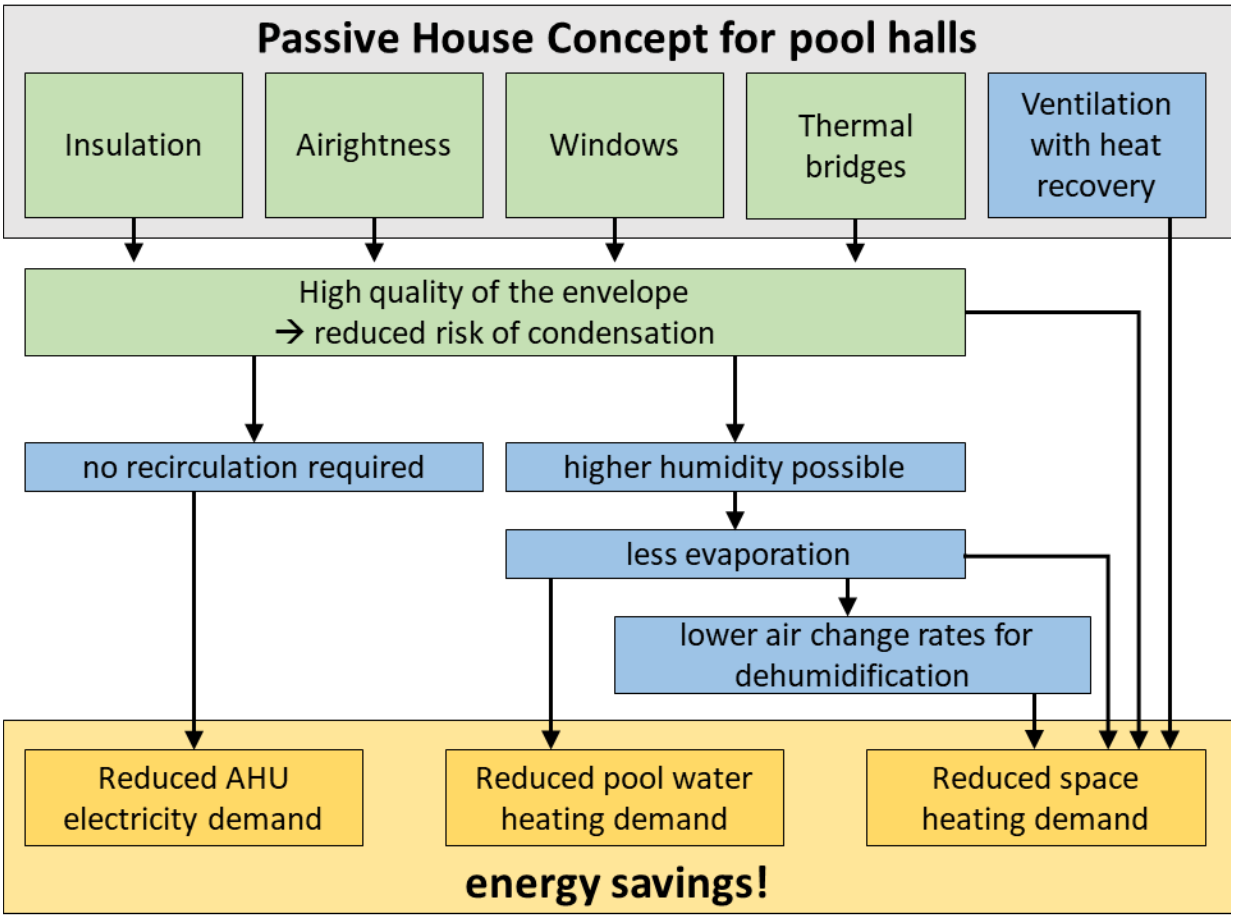


Fig. 2 **Schematic diagram: Relationship between the Passive House concept and energy savings**

In order to achieve a solution that is energy efficient as a whole, all other energy loads inside the building must also be considered besides heating of the swimming pool halls. This is true particularly for the following areas:

- Electricity demand for swimming pool technology
- Heating energy demand for hot water (mainly showers)
- Demand controlled ventilation with heat recovery
- Fresh water and heating energy demand of the pool water
- Electrical efficiency of other energy applications
  e.g. lighting, ventilation, building systems etc.
- High efficiency of any other leisure areas or additional facilities
  e.g. water features, sauna, spa, fitness equipment, catering etc.

The comprehensive and consistent application of Passive House principles in indoor swimming pools offers a high level of comfort and good air quality with the minimum possible use of energy and thus low operating costs.

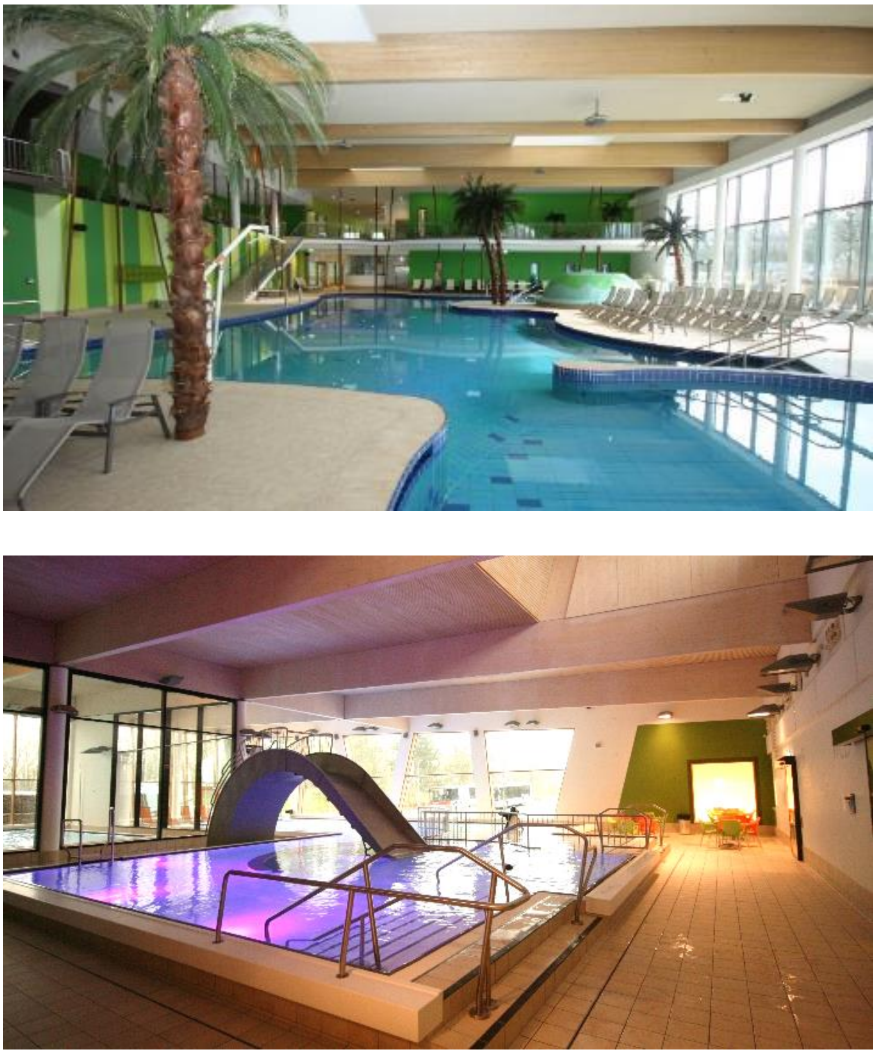


Fig. 3: The first two Passive House swimming pools Bambados in Bamberg (above) and the Lippe-Bad in Lünen (below), which were both completed in 2011.

2 Building envelope

A highly thermally insulated building envelope saves a significant amount of heating energy, increases structural protection and is therefore advisable both in economic terms and with regard to climate protection. Compared to typical buildings that are heated to 20 °C, the transmission heat losses of the exterior building components of indoor swimming pools with a warmer indoor temperature of ca. 30-32 °C are considerably higher, as are the savings with each additional centimetre of thermal insulation.

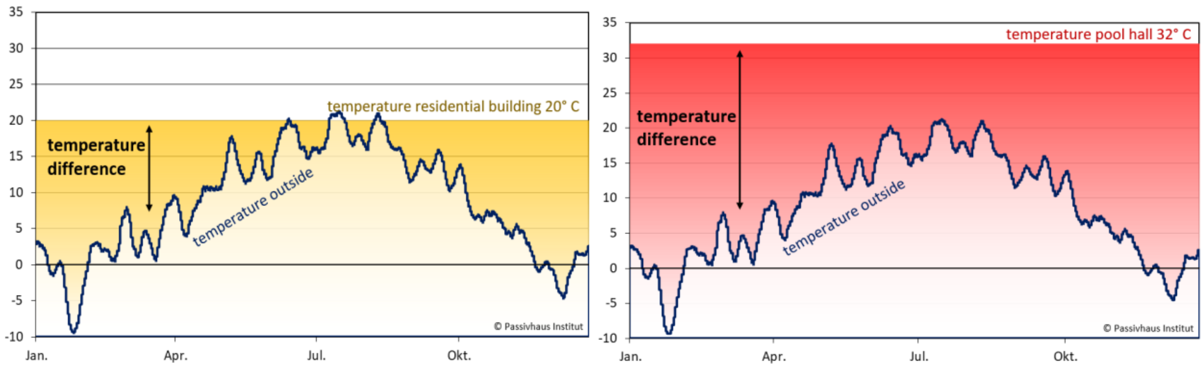


Fig. 4: Compared to a residential building with an indoor temperature of 20 °C, the temperature difference between the inside and the outside is much higher in the case of swimming pool buildings. The heating period is therefore significantly longer.

Due to the high indoor temperature and evaporation of the pool water, there is typically a year-round heating demand, as demonstrated by the following measurement data evaluation of the heating energy consumption of a swimming pool hall of the Lippe-Bad project:

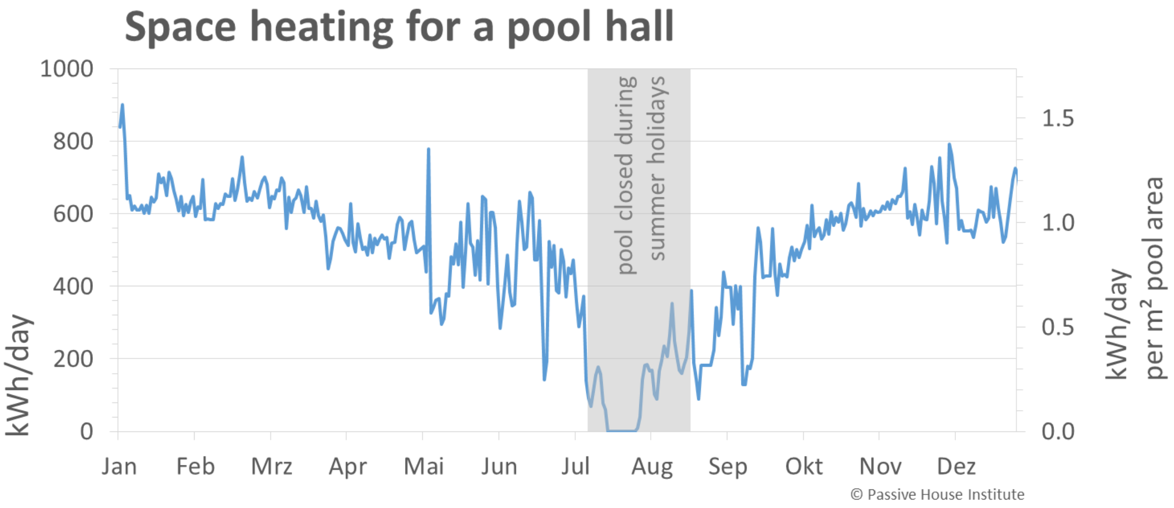
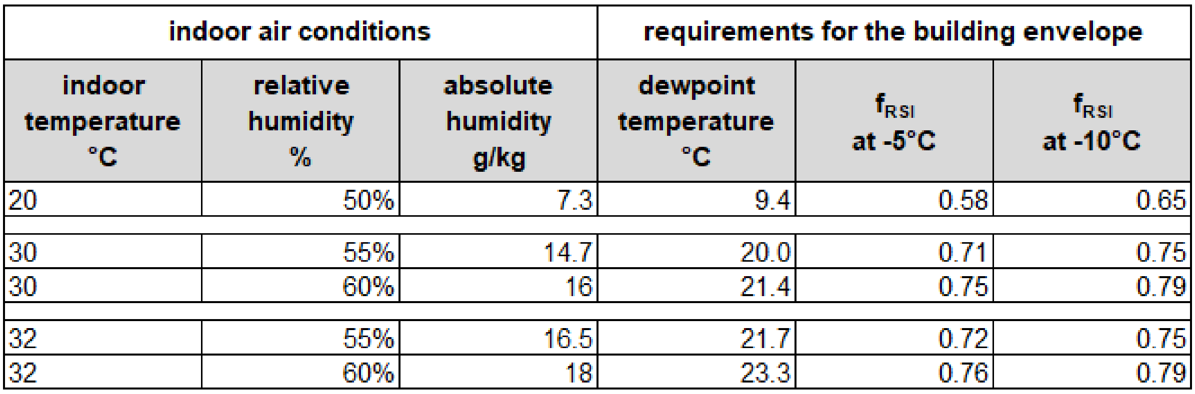


Fig. 5: Heating energy consumption of the sports pool of the Lippe-Bad in the year 2016 (pool area 575 m², average temperature in the hall 28°C & indoor humidity 52%)

The total energy demand can be reduced by increasing the humidity level in the pool hall (see schematic diagram on page 4). The limiting factor, among other things, is the minimal surface temperature of the building envelope, which is where the risk for condensation is most critical. This is usually the case at the windows and severe thermal bridges. In addition to low U-values, special attention must therefore also be given to thermal bridge free planning and implementation. The critical dew point temperatures for different indoor air conditions are compiled in Table 1.

Table 1: Dew point temperatures for different indoor air conditions



indoor air conditions			requirements for the building envelope		
indoor temperature °C	relative humidity %	absolute humidity g/kg	dewpoint temperature °C	f_{RSI} at -5°C	f_{RSI} at -10°C
20	50%	7.3	9.4	0.58	0.65
30	55%	14.7	20.0	0.71	0.75
30	60%	16	21.4	0.75	0.79
32	55%	16.5	21.7	0.72	0.75
32	60%	18	23.3	0.76	0.79

Windows and curtain wall façades have higher losses than the insulated wall and therefore lower surface temperatures. In conventional constructions these components are at high risk of condensation. In contrast, the high thermal quality of Passive House suitable triple glazing and the thermally separated frame profiles means that it is no longer necessary to blow warm dry air onto the façade in order to prevent condensation of occurring. This, in turn, means that alternative approaches can be considered for introducing supply air into the swimming pool hall and the proportion of air recirculation for the hall ventilation can be reduced significantly or even eliminated entirely.

Advantages of a highly thermally insulated building envelope for indoor swimming pools:

- High indoor temperatures -> year-round heating demand → high savings potential
- Greatly reduced transmission heat losses → additional insulation is very cost-effective
- Less or no air circulation is necessary for "drying" the façade → noteworthy amount of electricity savings
- Thermal bridge free → temperature does not fall below dew point -> component is protected

2.1 Opaque building components

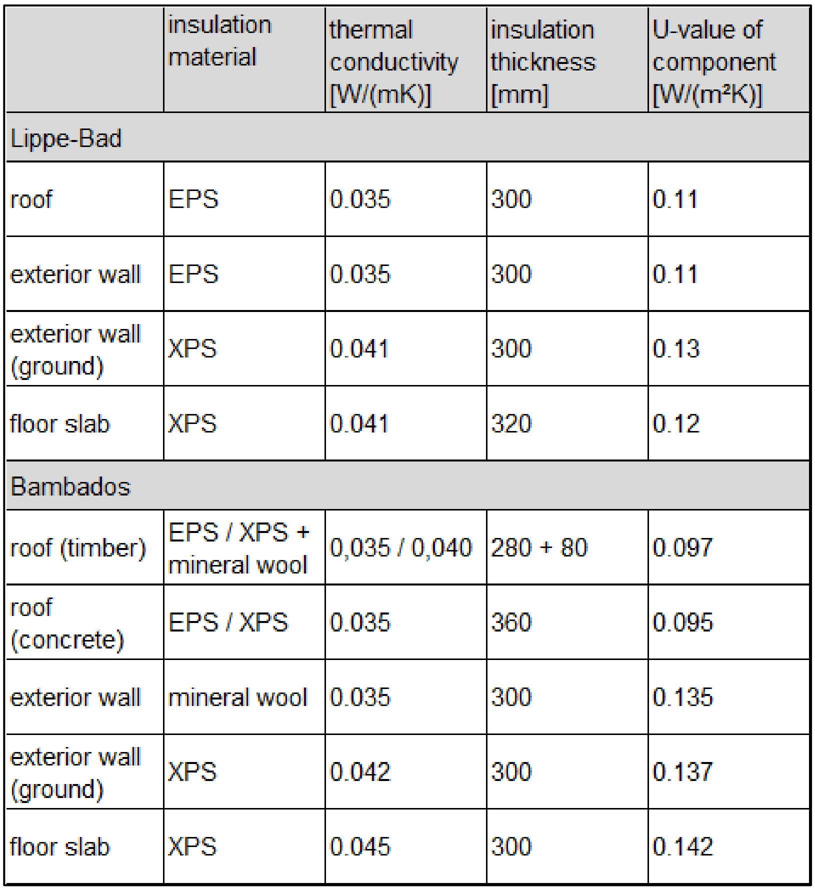
While the U-values (heat transfer coefficient) recommended for exterior walls at normal indoor temperatures of 20°C is 0.15 W/(m²K) at the most for Passive House buildings in Central Europe (see [PB 42]), much better U-values are strongly recommended from the economic view point in the case of higher indoor temperatures. Due to the higher indoor temperature (32°C), a swimming pool building exhibits significantly higher heating degree hours compared to a normally heated building (20°C). Based on an example of a swimming pool building in Germany with a compound insulation system, improving the U-value from 0.15 W/(m²K) to 0.10 W/(m²K) cuts the heating demand by almost a half.

When choosing the products, consideration should be given to the special indoor space conditions of swimming pools (high humidity levels and chlorine loads). Regular inspections of the structural integrity is important for swimming pool buildings in general, regardless of the efficiency standard.

Examples for the building component quality (Lippe-Bad / Bambados)

As an example, the following table lists the quality of the building components of the Lippe-Bad in Lünen and the Bambados swimming pool in Bamberg. Since then more insulation materials with lower thermal conductivities have become available on the market, therefore from the economic perspective even better U-values should certainly be realised in future projects.

Table 2: Overview of the quality of building components of the Lippe-Bad and Bambados pools:



	insulation material	thermal conductivity [W/(mK)]	insulation thickness [mm]	U-value of component [W/(m²K)]
Lippe-Bad				
roof	EPS	0.035	300	0.11
exterior wall	EPS	0.035	300	0.11
exterior wall (ground)	XPS	0.041	300	0.13
floor slab	XPS	0.041	320	0.12
Bambados				
roof (timber)	EPS / XPS + mineral wool	0,035 / 0,040	280 + 80	0.097
roof (concrete)	EPS / XPS	0.035	360	0.095
exterior wall	mineral wool	0.035	300	0.135
exterior wall (ground)	XPS	0.042	300	0.137
floor slab	XPS	0.045	300	0.142

Exterior wall

Compound insulation systems are thermal bridge free and comparatively low cost if suitable dowels are used. However, ventilated curtain wall façades are often also used. They are durable and allow the use of a wide range of different surface finishes. They necessitate a load-bearing sub-construction which may give rise to significant thermal bridges depending on the selected system. Thermal bridge free sub-constructions are available, which are presented e.g. in [AkkP 35] or listed in the component database of the Passive House Institute (www.passivehouse.com/component-database).

- Gap-free insulation of building components
- Use of thermal bridge free insulation dowels and façade anchors

Roof

In order to avoid thermal bridges in the roof, draining should be external i.e. rain pipes situated outside of the thermal envelope.

If tapered insulation is used for large roof areas, this can result in large differences in height of the insulation. Insulation is most effectively used if it is of a uniform thickness, as far as possible. It will therefore be helpful to plan short inclines or to implement an inclined roof construction so that a uniform insulation thickness can be used.

Basement and components against the ground

All zones of the building which are directly or indirectly heated should be integrated into the thermally insulated envelope. This also applies to the basement area of swimming pools. The insulation should be executed without gaps around the basement, avoiding thermal bridges in the process. It does not make sense to insulate the pool and exempt the basement from the thermal envelope, as the area to be insulated (pools themselves, all piping) would then be extremely large.

In the case of large buildings it might be possible to dispense with insulation of the basement walls and the floor slab. This may be the case if the heat losses through the ground can be reduced sufficiently by forming a "heat dome" under the floor slab. This can be done e.g. by means of perimeter insulation in the area of the exterior wall of the basement (see [AkkP 48]).

Typical thermal bridges

Large non-residential buildings have some typical details which can be executed without thermal bridges if they are looked at and detailed at an early planning stage. Planning in combination with statics is best. As a rule, subsequent adjustment of the detail solutions are complicated. These include the following:

- Thermal bridge free solutions for roof parapets
- Thermal separators in the area of reinforced concrete light shafts
- Thermal separation of porches and balconies
- Avoiding floor slab protrusions
- No penetrations of the building envelope by swim-out channels or slides
- Avoiding roof drainage systems on the inside
- Minimisation of ventilation ducts through the roof; the entire ascending pipes of the wastewater drainpipes must be insulated
- Realising pressure compensation of the balance tanks inside the building

Fig. 6 Example of a minimised thermal bridge:
left: thermal bridge free façade anchor for the curtain wall façade
right: roof parapet as a timber construction

2.2 Transparent building components

The energy relevant quality of windows and curtain wall façades results from the combination of the U-values of the frame and glazing and the glass edge thermal bridges. Besides the insulating characteristics, the absence of condensation is also of importance for selecting the frame. For these reasons, it is recommended that excellent quality certified frames are used. Aluminium frames offer the advantage of high f_{Rsi} values, which ensures the absence of condensation. In contrast, wooden frames can have even lower transmission losses. It is optimal to combine these aspects, that is, frames having the best possible efficiency class with a high f_{Rsi} value at the same time. The values for certified frames can be found at www.passivehouse.com/component-database.

For indoor swimming pools it is worthwhile to choose particularly low U-values of the glazing (below 0.60 W/(m²K)) because in this way the transmission losses are kept low and the high surface temperature of the glazing provides a pleasant level of comfort for pool visitors. Thermal bridge free installation is of great importance for optimal effectiveness of the thermal characteristics of the high quality windows and curtain wall façades.

The following recommendations should be followed for windows and doors and accordingly also curtain wall façades:

- Triple-paned low-e glazing
- Frames of a thermally high quality
- Thermally insulated edge bond ("warm edge"); the lowest surface temperature (influenced by the spacer and window frame) occurs at the glass edge. Condensation first appears here (see Table 1).
- Thermal bridge minimised installation: window frame in the insulation layer, attachment with the shortest possible angles and insulation covering the frame profile
- Airtight connection of the frame to the airtight layer
- Window partitioning: avoidance of glare for swimmers should already be taken into account in the design

Example: Lippe-Bad

By raising the top of the pool, the façade was placed on a parapet without impairing the swimmers' visual connection towards the outside. Due to this, the lower area of the curtain wall façade is less impacted by splashing water. Other advantages of this solution include the fact that pool cleaning can be carried out during operation since switching of the drainage channels is not necessary, and that the basement height is smaller.

Fig. 7: **Lippe-Bad, raised top of the pool allows a parapet to be implemented for the curtain wall façade without impairing visual connection of the swimmers towards the outside.**

2.3 Thermal separation

In swimming pools there are often also areas that are much cooler or that are heated normally (e.g. lounge areas, office rooms or event rooms). Intertwining areas with significantly different temperatures should be avoided. Well thought-out zoning at the design stage is very helpful for the further implementation of the Passive House concept and ultimately the operation.

Thermal separation should be executed near building components that remain between the different temperature zones, as otherwise a considerable amount of heat will flow from the warm areas into the cooler zones, which will then have to be actively cooled. Thermal separation can be implemented all the more easily if it is taken into account earlier in the planning process. As a rule, it is sufficient to execute the interior walls with lightly thermally insulating materials (e.g. porous concrete). Alternatively, reinforced steel concrete ceilings or walls can be improved by a moderate layer of insulation on the cold side of the wall or ceiling.

- Zoning should already be taken into account in the design
- U-value of the thermal separator should be in the range of 0.50 W/(m²K) from a temperature difference of ca. 4 K. Set point temperatures for the winter as well as the maximum temperatures for the summer should be taken into account in the process.
- Thermal separation between the pool and the basement is not necessary

2.4 Airtightness

Airtight execution of the building envelope provides protection from moisture-related damage. The more airtight the envelope is, the less moist air can enter the construction through leaks. An airtightness level of $q_{50} \leq 0.4$ m³/(hm²) is recommended for indoor swimming pools. As the airtightness test for Bambados pool shows, this value may be even lower (test result: $q_{50} = 0.2$ m³/(hm²), $n_{50} = 0.07$ h^{-1}). This saves ventilation heat losses additionally.

An airtightness test is essential in order to ensure this standard of airtightness and is compulsory for Passive House buildings. In the construction process it should be scheduled so that the main elements of the airtight envelope and any penetrations of this are still easily accessible. In particular this includes the connections of the windows, doors and the curtain wall constructions to the exterior walls. For lightweight roof constructions this also includes the connection of the airtight layer of the roof to those of the exterior walls. Once the cladding on the inside and suspended ceilings have been installed, it will be difficult or even impossible to carry out leakage detection and rectification.

- The airtightness concept is a planning task
- All connections of the components of the building envelope should be executed in an airtight manner
- All penetrations (e.g. ventilation ducts, water pipes) should be well sealed and part of the airtightness concept
- Penetrations (e.g. by pipes) at the fewest possible central points. Special sealing products can be used for durable solutions.
- An airtightness test should be carried out for quality assurance purposes

Fig. 8 **Airtightness test for the Bambados pool: on account of the excellent level of airtightness, the entire building could be measured using just one fan.**

3 Ventilation

In indoor swimming pools, an adjusted and optimised ventilation system plays a major role for health, building physics and energy-relevant reasons.

3.1 Ventilation of the pool hall

Task

The ventilation system for the pool hall has two main tasks: ensuring a good quality of air (hygienic ventilation for the removal of disinfection by-products in particular) and dehumidification of the pool hall air. In order to maintain a constant level of air humidity in the pool hall, the constantly evaporating water must be removed continuously. Ventilation units with highly efficient heat recovery are appropriate for keeping low the energy losses due to ventilation. The supply air flow can be used to bring the required heating energy into the pool hall.

In conventional pools, dry air is often blown onto the glazing in order to keep the façade free of condensation. This additional task of the ventilation system is usually omitted in Passive House swimming pools due to the high thermal quality of the window frames, glazing and spacers.

In a climate like that of Germany, this makes it possible to operate ventilation units with outdoor air only and to use smaller units. The usual share of recirculated air based on VDI 2089 can be omitted or at least reduced substantially, due to which significant electricity savings are achieved. The outdoor air volume flow is controlled based on the dehumidification demand, but it should not be less than the minimum volume flow for hygienic ventilation (depending on the water quality 15 % or 30 % of the nominal volume flow according to [VDI 2089]). Evaporation of the pool water can be reduced through various measures (e.g. higher air humidity), due to which the required dehumidification output of the ventilation system is decreased additionally (see Section 4.2).

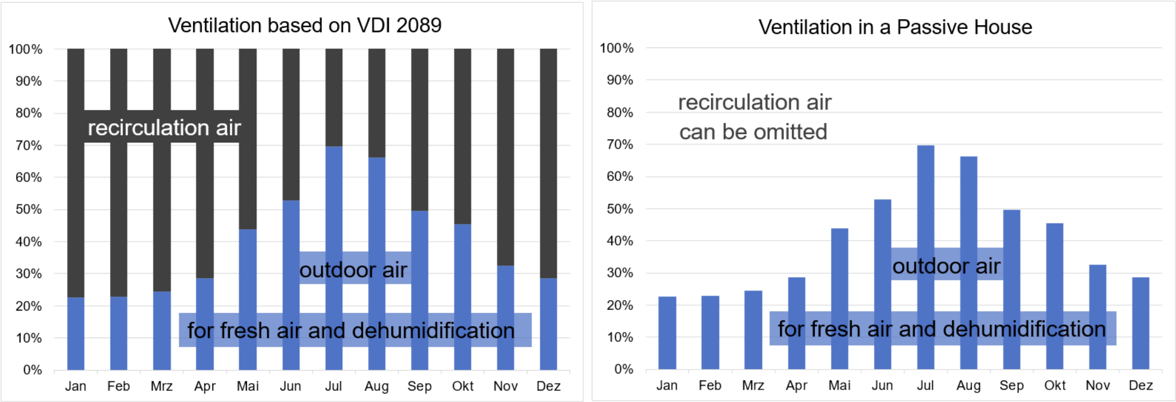


Fig. 9 **Comparison of the volume flow of ventilation based on VDI 2089 and according to the Passive House concept. (Monthly average values are shown here)**

Pool hall conditions

Because the requirements for pool hall conditions are contradictory in part, (requirements for different users, structural protection, energy demand), the set point temperatures and humidity levels should be set according to the specific project. A wet pool visitor will prefer relative air humidity levels that are as high as possible, while pool staff will feel better with lower humidities. For this reason, a separate temperature-controlled room for pool attendants could already be allowed for during the initial design phase. For structural protection reasons, a relative humidity of 64 % should not be exceeded for longer periods [Schulz et al. 2009].

On account of the different requirements, so-called stratified ventilation is recommended which is described below in the section on "Air flow through pool halls". A humidity level of ca. 55% in the pool surrounds (height 1.5 m) is suggested as a reference value for planning. The actual amount of humidity should then be tested and set during operation. If the air layer above the water surface can be made more humid, there will be less evaporation of the pool water and the energy costs will be accordingly lower. Fig. 10 shows how evaporation is affected by different pool hall conditions.

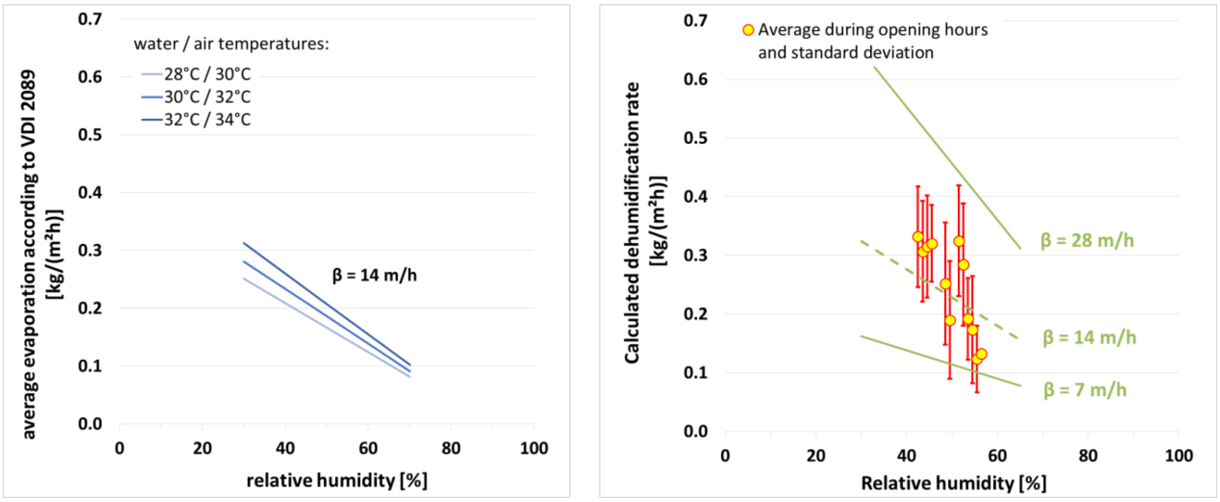


Fig. 10: Influence of air humidity on average evaporation per m² of pool area. Left: calculated in accordance with VDI 2089 (ß = 14 m/h) at different combinations of water and air temperatures. Right: measured dehumidification output through the hall ventilation in the year 2016 (pool hall of the parent/child pool of the Lippe-Bad: ca. 32 °C water air temperature) [Gollwitzer et al. 2018].

When measuring the air humidity, it must be kept in mind that the measurement uncertainty is relatively high even with high quality sensors and that additionally the sensors will drift over time, therefore deviations of over 10 percentage points may easily occur. For this reason, care should be taken in general when comparing humidities or specifying set point values.

A Passive House building envelope has the advantage that it has higher interior surface temperatures at all building components, which results in lower temperature stratification in the room, among other things. This means that the air temperature inside a Passive House is more homogeneous than it is with lower energy standards. Despite this, different levels of humidity are simultaneously encountered inside a pool hall due for example to the respective air routing. On account of the measurement uncertainties and the humidity differences in the room, building protection inspections should be carried out regularly for structurally relevant building components for the purpose of structural protection, rather than relying solely on regulations.

Air pollutants (THM)

A key factor for the implementation of an indoor pool according to the Passive House concept is the reduction of the recirculated air percentage for energy-relevant reasons. In doing so, the parameters that are crucial for air quality should be taken into account. For ensuring pool water safety, so-called disinfection by-products are formed in pools due to chlorination. The focus of health assessment is particularly on the resulting group of trihalogen methanes (THM). If pool ventilation is inadequate, THM may accumulate in the air in the pool hall. In pool water THM serves as a tracer substance for assessing the pool water quality. The connection between the concentration of harmful substances and their outdoor air percentage as well as elimination or reduction of recirculated air was systematically examined in three indoor pools by means of measurement surveys (see [Gollwitzer et al. 2018]). It was found that in comparison to the average values given in the reference literature, the measured values for THM in the three pools can be assessed as good. All in all, this proves that with adapted air routing, an indoor pool can be operated quite well with a reduced percentage of recirculated air or no air recirculation at all without impairing air quality. Considerable reductions in the electricity consumption are achievable in this way in the long-term.

Fig. 11 **THM measurement: air samples taken using suction pumps positioned 20 cm above the water surface and at a height of 1.5 m above the pool surrounds.**

Air flow through the pool hall

Good air routing and air flow through the pool hall is essential for effective removal of pollutants. It turns out that stratified ventilation has many advantages. With this, a moist layer forms directly above the water which leads to less evaporation. The air 50 cm above the water level is already much drier (about 10 percentage points) which in turn provides a pleasant climate for dry persons (staff) in the pool surrounds. In addition, the building envelope is exposed to less humidity in this way.

Stratified ventilation is achieved by removing the extract air in the lower part of the hall. This not only has energy-relevant advantages but also effectively eliminates the pollutants forming at the water surface. The supply air can be introduced either near the façade above the lounge area or near the ceiling. It is essential that the humid layer above the pool is not disturbed by the abrupt introduction of air. Apart from that, it must be ensured that cold air from adjacent rooms does not flow into the pool hall as this will raise the humid warm layer over the pool. Fig. 12 shows a graphical representation of stratified ventilation.

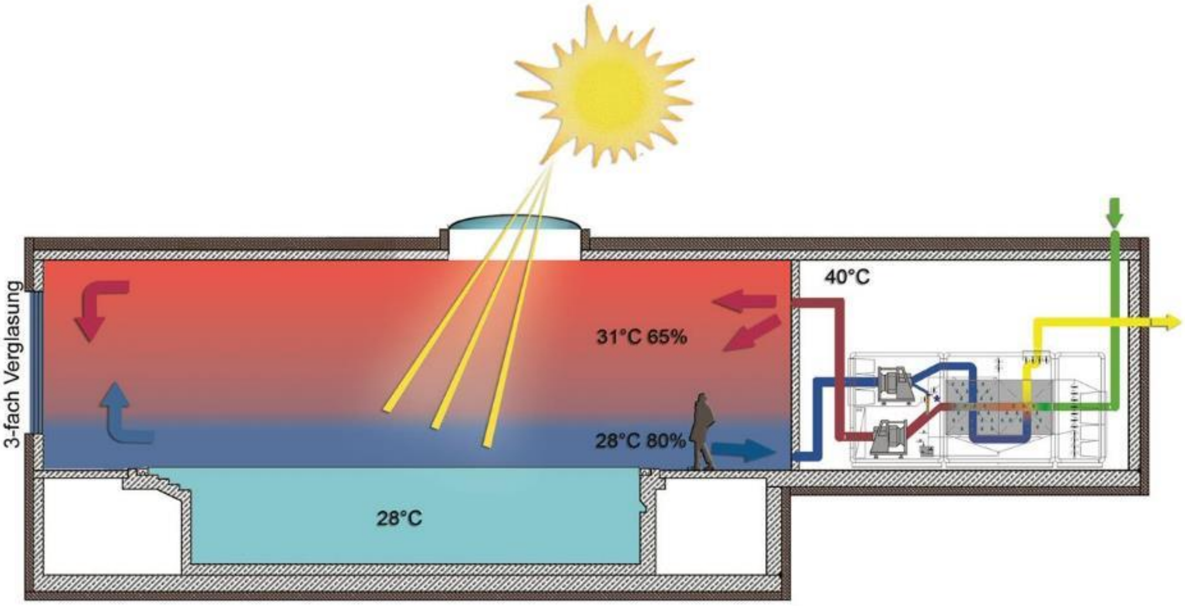


Fig. 12: **Air routing with extraction near the floor which results in advantageous temperature and moisture stratification. Source: [Kaluza 2016].**

Duct network for ventilation system

The more compactly implemented the duct network is, the lower the investment costs, space demand and electricity costs will be. The duct network should be designed so that the pressure losses are as low as possible. Air speeds below 3 m/s are recommended. More importantly, when choosing the components, attention should be given to built-in components with low pressure drops (e.g. larger duct cross-section for the outdoor air grille).

The ventilation unit should be installed as close as possible to the thermal envelope in order to be able to realise shorter duct routing of the outdoor air and exhaust air ducts (between the ventilation unit and the thermal envelope). These ducts must always be completely well-insulated in a vapour diffusion impermeable manner (at least 10 cm) since high heat losses between the interior space and the cold outdoor and exhaust air ducts significantly reduce the effective heat recovery efficiency of ventilation units. If longer routing of supply air and extract air ducts through colder adjacent zones is unavoidable, then these should also be insulated.

The extract air can be drawn away centrally via just one extract air grille. One example where this method is used is the Familienbad Niederheid (see [Gollwitzer et al. 2018]): with a maximum volume flow of 30 000 m³/h, an extract air grille with a size of 2 m x 2 m is adequate. Air movement is no longer perceptible at a distance of one metre from the grille. For this reason, the extract air grille should not be positioned directly next to seat benches or the like, unless the cross-section areas are large enough to avoid uncomfortable drafts. As an alternative to central air extraction, the extract air can be positioned along the length of an interior wall. In both cases of stratified ventilation it is essential that the extract air openings are installed near the floor of the hall.

Various options are available for introducing supply air. It is important to ensure that air flow in the room is also possible with a low supply air volume flow and that the moisture layer above the water surface is not disturbed.

If intermittent ventilation operation (ventilation units switched off during the night) is to be realised, then motor-driven dampers in the outdoor air and exhaust air ducts are recommended preferably at the level of the thermal building envelope. This will prevent cold outdoor air from entering the ducts outside of the operating hours. It is useful to already consider the procedure for adjustment in the planning and specify the places in the ducts where the volume flows should be measured. Accordingly, a list of the valves and measuring points in the ducts should be compiled for adjustment together with the respective standard volume flows (or average volume flows).

Ventilation units

The maximum volume flow of a ventilation unit for a pool hall is dimensioned so that even under humid outdoor air conditions in the summer it is possible to dehumidify the air in the hall. For this purpose, evaporation is calculated in according with VDI 2089. This is based on an estimate for the amount of evaporation depending on the type of pool (known as the water transfer coefficient β). It is advisable to consider dimensioning using smaller design volume flows compared to the norm (see next section), because potential savings in investment costs will result with smaller dimensioning. In addition, a reduced range of the volume flows to be covered facilitates the selection of components (e.g. fans) for efficient operation of the ventilation units as a whole.

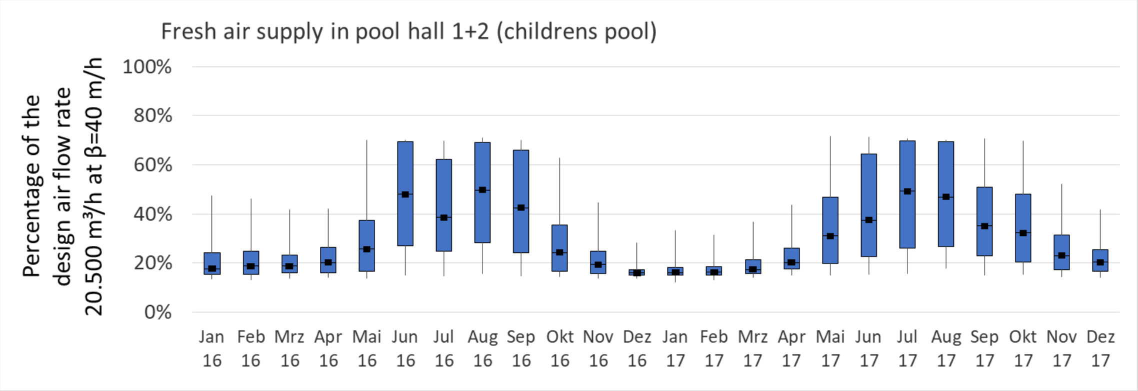


Fig. 13: **Lippe-Bad: Measured outdoor air volume flows as a percentage amount compared to the maximum volumetric flow according to VDI. The box plots show monthly average values, the highest and lowest quartiles, and extreme values (2.5 and 97.5% percentile). This means that 50% of the measured values lie within the rectangle in each case. The pool remained closed in the summer holidays.**

Assuming a water transfer coefficient of β = 20 m/h (formula based on VDI 2089) irrespective of the pool depth (derived from [Gollwitzer et al. 2018]) is suitable as a reference value for typical usage (without special attractions). As a rule, this leads to smaller device sizes compared to conventional dimensioning according to VDI: ca. 70% with a water depth > 1.35 m (β = 28 m/h according to VDI) and ca. 50% for shallower pools (β = 40 m/h according to VDI). Of course, the boundary conditions of the specific project must be taken into account for this, in particular the expected use. If continuous operation of the indoor pool is expected also during the summer time with high outdoor air humidity levels, then an increased air change rate must be ensured for dehumidification, either via additional opening of windows or by designing a correspondingly large ventilation unit. Alternatively, active dehumidification can be considered. With a higher number of expected pool visitors or maximum occupancy rate of the pool (large catchment area, many schools/clubs with large swimming teams), more buffers/capacities should be planned for when dimensioning the ventilation units. The evaporation expected due to special attractions must be calculated for individual cases and taken into account when dimensioning the ventilation units. However, in this case it must be ensured that the volume flows can be reduced sufficiently when the attractions are not in operation.

In the Lippe-Bad, evaporation for the parent/child pool was already set lower in the planning (β = 28 m/h instead of β = 40 m/h). In practice, it has been confirmed that this matches the actual evaporation rate.

Because the air in the pool hall contains a lot of energy on account of the high temperature and air humidity, a higher heat recovery rate of the system pays off twice. Some of the sensible heat as well as the latent energy can be recovered and the heat demand can be reduced as a result. Counter-flow heat exchangers are suitable for this purpose. The material of the heat exchanger must be appropriate for the air in a swimming pool hall (high humidity, chlorine). A heat recovery efficiency (dry) of ≥ 85% is recommended for swimming pool halls, for the expected average outdoor air volume flows during the winter months. In consultation with the manufacturer, this efficiency should be checked in the planning phase for full operation as well as for minimum operation.

When choosing the fans it is imperative that attention is given to a high level of efficiency also for partial loads, because the volume flows fluctuate greatly during the course of the day as well as annually and the device is largely operated with partial load. In order to efficiently cover the large range of volume flows it makes sense to use two fans in parallel instead of one. A maximum value of 0.45 Wh/m³ is generally used as a reference value for the electricity demand of the ventilation system in Passive House buildings.

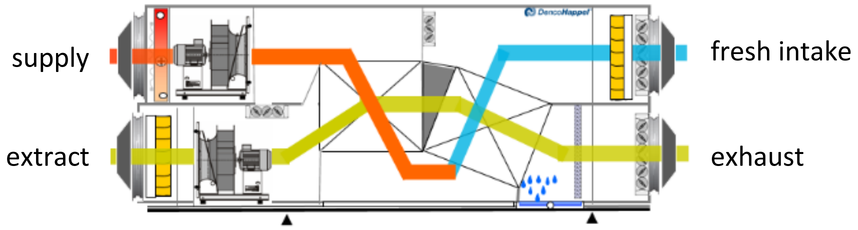


Fig. 14: **Swimming pool hall ventilation with purely outdoor air operation, i.e. without any air recirculation (illustration © FlaktGroup Deutschland GmbH, adapted by PHI). The damper/valve between the extract air and supply air remains shut.**

Another requirement for a ventilation unit for a pool hall is automatic internal balance adjustment for the outdoor air and exhaust air, so that excess pressure in the building can be prevented in order to protect the building envelope. A slight negative pressure in the pool hall is advisable. To reduce the pressure drop, one-stage filtration should be considered in place of two-stage filtration. In doing so, it should be kept in mind that pocket filters with low pressure losses may require more space, therefore it is essential to consider and specify this early on in the planning.

Whether the use of an exhaust air heat pump would be advantageous must be checked for the specific project since heat pumps often have to compete with cogeneration plants or local heat networks in terms of energy. If a heat pump is used, then it should be designed so that operation is possible even when the ventilation unit is operated with only the minimum volumetric flow (partial load). The additional pressure drop of the exchanger must also be balanced in every case.

Controls

The ventilation system control unit of swimming pool halls must ensure a minimum volumetric flow for the removal of harmful substances and moreover, increase the outdoor air volumetric flow depending on the dehumidification demand. Circulating air flow can and should be avoided. An example of the effects in terms of energy is shown in Fig. 15.

The measurements in the Passive House swimming pool Bambados have shown that in practice, additional air recirculation for heating the halls was not necessary. However, if the supply air is not enough for adequately introducing the heating load then air recirculation can be operated temporarily (bypassing the heat exchanger). It is recommended that the devices are switched off with monitoring of the humidity in the hall during the standby mode.

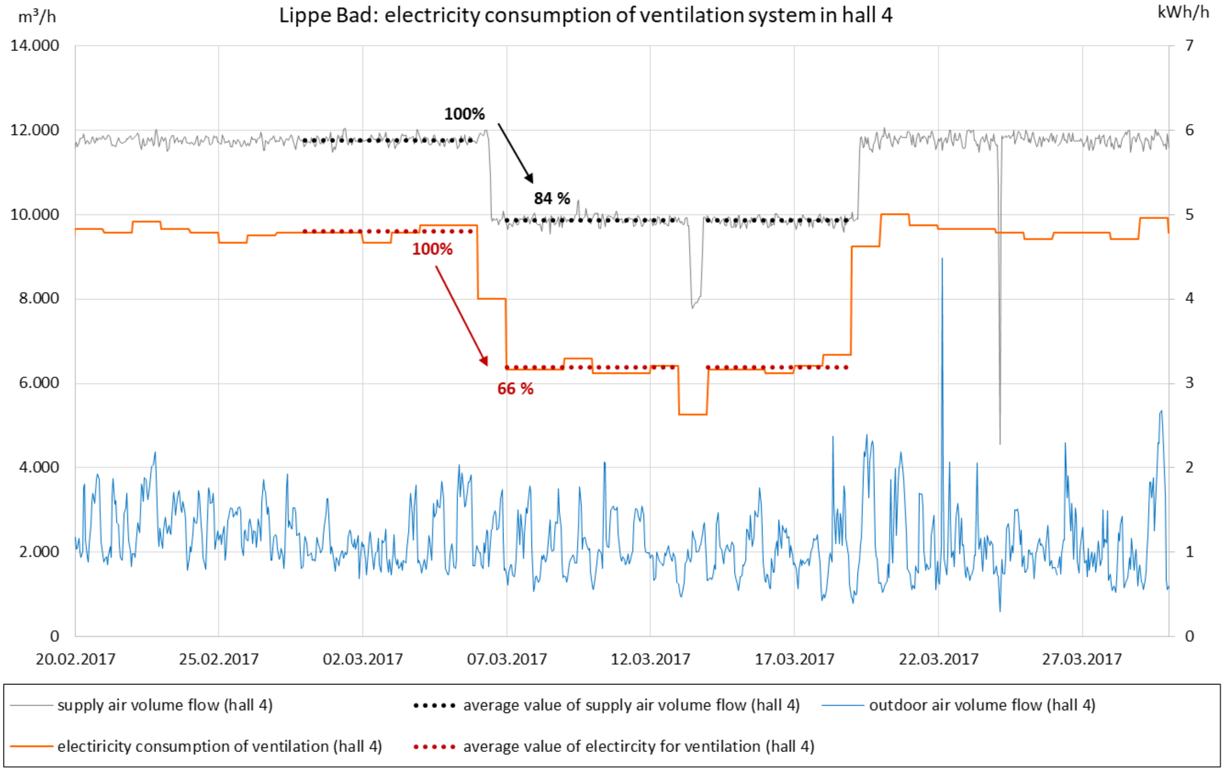


Fig. 15: Test in the Lippe-Bad: the supply air volume flow was reduced while the outdoor air volume flow remained the same. This significantly reduced the electricity consumption of the ventilation unit.

Regulation of the building's technical systems normally takes place by means of a building management system (BMS). For subsequent checking of operation, it is useful if the different measurement parameters and settings are visible for the operator (see Section 8 Commissioning and operations management).

For implementing the ventilation concept described above without air recirculation, the Passive House Institute has developed an exemplary ventilation regulation system to assist with other projects (see [Gollwitzer et al. 2018]).

Commissioning

The following points should be checked for commissioning of the ventilation system:

- Device is balanced (outdoor and exhaust air) or there is slight negative pressure inside the building
- For operation without air recirculation: extract air, supply air, exhaust air and outdoor air valves are completely open and air recirculation valves are completely closed?
- Are there any draughts or noises with maximum volume flows?
- Possibly smoke test for checking air mixing
- Obviously the different types of regulation can best be tested if the corresponding situation is induced (e.g. strong evaporation: the ventilation unit should then increase the volume flow for dehumidification).

Normally the ventilation units are put into operation on one day; however, regulation of the devices should be checked over a longer period of time through evaluation of the operating data. Different operating conditions can be checked in this way. An indoor pool is a technically complex building. Thorough "commissioning" (interplay of the different disciplines and regulation systems) during the first year ensures that unnecessary investments are not made and that the desired building performance is achieved instead. For this, the contracting companies (ventilation company, ventilation system manufacturers) should be commissioned in good time.

Process optimisation and system management

Transparent and verifiable system management as well as trained operations managers are essential. If the control unit of the ventilation programming (dehumidification, heating, possibly cooling) is simply displayed, one has an overview of the time and duration of e.g. the heating requirement and the dehumidification demand. Only a regular overview enables deviations in operations to be detected easily. Monitoring of the outdoor air, supply air and extract air volume flows in the form of time charts is just as important. If weekly cycles are compared with each other for this purpose, differences will immediately become apparent. If pool hall ventilation is operated without air recirculation, the three volumetric flows should generally be equally high. In order to keep pressure drop low, it would be expedient to check the valve positions from time to time: extract air, supply air and outdoor air valves should be kept completely open during operation of the ventilation units.

3.2 Ventilation in adjoining zones

In indoor swimming pools, besides the pool hall there are usually adjoining zones with other temperature and humidity conditions: showers, changing rooms and plant rooms. In addition, there are often offices, lobbies, saunas, catering areas, spas, fitness rooms, and rooms for training courses and computing or electrical equipment. It is helpful if the requirements for these rooms are already clarified during the planning and grouped together into appropriate zones. Thermal separation should be implemented between zones with a large difference in the air temperature. The following factors should be taken into account when selecting the ventilation zones: set point temperature, maximum temperatures, dehumidification demand, operating hours and variations in usage. It must be specified which rooms will be supplied by a single ventilation unit as a group and how many ventilation units are planned in total. It is easiest if the temperature and ventilation zones correspond with each other. If several small ventilation units are planned, then regulation can best take place according to the actual demand. However, a practicable, moderate approach should be used and areas should be grouped together. For energy and comfort relevant reasons, ventilation should take place according to demand, but at the same time, the investment costs should be kept low and regulation should be simple. For single rooms or small zones which are completely different in use from the rest, it may be worthwhile to check whether a small decentral unit can be used. The fundamental purpose of the ventilation system is to provide hygienic air exchange. At the same time, the ventilation unit can serve to heat the adjoining areas and thus make the installation of heaters unnecessary.

When implementing this, the following key objectives should be pursued: a duct network with low pressure losses, efficient fans, a high level of heat recovery efficiency and demand-based regulation of the volumetric flow.

Demand-based volumetric flows

Various requirements apply in norms and regulations for the amount of the volumetric flows in adjoining zones. It is always the volume flow for the most unfavourable case which is stated. Realising a volume flow which is adapted to the demand is a fundamental and absolutely important principle of the Passive House concept. In this way, the electricity costs for the ventilation system of the Passive House pool Bambados were reduced by 50 %. In addition to the electricity savings, the ventilation heat losses and thus also the heating demand were also reduced.

The first step for demand-based regulation is to operate the unit only during the operating hours. In doing so, the planning should include possibly a post-ventilation phase and certainly a pre-ventilation phase before the start of building operation. During the pre-ventilation phase the air is replaced so that a good quality of air can be ensured right at the start of the indoor space use. A one-fold air change rate is suitable for pre-ventilation. The second step of demand-based regulation is to adjust the volumetric flow to every current actual use of the zone. For example, moisture sensors, CO_2 sensors or presence detectors are suitable depending on the type of use.

Shower areas and changing rooms

Directed air transfer from the changing rooms to the showers is recommended. In this way the air can be utilised twice, due to which lower total volumetric flows and smaller ventilation units are required overall.

Showers and changing rooms can then be supplied with just one ventilation unit: the supply air is conducted into the changing rooms and flows from there into the shower areas. In addition to basic air exchange during the usage time, the volume flow is controlled according to the moisture level: with a higher dehumidification demand in the showers the total volumetric flow of the device is increased. At night the device is switched off and a safety circuit is used to prevent excessively high humidity levels in the showers.

Plant rooms

The basement plant room must also be supplied with fresh air as pool staff are present here on a daily basis. In addition, the ventilation system is used for dehumidification. As in the rest of the swimming pool building, a ventilation system with heat recovery is self-evident since heat is given off into the surrounding space even with efficient ventilation and swimming pool technology. In the process, it should be considered whether the plant room will be supplied by a separate ventilation unit or by the ventilation unit that is used to ventilate the changing rooms. In order to keep the ventilation heat losses low, the design air change should not be unnecessarily high.

Duct network and ventilation units

The basic principles described in Section 3.1 "Ventilation of the pool hall also apply for the duct network and the ventilation units of adjoining zones. During the planning phase, it should already be specified which duct sections can be measured for adjustment at which points. If volume flow controllers are planned for separate regulation of individual areas, the saving achieved through regulation should be weighed against the increased consumption due to additional pressure drops.

Controls

An important principle is to keep the regulation as simple as possible! Even though many possibilities are offered by engineering and manufacturers, it must not be forgotten that control concepts will have to be prepared, and programming will have to be carried out and checked. Planning is most effective if it is possible to involve the subsequent operator/operations manager. If he knows about the planned control strategies, he can monitor, manage and optimise these in a better way during operation.

In some cooler areas of the building (e.g. offices), passive night cooling may be useful and necessary for cooling down. In the process it is important that this is used in a targeted manner as a heating demand exists all year round in most of the building. Night-time ventilation can take place passively through the ventilation system or the windows, or actively via a ventilation unit with summer bypass. This passive ventilation strategy has the advantage that compared to ventilation using fans, no additional heat loads are introduced. In these areas, exterior shading for solar control is recommended on the outside as this will reduce the solar gains substantially.

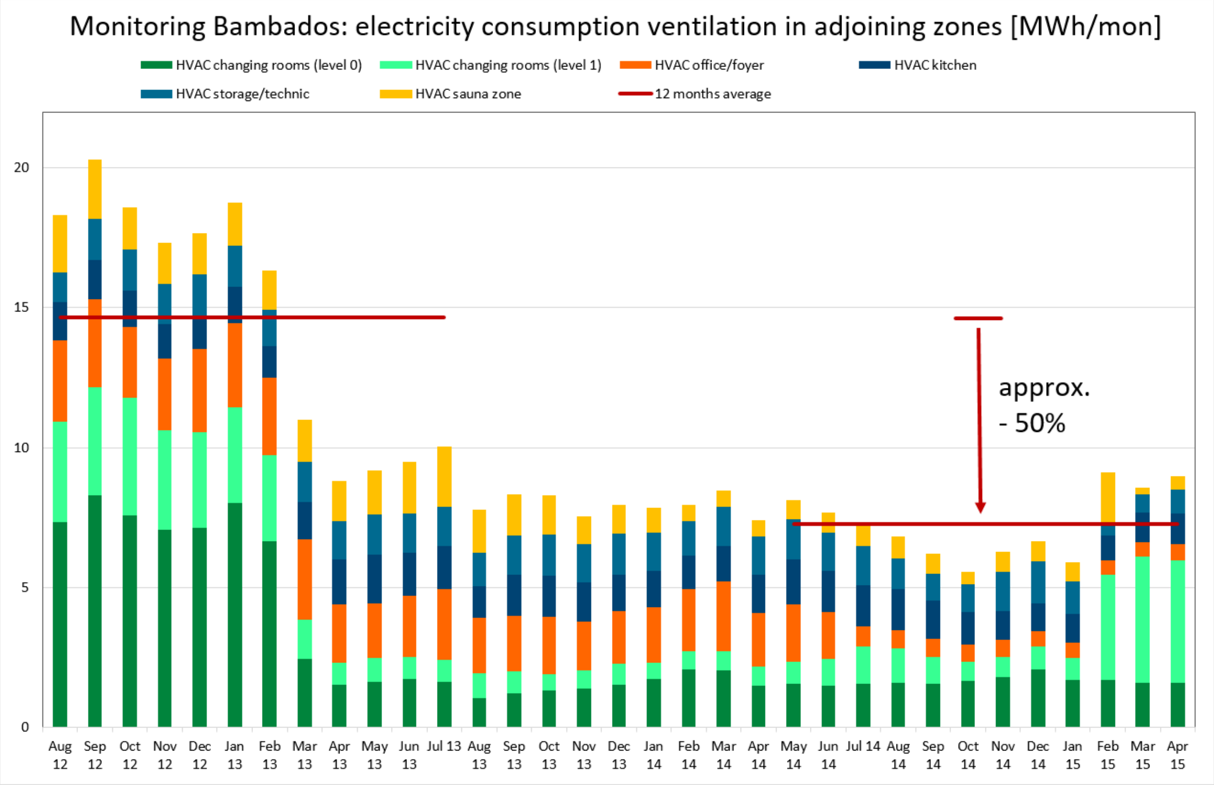


Fig. 16 **Bambados: Due to adjustment of the ventilation units of the adjoining areas, the volumetric flows were adapted to the actual demand and 50 % of the electricity demand could thus be saved.**

4 Swimming pool technology

A major part of the energy consumption of swimming pools is used to provide a warm, hygienic quality of the pool water. On the one hand, electrical energy is required for cleaning and transferring the pool water and on the other hand there is a heating demand for heating the pool water. With well thought-out planning of the swimming pool technology including selection of components and optimisation of the method of operation, it is possible to reduce the energy demand considerably. In the case of learner and recreational pools, the savings potential compared to the swimmers' pool is higher on account of the usually higher temperatures and loads (more pool visitors per pool area and thus higher fresh water demand), therefore it is particularly worthwhile to pay attention to a high level of efficiency.

There are many different approaches for pool water treatment /swimming pool sanitation using different filtration systems, which should be chosen for each pool according to the boundary conditions and with regard to energy efficiency.

4.1 Electricity demand for pool water circulation

The pumps for pool water circulation account for a major part of the electricity demand for swimming pool technology. Due to their long operating times and comparatively high outputs, even small improvements have a significant impact in terms of energy and costs. With very efficient systems, an electricity consumption of 25-40 W per m³/h circulating volume flow can be achieved (based on the treatment volumetric flow at a nominal load according to DIN 19643 with a loading capacity factor k = 0.5 m^{-3}). Based on the pool area, this corresponds to ca. 10-17 W/m² for the swimmers' pool and ca. 17-29 W/m² for the learner pool.

Table 3: Estimation of the specific electricity demand of the circulation pumps for different pressure drops. The following assumptions were made: loading capacity factor k = 0.5 m-³, overall efficiency of the pump = 70%.

Swimmer pool

nominal bather load	pressure head	average specific pump power	
m²/P	m	Wh/m³	W/m²
4.5	4	16	7
4.5	6	23	10
4.5	8	31	14
4.5	10	39	17
4.5	15	58	26
4.5	20	78	35
4.5	25	97	43

Learner pool

nominal bather load	pressure head	average specific pump power	
m²/P	m	Wh/m³	W/m²
2.7	4	16	12
2.7	6	23	17
2.7	8	31	23
2.7	10	39	29
2.7	15	58	43
2.7	20	78	58
2.7	25	97	72

Pressure drop of the pipe network

The configuration of the overall pipe network determines the pressure head to be delivered by the pump. In general, the lower the pressure drop is, the less energy will be required for operation. It is therefore a fundamental planning task to keep the pressure drop as low as possible in order to achieve efficient operation. As a guideline for an efficient solution, 5-10 m pressure head (with average filter clogging) should be strived for - the lower, the better.

The following measures contribute to a reduction in the pressure drop:

- Compact pipe network with preferably short and direct lines
- Generous dimensioning of the pipe diameters. A reference value of 1-1.3 m/s is recommended for dimensioning the speed of the medium to be pumped
- Pipe fittings with low pressure drop (e.g. two pipe sections with 45° instead of one with 90°, FW valves (spring-force shutting) in place of conventional check valves etc.
- Position of the balance tank (the difference in height to the pool water surface should be as small as possible)
- Choice of pool water inflow
- Use of diffusers after the pumps

In practice the pressure drops are often significantly higher than the technical potential, and the savings potentials are not fully utilised in conventional planning approaches. To assist with reference values, pressure drops (at the typical operating point) of individual components in the pool circulation are shown in Fig. 17. In the optimised case the total pressure drops in these examples are about 5.8 m pressure head. Each individual pool has a slightly different structure and it is important to optimise the overall system in each individual case.

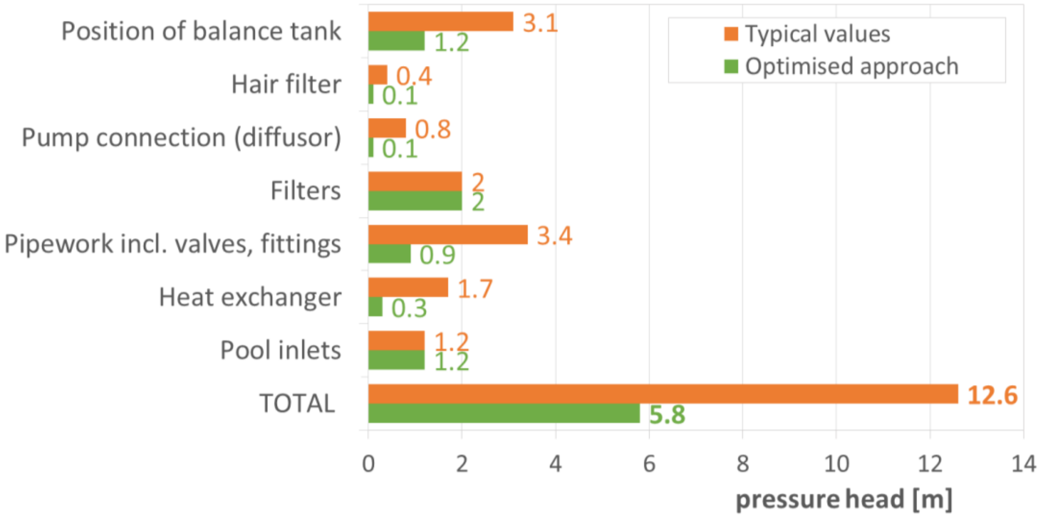


Fig. 17: Pressure drop of individual components of the pool circulation for conventional solutions (orange) and for an optimised approach (green). The data was collected by the engineering firm Inco and depicts average values from measurements and analyses of many pools. In total, the pressure drops are reduced by more than 50% here, from 12.6 m to 5.8 m.

Selecting pumps

It is ultimately the efficiency of the overall system at the actual operating point which is decisive for the efficiency of the pump, i.e. the combined efficiency of the electric motor plus the pump hydraulics and the electronic regulation. For an efficient solution, overall efficiencies (pump, motor and frequency converter) of over 70 % should be aimed for.

Recommendations and tips for selecting pumps:

- Top priority should be given to a high efficiency of the electric motor. These are usually permanent magnet motors and synchronous motors as compared to conventional asynchronous motors.
- In practice a higher efficiency can only be achieved through appropriate selection of a pump. Correct adjustment of the system to the actual operating points is important. A prerequisite for this is exact planning and a good understanding of the pressure drop during operation. For example, here the selected pump should be optimised for average pressure drop with the filters, instead of the pressure drop with maximum dimensioning.
- For efficient operation, the use of frequency converters has now become standard. Due to the rotation speed control of the pump by means of frequency converters, a high level of efficiency can also be achieved with different operating points (e.g. night setback or with different degree of filter clogging). In addition, the use of a frequency converter ensures a buffer for efficient pump operation in the event that pressure drops of the system in practice should differ from the planned values.
- The choice of material of the pump has an influence on its efficiency and on wear and tear in particular. The risk of corrosion can be reduced through the use of coated pumps.

Fig. 18: Circulation pumps in the pool circulation without (left) and with (right) a downstream diffuser (pictures: left PHI; right INCO)

Operating modes of circulation pumps

It is not absolutely necessary to continuously circulate the pool water with the full design volume flow. The electricity consumption can be decreased through partial load operation outside of the operating hours or when there are few pool visitors. Ensuring a good quality of the water is an absolute prerequisite for this. Regulation can take place very easily e.g. by means of a time switch for different reduction levels (e.g. smallest partial load outside of operating hours, average partial load during low occupancy). The savings potential is especially high for the learner pool for which the nominal circulation volume flow is set with a higher pool occupancy rate in accordance with DIN. A high pool water change rate (circulation 1/h) can also be achieved here even with a reduced volume flow.

- Internal circulation:

  Here the volume flow is taken from below the pool water surface, thus it circulates without the overflow channel and overflow/balance tank. Due to correspondingly lower pressure drops, the electricity demand also decreases. In doing so, it should be ensured that there is adequate flow through the pool. Internal circulation can be implemented for the entire volume flow or for a partial volume.

- Temporary volume flow setback:

  The electricity consumption decreases proportionately to the third power of the reduction factor, i.e. even small reductions are very effective. In any case care must be taken that flow through the pool is assured. With small reductions in the volume flow, there is less impairment of the flow and water change rate, this means that compared to temporary large reductions, smaller reductions over longer periods of time are more advantageous in terms of ensuring a good water quality.

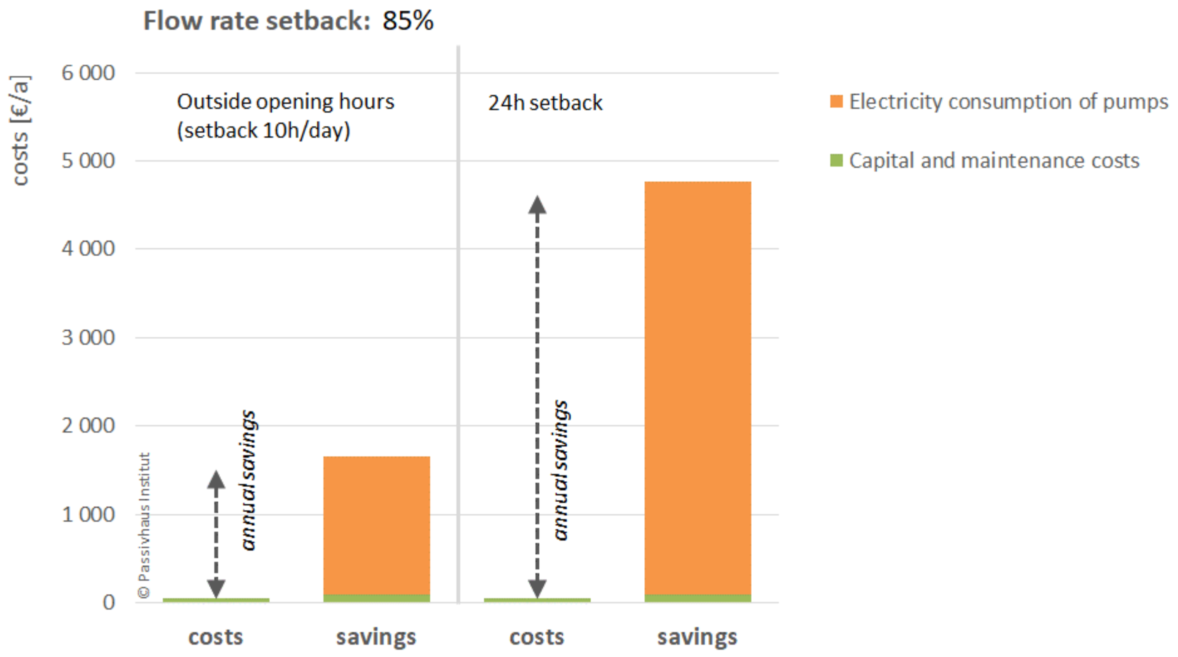


Fig. 19: **Example cost-benefit analysis for reduced pool water circulation to 85 % outside of operating hours (left) and continuous operation (right). Source: [Gollwitzer et al. 2018]**

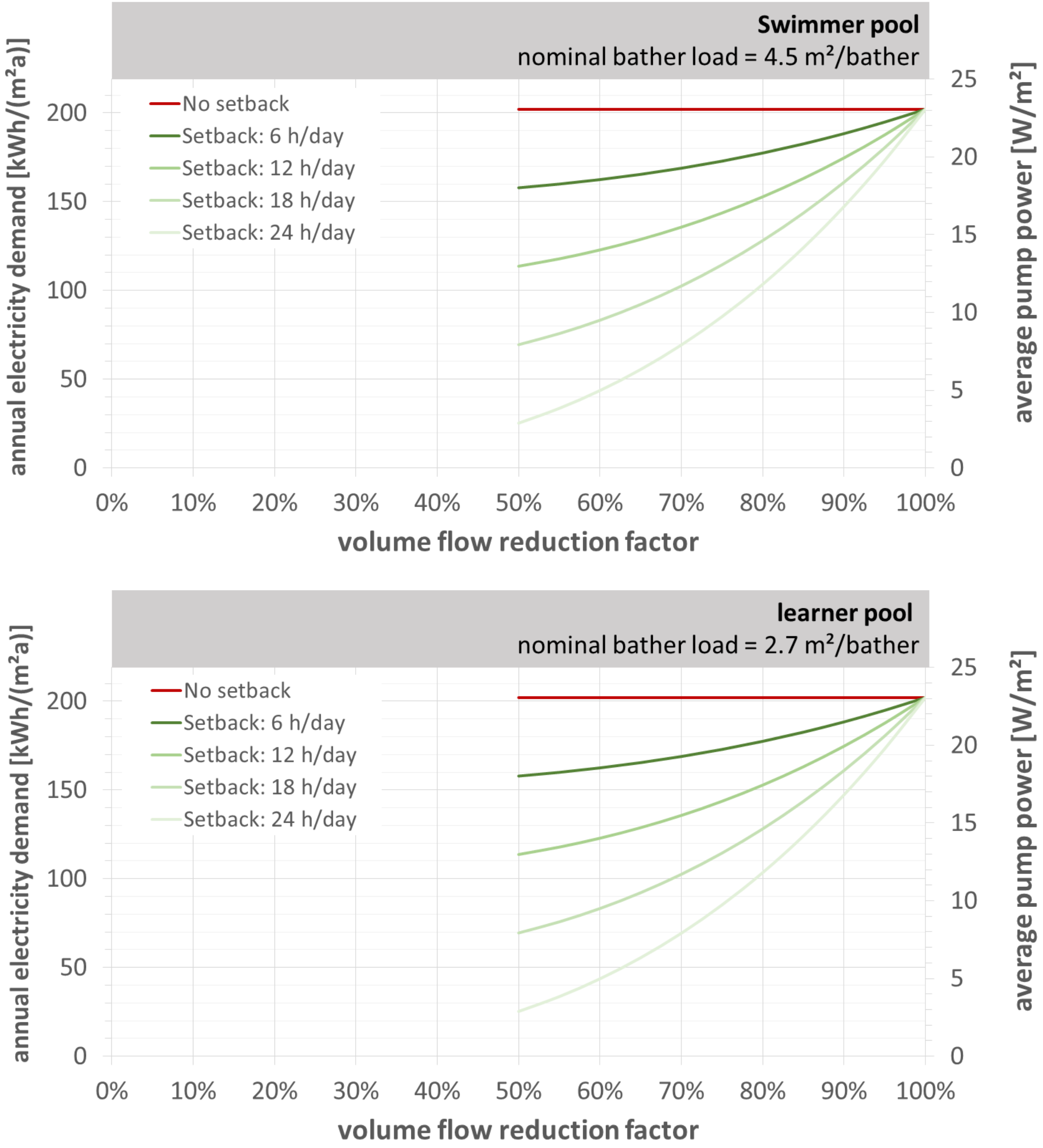


Fig. 20: **Example of electricity demands of circulation pumps with various types of partial load operation for a learner pool (above) and a swimmers' pool (below). Boundary conditions: 8 m pressure drop and 70% overall efficiency of the pump. Source: [Gollwitzer et al. 2018]**

Here is an example from Fig. 20 above (learner pool): If the circulation volume flow is reduced to 60 % during 12 hours, the electricity demand will be ca. 120 kWh per m² of pool area per year. In contrast, if the reduction is equally divided over 24 hours instead of 12 hours, the circulation volume flow is consistently around 80 % and the electricity demand is even lower, namely ca.100 kWh/(m²a). In both cases the overall water change rate over 24 hours remains the same.

4.2 Heating demand for pool water heating

The heating demand for pool water is expected to be in the range of ca. 400-700 kWh/(m^2_{pool}a) with efficient approaches. However, there are many influencing factors that will lead to strong deviations, and make comparison difficult without any further information, e.g. the efficiency and heat losses of the swimming pool pumps and technology: inefficient pumps with a high electricity consumption give off more heat towards the pool water, due to which the heating demand is lower.

The influencing factors and the expected heating demand can be calculated with an energy balance calculation. For this purpose, a calculation was developed by the Passive House Institute which can provide valuable assistance for better estimating the energy-relevant effects of the boundary conditions (e.g. temperature and humidity), as well as the selected components (e.g. filtration technology and corresponding demand for backwash water).

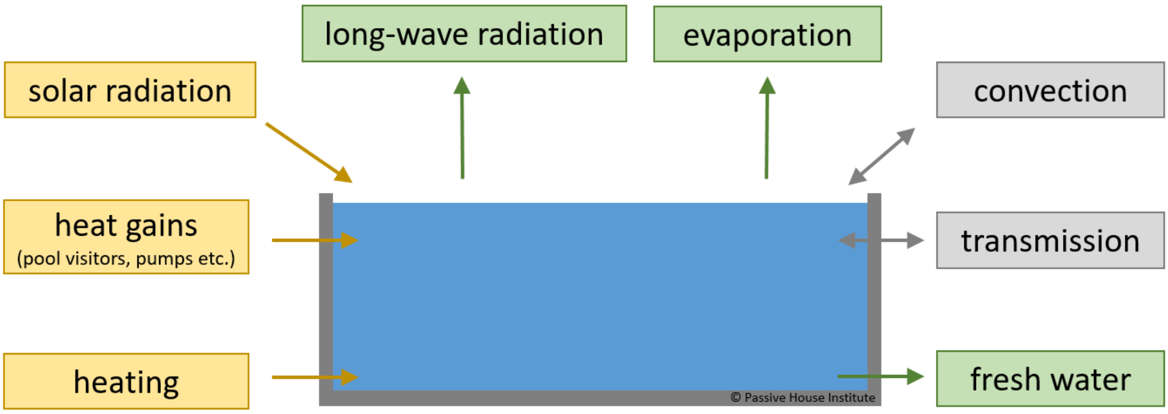


Fig. 21: **The main parameters for the energy balance for a swimming pool (indoor pool).**

Generally, the lower the water temperature is, the lower the heating demand will be. The temperature should thus be kept as low as possible depending on the foreseen building use and comfort for visitors. In addition, the amount of fresh pool water that is required each day is decisive for the heating demand. 30 litres per pool visitor are considered a standard amount for the hygienic minimum volume. Frequently the amount of water required for the filter backwash is also decisive for the water consumption in practice. This amount depends on the chosen filtration technology and the boundary conditions in the individual case. As a reference value in the case of conventional multi-layer filters, a monthly amount of ca. 0.6 $m^3/(m^2$ month) for the swimmers' pool and 1 $m^3/(m^2$ month) for the learner pool can be used as the water requirement for filter flushing. In the planning phase when selecting the swimming pool technology, it should be ensured that the required amounts of fresh water are not unnecessarily high because a high water consumption is associated with a higher energy demand and also with higher operating costs.

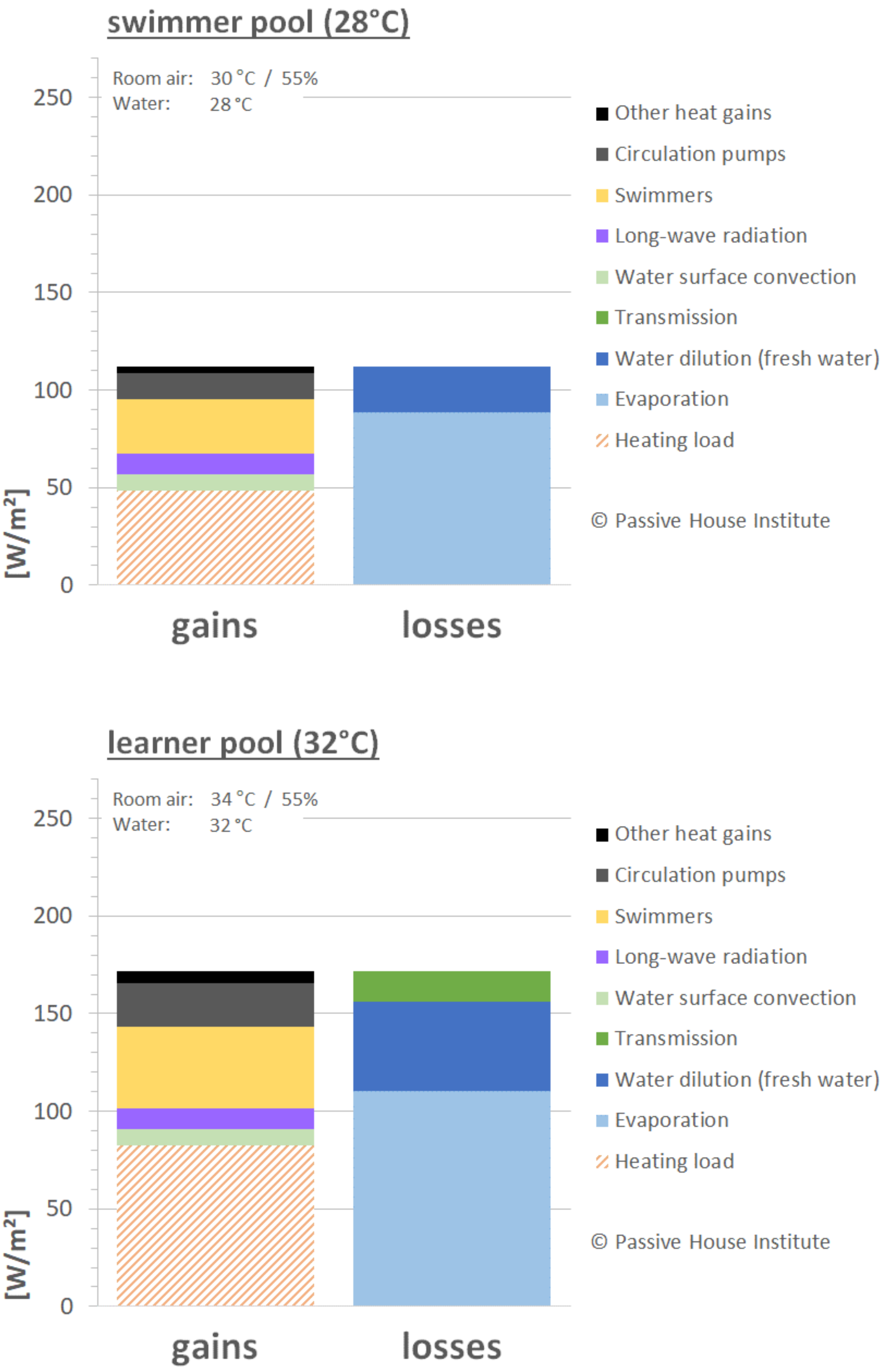


Fig. 22: **Examples of energy balances for a swimmers' pool and a learner pool. The specific heating demand per m² of water area is usually higher for learner pools on account of the higher water temperature and higher occupancy rate (more fresh water is required). Source: [Gollwitzer et al. 2018]**

Basically, there are two different approaches with the aid of which the heat losses for fresh water replenishment can be effectively reduced. The larger the amount of fresh water that is required, the more relevant these measures will be:

- Treatment of filter backwash wastewater for re-use in the pool e.g. as process water (toilets) and/or as refill water for the pool.
- Heat recovery from the warm filter backwash wastewater, either with a passive approach using a heat exchanger or an active system with a heat pump.

Filter backwash water treatment

In the Lippe-Bad pilot project the solution realised for the treatment of filter backwash wastewater with triple use (recipient feed-in, pool water refill and process water use) combined with passive heat recovery is very cost-effective (see Fig. 23). Such potentials are available particularly with e.g. ultrafiltration with a comparably high backwash water demand. With reference to the savings potential (energy and water) as well as economic efficiency, a suitable system solution should be considered in individual cases. A significant influencing factor for the economic efficiency of a backwash treatment plant for example is the chosen filter and disinfection technology. Due to the saving of the comparably high wastewater costs, a water treatment plant for direct feeding into a body of water can usually be regarded as economically efficient. In contrast, treatment for use as refill water for the pool circulation is technically more complicated and expensive (higher requirements for water quality, a second virus barrier may be necessary) - but may also be economically feasible in individual cases. Examples of cost-benefit analyses for this purpose were carried out in [Gollwitzer et al. 2018].

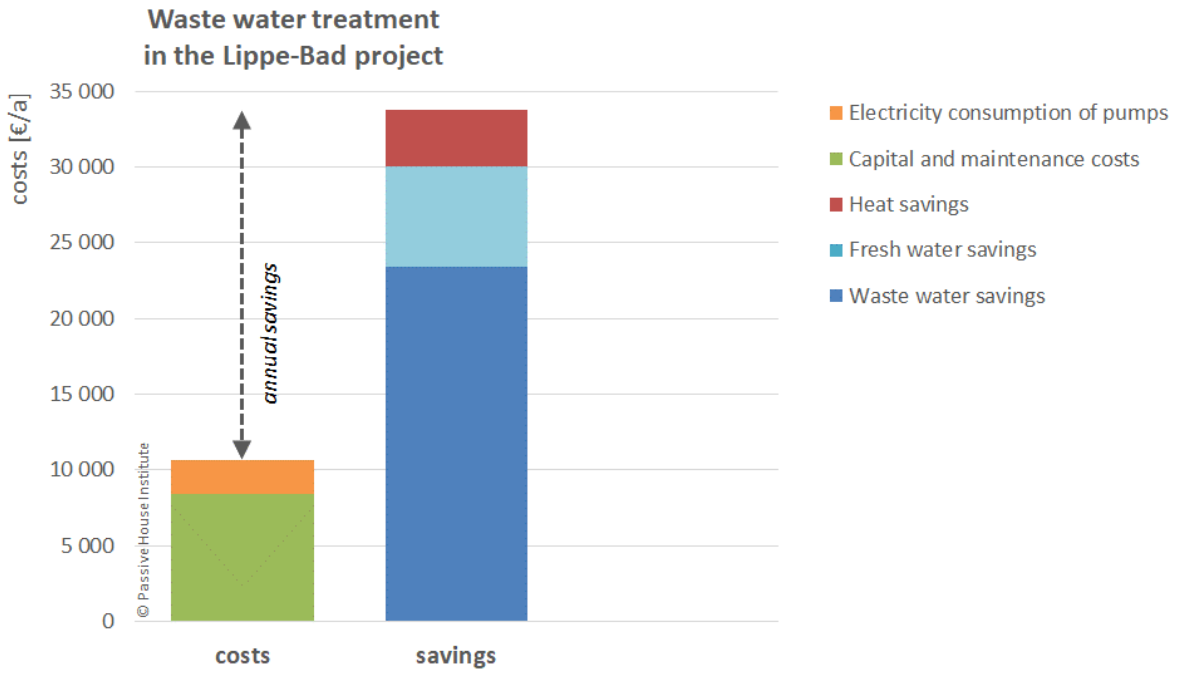


Fig. 23: Cost-benefit analysis for the backwash wastewater treatment plant in the Lippe-Bad. Source: [Gollwitzer et al. 2018].

Heat recovery from filter backwash water

There are different systems with which heat can be recovered from the warm filter backwash wastewater. Essentially a distinction is made between a passive system with a heat exchanger or an active system with a heat pump. The energy-relevant savings potentials are higher with an active system, but so are the investment costs. The investigations in [Gollwitzer et al. 2018] show that passive systems for an individual swimmers' pool are more cost-effective than a more cost-intensive active system (see Fig. 24).

Additional intermediate storage is necessary for both approaches so that the wastewater is saved and is only routed for heat recovery at the times when cold fresh water is fed in.

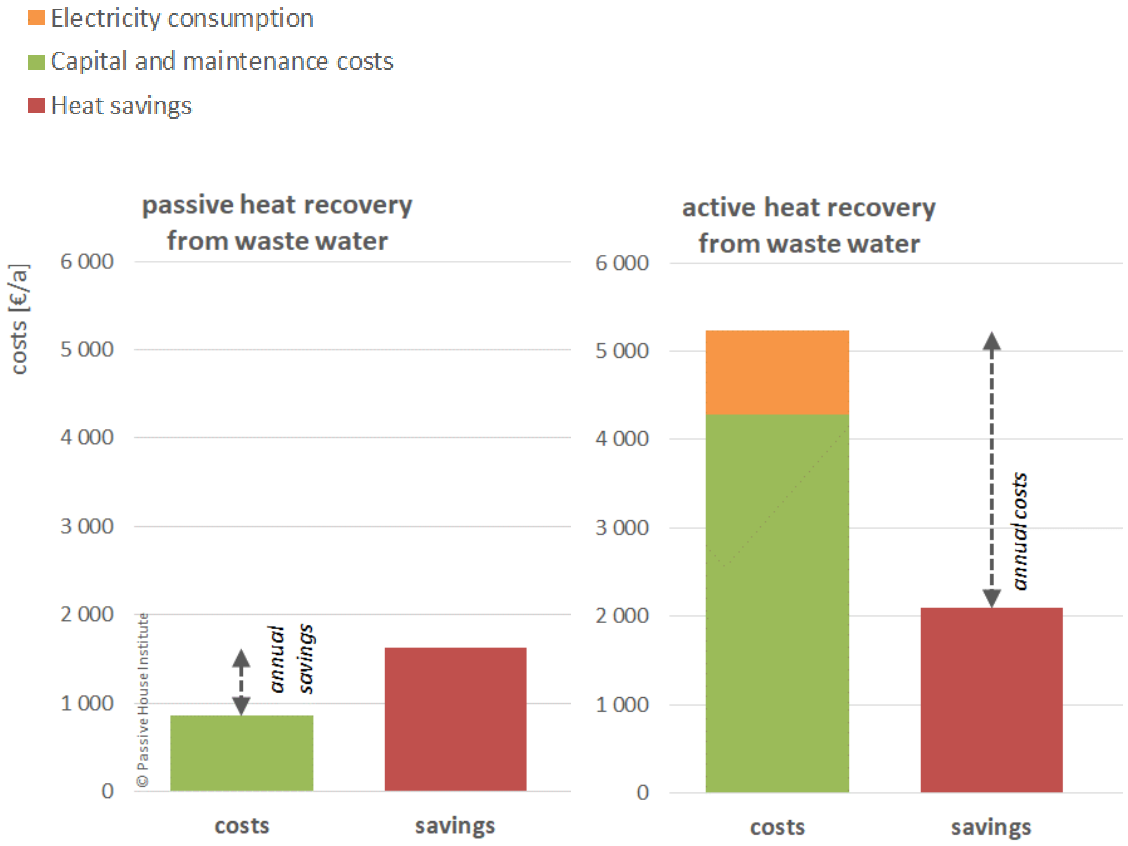


Fig. 24: **Example cost-benefit analysis for heat recovery from backwash water by means of a heat pump. 25m swimmers' pool. Source: [Gollwitzer et al. 2018]**

Evaporation

Much heat is lost from the pool during water evaporation at the surface. There are various methods for reducing this evaporation. In addition to reducing the heating energy demand, these also have advantages for the ventilation system of the pool hall because less dehumidification of the air is necessary (see chapter 3).

Effective measures for reducing evaporation are as follows:

- Increasing air humidity in the pool hall, continuously or at least outside of the opening times. A humidity of around 55 - 60 % during the operating times is suggested as a reference value for planning. A prerequisite for this is a well-insulated building envelope and the prevention of condensation formation as a result. For structural protection reasons, the relative humidity should not exceed 64 %.
- Night setback of the water level by means of internal circulation (no evaporation from the channel system, and reduced overall evaporation surface).
- Design of the water overflow channels (channel system)
- Fewer water attractions and reduced operating times/ shorter durations (only if actually used).

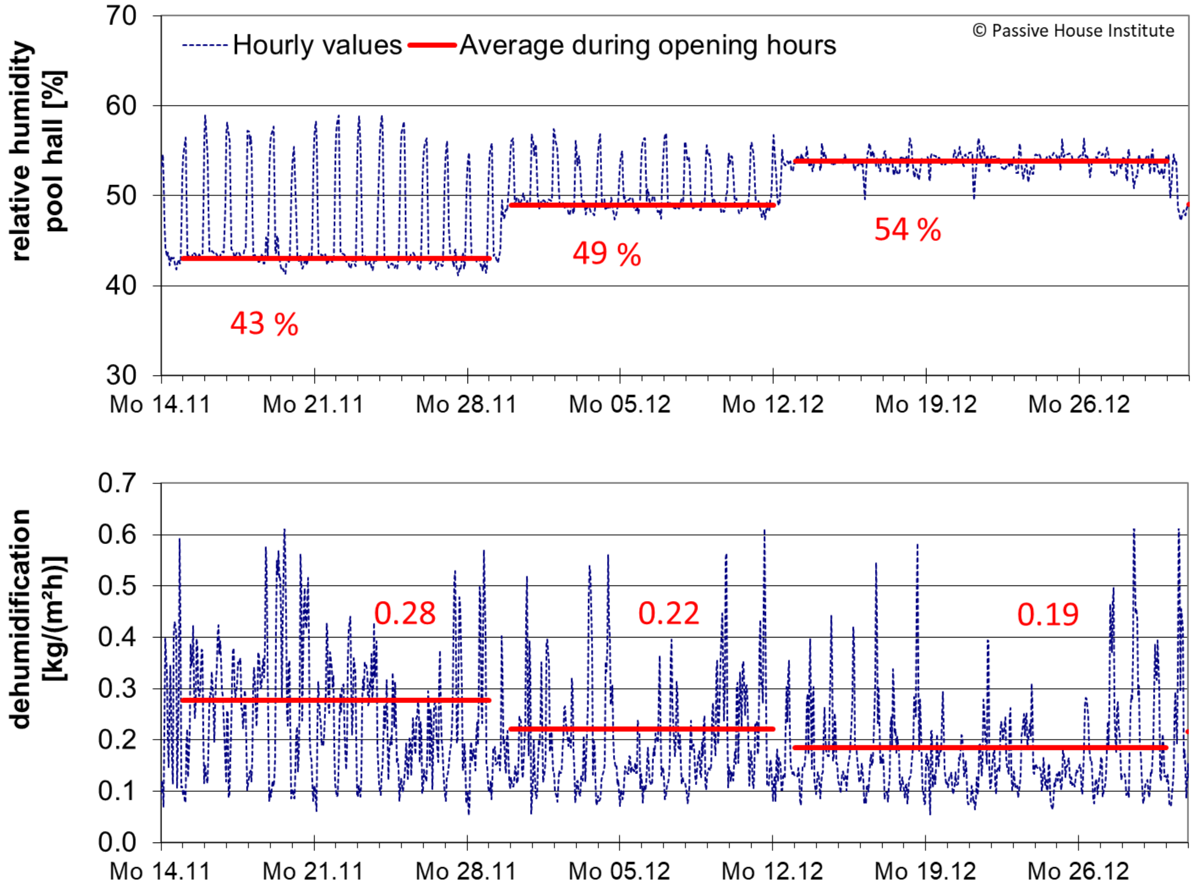


Fig. 25: **Series of experiments in the Lippe-Bad: when the humidity level (above) is increased, the dehumidification performance of the ventilation system decreases (below). The average values during opening times are shown in red. This also indicates reduced evaporation [Gollwitzer et al. 2018].**

Water attractions and other savings potentials with swimming pool technology

There are further ways to save energy in the area of swimming pool technology. It is important that the overall system - components and control technology - are adapted to the type of use and the chosen filtration technology. It is necessary to reduce the number of electricity consumers, use technology that is as efficient as possible and keep the heating and electricity demands low through appropriate operating methods.

Specific examples for other savings measures include:

- Attractions:
  Water features, such as slides, massage jets, water fountains etc. require additional electricity for operating the pumps. In addition, operation causes increased evaporation with concomitant evaporative heat losses and a higher ventilation demand. A major energy saving measure in the case of water attractions is ensuring good regulation, i.e. these should preferably only be activated when required. Various options are possible for this e.g. use of manual buttons with a timer (automatic switch-off after a pre-set operating time), or using automatic triggering mechanisms (e.g. light barriers for slides) or with time switches (fixed times or intelligent control system taking into account the number of pool visitors).
- Integrate routing of the water to be analysed for checking water quality into the water circulation system, i.e. implementation without additional pumps. Apart from this, returning the measured water to the pool circuit instead of draining away as wastewater. This will reduce both electricity consumption and water consumption.
- Reduced heat losses so that air vents through the roof (e.g. of the balance tank) are avoided
- Cleaning of the pump filter on a regular basis for efficient pump operation

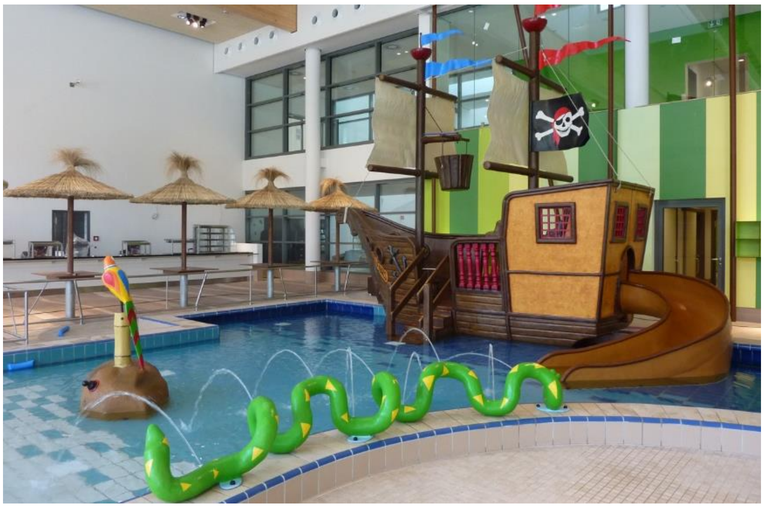


Fig. 26: Toddlers' pool with attractions (Bambados)

5 Hot water for showering

In indoor swimming pools, besides heating pool water a high heating demand also arises for hot water due mainly to use of showers. The use of water-saving fittings that close automatically is recommended with regard to energy, water and cost savings. Water flow through shower fittings should be 6 l/min and at the same time the water stream should be strong. Water-saving systems with integrated heat recovery and/or water treatment are also available for so-called rain-style showers which are used in spa areas for example.

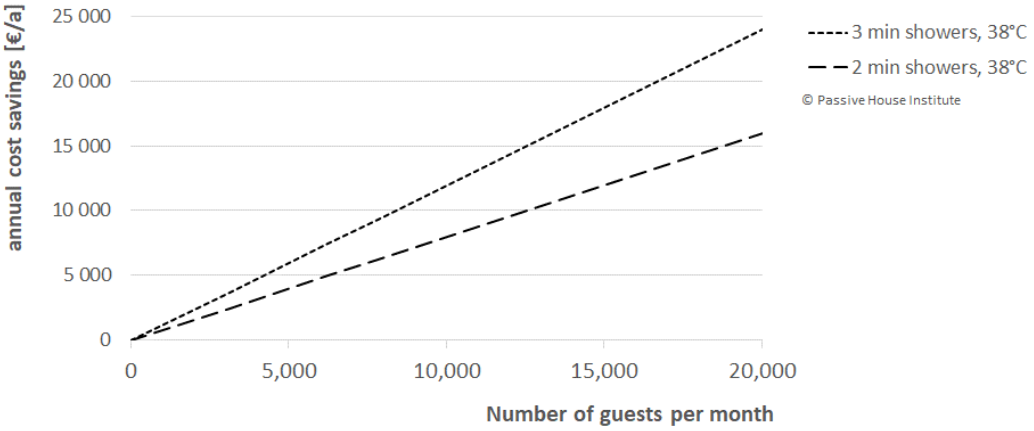


Fig. 27: Example showing the annual cost savings if water-saving fittings (6 l/min, compared to the usual 12 l/min) are used, for different numbers of visitors and average showering times per pool visitor. Source: [Gollwitzer et al. 2018]

If hot water generation and hot water points of use can be grouped closer together through clever planning, this allows for a compact pipe network with short line lengths. In this way, not only will electricity for water circulation pumps be saved, but also the distribution losses and thus the heating energy demand for hot water will be reduced. A hot water storage tank that is insulated without any gaps also contributes to this.

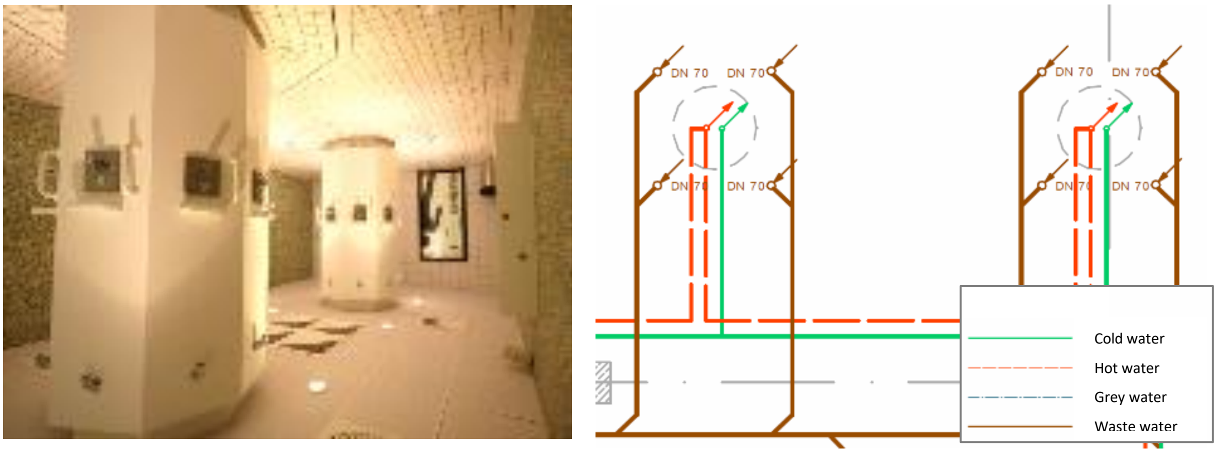


Fig. 28: Shower areas in the Lippe-Bad in Lünen with central pipe routing in the middle of both shower columns. Right: section from the implementation planning for plumbing, basement layout. Source: ENERATIO.

Heat recovery

Heat recovery from shower wastewater offers another significant savings potential in terms of energy. On account of the high wastewater temperature of ca. 35 °C and the frequent use, it is possible to achieve considerable savings even with simple passive measures for heat recovery. Active systems with heat pumps especially for use in indoor swimming pools are also offered on the market.

Tried and tested systems for heat recovery from shower wastewater with an integrated passive counter-flow heat exchanger in the wastewater pipe are increasingly being used in residential housing (see e.g. [Schnieders 2015]). Systems with several heat exchanger tubes connected in parallel are available for large amounts of wastewater as in the case of swimming pools. According to the manufacturers, an overall efficiency of 35 to 50 % is achieved in practice, depending on the type of installation and usage.

It must be noted that preheating of cold water may be problematic from the hygiene point of view (legionella). This can be prevented if the preheated water is not directly conducted to the cold water outlets of the showers and instead is routed to the heating centre and heated to safe temperatures first.

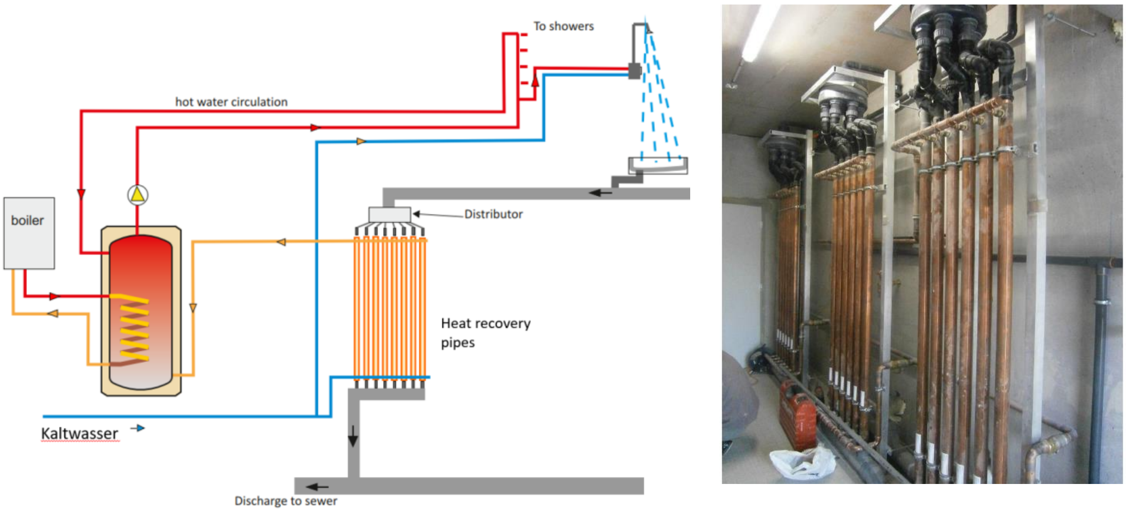


Fig. 29: Left: example connection of the heat exchanger collector tube for heat recovery from shower water; source: Q-Blue (adapted by PHI)
Right: Shower water heat recovery MulitVert in the Mons en Baroeul indoor swimming pool (France); source: Gaïa Green

6 Other potentials

A high level of energy efficiency should be strived for in all areas of the indoor swimming pool. There are two reasons for this: for one thing, there is a large potential for reducing energy costs in operation. For another thing, the internal heat loads are kept low in this way, which is advantageous for thermal comfort and the overall Passive House concept. Besides the already discussed areas, there are also other project-specific areas with savings potentials:

Catering

- Clarification of the actual requirements and suitable choice of the cooking process
- Thermal optimisation of the cooking device
- Efficient kitchen appliances
- Kitchen devices with direct extract air connection
- Demand-based ventilation (preparation and cooking phases)
- Heat recovery from wastewater and extracted air (vapours)
- Location and implementation of cold stores in the building (preferably near the northern façade and next to cooler rooms, excellent insulation on all sides)

Spa

- High level of efficiency particularly for devices for cooling or heating
- Low standby consumption
- Demand-based ventilation

Fitness area

- Location in the building (preferably near the northern façade and next to cooler rooms, thermally separated from warm parts of the building)
- In case of active cooling, technical and financial assessment of waste heat utilisation for indoor pool
- Compare utilisation times with the indoor pool: either synchronisation or separate ventilation and lighting regulation, possibly separate entrance, changing rooms

Sauna

- Location of the sauna cabins (preferably next to warm areas, away from colder areas)
- Excellent insulation of the sauna cabins, especially additional insulation of the roof can be realised easily and cost-effectively.
- Ventilation of sauna cabins: the greatest conservation of energy is achieved when the sauna cabins are/each sauna cabin is ventilated by a separate ventilation unit with heat recovery. This should be checked for the specific project. Alternatively, the entire sauna area can be supplied by a single ventilation unit (supply air in the relaxation rooms/anterooms and extract air in the sauna cabins).
- Anterooms and relaxation rooms in saunas: demand-based control of ventilation, e.g. according to CO_2 levels
- Plunge pools: with active water cooling, consider utilisation of waste heat

Lighting

Due to the long usage times and large rooms, the electricity demand for lighting is often one of the main electricity loads in indoor swimming pools. By using efficient technology (particularly LED) and demand-based control strategies, the electricity consumption can be reduced significantly.

- In the case of LEDs, attention should be given to suitability for high temperatures. (Higher temperatures usually mean greatly reduced life duration)
- Motion/presence detectors
- Daylight control for the swimming pool hall; suitable subdivision of lighting (near façade, away from façade)
- For positioning windows, attention should be given to daylight use

Elevators

For assessing efficiency of elevators, it is possible to use the method and classification into energy classes according to VDI 4707. The Passive House Institute provides a calculation tool for assistance which can be downloaded from:
http://www.passiv.de/de/05_service/02_tools/02_tools.htm

Often the electricity consumption during standby times may exceed electricity consumption for the active transport of users. For a high level of efficiency, it is necessary to give attention to the following aspects in particular:

- Interior lighting of elevators: equipping with efficient LED lighting which switches off during standby times
- Safety equipment: solutions with permanently low electricity consumption, e.g. safety brakes with mechanical control
- Ventilation: demand-based
- Smoke vents in elevator shafts: kept closed permanently, open only in case of fire
  Elevator overruns/travel paths should be insulated all around on the outside

Building management/automation system (BMS)

- Low standby consumption of the BMS system that is used, including all sub-components

Cleaning of the swimming pool hall

If cleaning takes place during the daytime, parallel to pool operation, then there will be no additional electricity consumption required for lighting and possibly ventilation. On the other hand, it makes sense if the cleaning staff can turn the appropriate lights on and off according to areas. In this way it may be possible to avoid the building having to be kept fully lighted over several hours.

7 Heat supply

In the interest of sustainability and reducing costs, lowering the energy demand has the highest priority. If the energy efficiency measures have been exhausted, there are various possibilities for meeting the remaining small energy demand. The available systems for efficient energy generation are wide-ranging, e.g. heat pumps, cogeneration units (CHP), condensing gas boiler, solar thermal power etc. It may also be quite advantageous to combine different systems e.g. for differentiation between the basic heating load and peak load coverage.

When selecting the energy generator, it is important to consider the context of the individual project and make use of any potential synergies. Due to the permanent and comparatively high heating load, indoor swimming pools may be of interest in relation to waste heat utilisation (from industrial processes, as a heat sink for cooling systems of nearby buildings, waste heat from central heating plants etc.) for example. A concrete example is the Lippe-Bad: two CHPs are operated in a nearby basement plant room, which supply the local heating network of the town. Ca. 60% of the total heating energy demand of the pool is met solely by the waste heat utilisation of these CHPs. In addition to utilisation of condensing technology (exhaust gas heat), dissipated heat from device housing is also used in this case (see [BGL 2011], [Peper/Grove-Smith 2013] and [Gollwitzer et al. 2018] for a system description and monitoring data). This utilisation of synergies is not only advantageous in terms of energy efficiency, but is also cost-efficient (see Fig. 30).

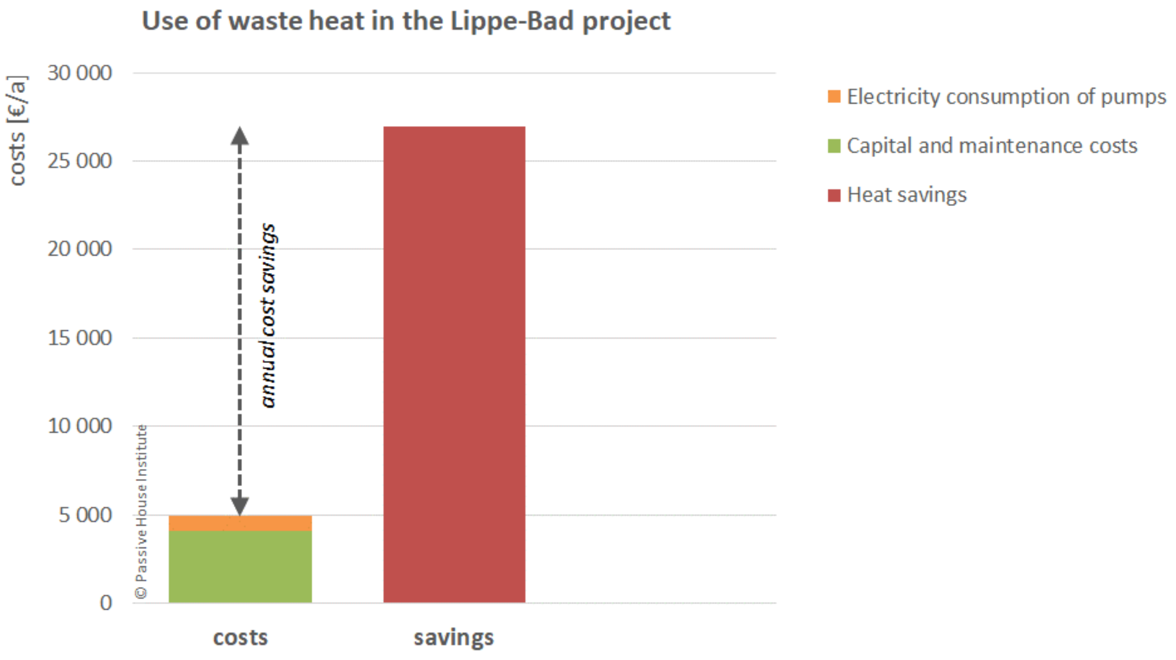


Fig. 30: **Cost-benefit analysis of waste heat utilisation of the CHP in the Lippe-Bad.**

In general, indoor swimming pools offer extremely advantageous conditions for the use of cogeneration plants (CHPs) on account of the year-round demand for heating energy and electricity. As a whole, the combined generation of electricity and heat is largely an extremely efficient way to utilise fuel. This can then be supplemented with e.g. condensing gas boilers for covering peak loads.

In light of the energy revolution, electricity - and thus the use of heat pumps as energy generators - is gaining importance as a renewable source of energy. For example, an outdoor air pump can be considered as a contribution towards meeting the heating energy demand. The use of heat pumps for utilising enthalpy of the exhaust air also serves as a special feature in indoor swimming pools. Due to the high temperatures and air humidity levels, there is a considerable potential for recovering heat from the exhaust air of the pool hall ventilation system. This kind of system is offered by various ventilation manufacturers. The method of operation of the ventilation system (possibly lower air quantities in a Passive House swimming pool) influences the achieved efficiency of the heat pump, therefore it is imperative to ensure that the individual components are consistent with regard to dimensioning and the planned operation method.

Regardless of the chosen system, for efficient heat generation it is important that the systems are designed in accordance with the expected heating outputs and that the individual components are coordinated well with each other. In addition, the distribution and transmission losses should be kept low through adequate insulation of the pipes and heat exchanger. The final decision is then often ultimately a question of the investment costs and the preferences of the operator.

Fig. 31: Lippe-Bad Lünen: Natural gas and biogas CHP (left) and exhaust air heat exchanger of one of the CHP (right) makes waste heat usable "for free".

8 Commissioning and operations management

8.1 Measurement technology and BMS

Normally every swimming pool has a building management system (BMS) for central control of diverse processes and monitoring of the building services and systems technology. The tasks and design capacity of the systems may differ greatly. Generally, the data that is collected, stored and visualised using these systems can also be used for testing, documentation and operation optimisation.

There are various possibilities depending on the extent and function of the system as well as the quality of sensors and meters: the more installed meters and measuring points there are, the more detailed the possibilities for monitoring operation will be. However, this also results in less transparency. For this reason, subsequent monitoring of operation should already be foreseen in the planning phase. The measurement parameters to be monitored should be specified, and options for depiction on the BMS should also be included in the process as measured values are only useful if they are clearly depicted and easy to evaluate.

Appropriately displayed in the BMS:

- Meters for electricity and heat quantities: consumption values (e.g. kWh/month)
- Monthly comparisons (as bar charts showing annual variation)
- Average values for various time periods (hourly, weekly, monthly averages) in order to obtain readable schemata in case of greatly fluctuating values even for bigger time periods
- Depiction of nightly or daily average values in case of differences in daytime/night-time operation

Fig. 32 Electricity meter in a BMS

Allocation of meters

As fundamental consumption variables, the total consumption meters for heat or gas, electricity and water should be metered at the building boundary. These are usually already installed for billing reasons. It should be checked whether they can be connected to the BMS with reasonable effort.

To gain an overview of the functions in the building and the amount of energy they require, it makes sense to install sub-meters for heat and electricity (see Fig. 33: 2nd level). For electricity, the large consumers in particular should be measured separately (ventilation system, swimming pool technology, possibly lighting). The remaining electricity consumption can be measured by separating according to zones (changing rooms, offices etc.). In most cases it will be complicated to centrally measure the consumption for lighting of the building as a whole. In that case the electricity consumption for lighting will be included in the consumption values of the separate zones. In individual cases, metering of an area in the 2nd level using a single meter will not be possible, in which case several meters arranged in parallel can be used, the sum of which in turn will depict the total consumption.

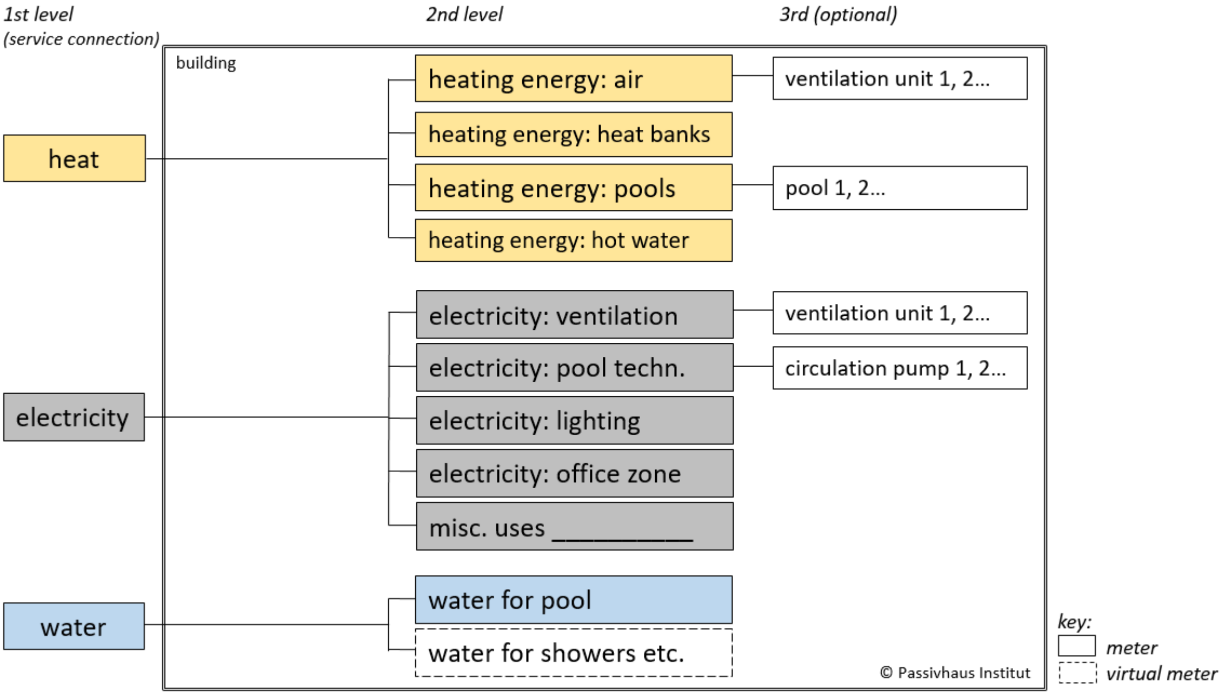


Fig. 33: Suggested concepts for meters (example with district/local heating connection). A calculated meter value is designated as a "virtual meter" here: e.g. the difference between different meters.

For successful operation optimisation and fault detection during ongoing operation, it is often advisable to install further sub-meters, e.g. for the electricity consumption of the individual ventilation units. Suggested concepts are listed in Fig. 33 in the 3rd level. In its guidelines for cost-effective construction [Stadt Frankfurt 2014], the city of Frankfurt recommends that in general, all consumers/loads which are expected to incur annual costs exceeding € 2500 should be equipped with sub-meters.

Especially with electricity consumption in the 2nd level various consumers still remain which are not measured separately. It makes sense and is helpful to document exactly which consumers these are, at the latest during commissioning. Ideally, the total consumption of an energy source can be evaluated and compared directly using one meter or as a total from several meters.

If the heat is generated inside the building itself (e.g. by a gas boiler or heat pump) then it should be clarified whether the efficiency of heat generation is to be measured during operation. Accordingly, further meters will have to be installed (shown in red in Fig. 34). The performance of the gas boiler or heat pump etc. can be checked continuously with the help of these meters. In contrast, the meters in the 2nd and 3rd levels will be useful for energy-relevant optimisation of pool operation.

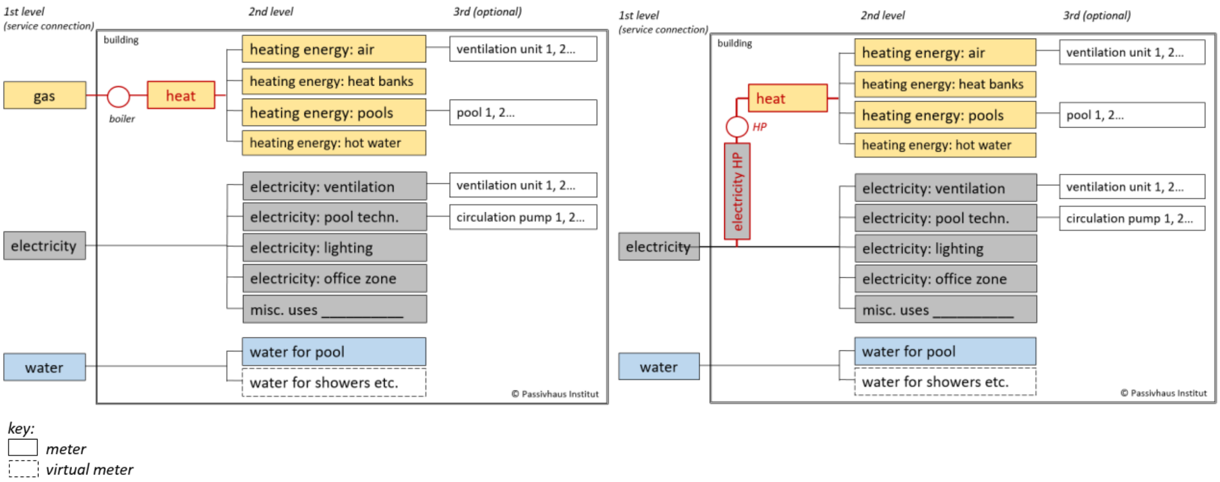


Fig. 34: **Suggested concepts for meters:**
Left: example with a gas boiler; the efficiency of the boiler can be monitored with the aid of another meter (in red).
Right: example with a heat pump: The COP of the heat pump can be monitored with the aid of two more meters (in red).

For setting up a concept for meters, it is essential to identify in advance the objectives behind these measurements.

Required sensors

Different sensors are necessary for demand-based control of an indoor swimming pool. Besides the necessity for sensors for controlling and regulation, it is also possible to record the boundary conditions of pool operation using sensors. These boundary conditions are fundamental for subsequent evaluation of the measured energy consumptions, which is why the selection of the necessary sensors plays an essential role. The following measuring points are recommended:

Sensors**:**

- Outside: temperature + humidity
- Indoor temperature + indoor humidity (if required as a control variable)
- Water temperature
- CO_2 (if required as a control variable)
- Presence detector (if required as a control variable)
- Daylight sensor (if required as a control variable)
- Ventilation units: volume flows (extract air, supply air; possibly air recirculation or exhaust air)
- Ventilation units: temperature + humidity (extract air, supply air; if frost protection is necessary then exhaust air)

Number of pool visitors**:**

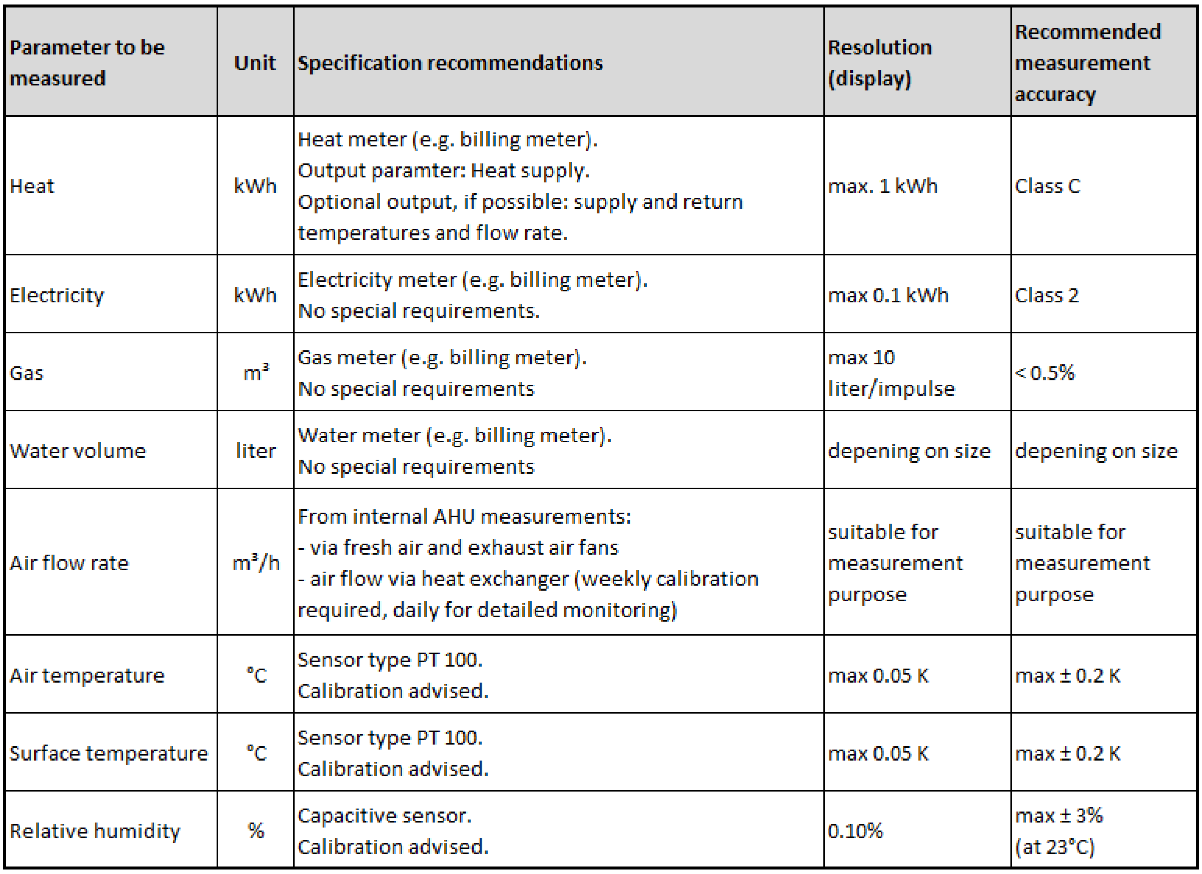
- data collection on a daily basis

It is recommended that a high quality mobile hand-held device should be acquired for measuring the temperature and humidity (at least: relative humidity ± 3 %, temperature ± 0.5 K). Measurements can be checked in different rooms or at different heights and in different areas of the pool hall using this; for example, a drifting humidity sensor of a ventilation unit can be detected with this and volume flows that are too high or too low as a result of this can be corrected.

Requirements for meters and sensors

After specification of the required sensors and meters, their quality should also be specified respectively. For this, consideration of the intended objectives of the measurements using the sensors or meters is fundamental: are relatively coarse resolutions and accuracies sufficient, or do e.g. consumption values (such as heating energy) need to be evaluated based on the measured data (e.g. air temperature and humidity)? These considerations will determine the requirements for the quality of the sensors and meters. Usually the standard sensors for BMS are not adequate for more extensive investigations and assessments. However, the manufacturers often also have other sensors of a better quality which can be requested. If higher accuracies of sensors are necessary, it is not only the quality of the sensor which is decisive but also the position and type of installation are important (e.g. height and whether on-wall or in-wall), and possibly the length of the cables (in case of voltage signals). These points must be discussed with the specialist planner and the manufacturer.

Table 4: Overview of requirements and recommendation for meters and sensors



Parameter to be measured	**Unit**	**Specification recommendations**	**Resolution (display)**	**Recommended measurement accuracy**
Heat	kWh	Heat meter (e.g. billing meter). Output paramter: Heat supply. Optional output, if possible: supply and return temperatures and flow rate.	max. 1 kWh	Class C
Electricity	kWh	Electricity meter (e.g. billing meter). No special requirements.	max 0.1 kWh	Class 2
Gas	m^3	Gas meter (e.g. billing meter). No special requirements	max 10 liter/impulse	< 0.5%
Water volume	liter	Water meter (e.g. billing meter). No special requirements	depening on size	depening on size
Air flow rate	m^3/h	From internal AHU measurements: - via fresh air and exhaust air fans - air flow via heat exchanger (weekly calibration required, daily for detailed monitoring)	suitable for measurement purpose	suitable for measurement purpose
Air temperature	°C	Sensor type PT 100. Calibration advised.	max 0.05 K	max ± 0.2 K
Surface temperature	°C	Sensor type PT 100. Calibration advised.	max 0.05 K	max ± 0.2 K
Relative humidity	%	Capacitive sensor. Calibration advised.	0.10%	max ± 3% (at 23°C)

The sensors and meters must be checked for proper functioning on a regular basis during the entire operation phase. In the case of billing meters, the energy supplier or grid operator will be responsible for compliance with the calibration periods of the measuring devices. In this regard, the internal sub-meters should also be checked and replaced if necessary. It makes sense to perform functional checks for sensors when the BMS is serviced. If higher requirements are wished for, then calibration of the sensors may also be necessary (calibration using a better quality measuring device). This is not possible with reasonable effort for all sensors. For CO_2 sensors test gases are necessary for this purpose, which involves disproportionate effort. On the other hand, a strong temporal drift is identifiable with many of these sensors. If this signal is used to control the ventilation units, this may result in differing air qualities or excessively high air change rates and therefore unnecessarily high electricity costs associated with this. In the case of CO_2 sensors it is therefore advisable to use so-called "self-calibrating" sensors (with a double calibration distance internally).

Building Management System (BMS)

With regard to subsequent operation monitoring, during the planning phase already it should be considered which of the measuring points/information can be connected to the BAS, which can be recorded, and which of these can be changed by the user. For subsequent analyses and evaluations of consumption data, many of the measured values should not only be displayed as momentary values but their temporal course should also be retrievable. For assistance, some parameters are listed here that often aren't recorded as time profiles, which would however be helpful for an analysis:

- Circulation volume flow
- Fresh water addition to pool
- Water temperature
- Damper position of the ventilation units
- Specified control unit from ventilation unit programming (e.g. heating dehumidification)

In doing so, it is key and imperative that the various set points that have been set are documented. Only in this way will it be possible to optimise operation at all. The set points do not have to be recorded in chronological order. However, documentation in at least a secure protocol form is definitely necessary. This applies to each change made to a set point. If the values are documented digitally in the BAS, it should be ensured that the values cannot be deleted e.g. when the BMS program is updated.

Unambiguous and concise description of the measuring points is essential for later use of the BMS for operations management and energy-relevant operation monitoring. When choosing the descriptions, it is helpful if all those involved (building services engineer, specialist company, BMS programmer and operator) work together and agree on the same distinct designations.

Pre-set schemata ("recipes") which can be called repeatedly for new time periods during operation will facilitate regular checking of the energy consumption by the operator. This may even decide whether such checking is carried out at all (an example schema is shown in Fig. 39 on page 56).

8.2 Commissioning

The purpose of commissioning of the swimming pool building systems technology is to check whether the planned functions are actually working and performing accordingly. The technology with all interactions within the entire swimming pool is tested during operation by means of various tests. Moreover, specific settings and adjustments for the pool must be made during commissioning. For this, set points are specified and adjusted if necessary.

For the building owner, commissioning is important for checking whether all commissioned and required functions are available and applicable. This exactly is the time when information relating to the technology and all settings made by specialists should be transferred to the operator. This communication of knowledge plays a decisive role in operation, optimisation of operation and for future operating costs (energy, maintenance etc.) as well as for comfort! It is important that the contracting companies (with knowledge of the installed technology including their programming), the designer (with knowledge of the planned operating conditions/controls), and the operator (responsible for future operation) work well together. For this reason, sufficient time for commissioning should be planned in advance by all those involved. The invested time will pay off manifold through smooth running and the resulting operations optimisation. It is recommended that the importance of commissioning is already emphasised in the tender and that the costs are reasonably taken into account. In doing so, it may be helpful to exactly describe the requirements and the procedure (e.g. demands for several dates).

Points relating to handing over and commissioning with reference to the energy consumption and energy efficient operation are set out below. Assessment with reference to other areas such as safety, water hygiene, occupational health and safety etc. are not part of the list compiled here.

Preparation

All three parties involved (designer, contractor, operator) should prepare well for the commissioning process. The contents and allocation of tasks should be agreed in advance for this.

- Designer: technical descriptions, specifications in the invitation to tender, set points, concepts for regulation, lists for adjustment, inspection plans, checklists for commissioning
- Contractor: operating manuals, technical datasheets, inspection plans, pre-set schemata on the BAS
- Operator: set points, operating times, required personnel

Ventilation

- Adjustment of the ventilation units; are the units balanced (outdoor air and exhaust air)? (The pool halls can also be operated with a slight negative pressure).
- Filters: Do the filter stages correspond with the planning? Are they clean?
- Ducts: Has insulation of the supply air and extract air ducts been implemented in accordance with the planning?
- Ducts: Has insulation of the air ducts (exhaust air and outdoor air) between the ventilation unit and the thermal envelope been implemented without any gaps?
- Exhaust and extract air grilles: has the free cross-section been executed in accordance with the planning?
- Check airtightness of the valves for the outdoor air and exhaust air ducts
- Adjustment of the duct network and the supply air and extract air valves: the objective is to distribute the air quantities according to the planning, i.e. usually a series of measurements will be necessary (iterative procedure). If it is not possible to measure each valve in the case of large duct networks, then measurements should be carried out for each duct section in order to check whether the planned air quantities are flowing through the individual areas. Adjustment should be carried out with the average volume flows and not maximum volume flows. Lists with corresponding information must be prepared by the designers for this purpose.
- BMS monitoring of operation: test/create pre-set schemata ("recipes") for continuous monitoring of operation (volume flows, control units for heating, dehumidification, cooling, control variables such as humidity and temperature, electricity consumption).
- Checking of adjusted set points (temperature, humidity, minimum air change rate)
- Document set points
- Time program: comparison between designer and operator
- Frost protection: check limit values (this is of interest particularly for colder adjacent zones. Example: if a limit temperature of - 3 °C is chosen instead of + 3 °C, the number of hours of frost protection operation can be reduced to about a quarter) [AkkP 52]
- Additional date: in order to check operation based on the past time period and to adjust or optimise operation if necessary, a second additional date for commissioning should be foreseen because regulation of the ventilation system is complex and is influenced by the various pool applications. This date should be scheduled so that the filtration technology is already providing a constantly good quality of water and the pool has already been in normal use for at least one or two months.
- Measurement of the airtightness of the ductwork (at least Class/Category B according to DIN EN 16798-3:2017-11)
- Electrical efficiency: determined at nominal volume flow by measuring the electrical power consumption of the ventilation unit. The electrical efficiency thus achieved (output divided by nominal volume flow) provides information about the efficiency of the ventilation unit in relation to the existing pressure losses.

Swimming pool technology

- First let the water to the building run freely and take samples. Connect the building pipes with the water supply only if the water quality is good.
- Check control of the demand-based circulation volume flow.
- If present, check operation and regulation of the internal circulation.
- Check water flow in the pool through colour testing. Perform the tests with full as well as partial load circulation operation (to secure savings potential).
- Check time program and manual switching of pool attractions.
- If possible, adjust the output of the recirculation pump to the characteristic curve of the pump for the planned delivery head and circulation volume flow.
- The electricity consumption of the swimming pool technology or the circulating pumps should be recorded separately. For this, suitable schemata should be pre-set on the BMS for visualisation. These will then be used for constant monitoring of the electricity consumption of the swimming pool technology during operation. During commissioning the operator should be informed in relation to the function, statement and possibility of intervention.
- Document set points.

Hot water for showers

- Insulation of the storage tank: implementation of insulation without gaps also at the base and connecting points; thermal imaging is suitable for testing.
- Insulation of the water pipes: gap-free implementation; cold pipes in warm areas must also be insulated for protection against legionella bacteria. Use diffusion-tight insulation for colder pipes in order to avoid condensation.
- Showers: possibly test flow rate by counting litres (catching water in bucket while clocking the time)
- Self-closing faucets: consider suitable time setting
- For intermittent or demand-based operation: check regulation of pumps and fresh water stations.

Fig. 35: Lippe-Bad: Counting flow rate of showers

Heating and cooling

- Check time program and regulation
- Perform hydraulic adjustment
- BMS monitoring of operation: test/create pre-set schemata ("recipes") on BMS for continuous monitoring of heating energy consumption (pool heating, space heating, possibly cooling for pool, possibly space cooling). It should be easy to see if heating and cooling is taking place simultaneously, exceptions are the cold pool or critical server rooms or similar. Nevertheless these should be shown in a (separate) schema for constant monitoring.
- Shading: check that the solar shading is drawn up or a corresponding message is displayed if heating is switched on in building parts (utilisation of solar radiation).
- Pumps in partial load operation: regulation without restriction by valves?
- Heating coil of ventilation system: is it adequately dimensioned?
- Heating regulation: forward flow temperature should not be regulated according to the outdoor temperature (if necessary the heating curve should be extremely flat)
- Document set points

Passive cooling for colder adjacent zones

- Description of the operating principle: window ventilation (manual or motor-driven), extract air operation, Ventilation system with summer bypass, open connecting doors
- Description of the control strategy; in case of manual measures, ensure that these are carried out

Specification of a limited number of cooling periods in the summer (blocked for the winter)

Fig. 36: Bambados: Sauna

Lighting

- LED: check suitability of lamps (whether it matches the high indoor temperatures; temperature-dependent service life)
- Check presence detectors or similar with set switch-off times and sensitivity
- Consider group switching for optimal daylight utilisation (compare with planning)
- Check the configured lighting scenarios (e.g. standard operation, illumination for contests, lights for cleaning)
- Comparison of configured time programs with the actual utilisation times
- Lighting control: operating instructions given to operations manager by the contracting company
- Electricity for lighting: with separate data collection, suitable pre-set schemata on BMS for constant monitoring

Fig. 37: Left: Sauna in Bambados; right: changing rooms of the Lippe-Bad

Documentation for commissioning

- Documentation of everything that has been checked during commissioning (e.g. checklist based on points in this section)
- Documentation of flow rate adjustment
- Collection of all operating instructions and product datasheets (kept accessibly)
- Documentation of programming (explanation of the program and flow diagrams in written form which can be followed by the operator) including configured set points in the program code
- Configured set points on the BMS or other devices
- Documentation relating to diagrams/lists which have been pre-configured for commissioning and should be used for constant operations monitoring
- Prepare training materials for personnel

8.3 Operations management and operation optimisation

Indoor swimming pools are technically complex buildings, the operation of which must be managed by experts. An operations manager should be in charge who keeps an eye on everything and has the authority to implement adjustments to operations. Whether and how further responsibilities are delegated depends on the size of the pool facility among other things. In any case it makes sense to provide introductory training for staff. Besides the operations manager, the specialist companies executing the work may also be consulted for this purpose. It makes sense if this is already taken into account in the tender.

For successful operation, different objectives have to be combined: e.g. safety, customer satisfaction, durability and low running costs (energy + personnel). This section will focus on control of energy consumption. This should be performed at regular intervals so that an increase in the energy consumption without any desirable additional benefits can be quickly identified and remedied. Furthermore, operations management must aim for operations optimisation (particularly in the first few years). The desired utilisation should be achieved with the minimum possible energy consumption. The operations optimisation potential can be utilised with little monetary expenditure and may lead to large savings in operating costs for some years. The effort required consists mostly of work hours of the operations manager and possibly small investments. In the Bambados pool for example, the electricity consumption of all ventilation units could be reduced significantly by ca. 60 % solely through changes in the control system (see Fig. 38).

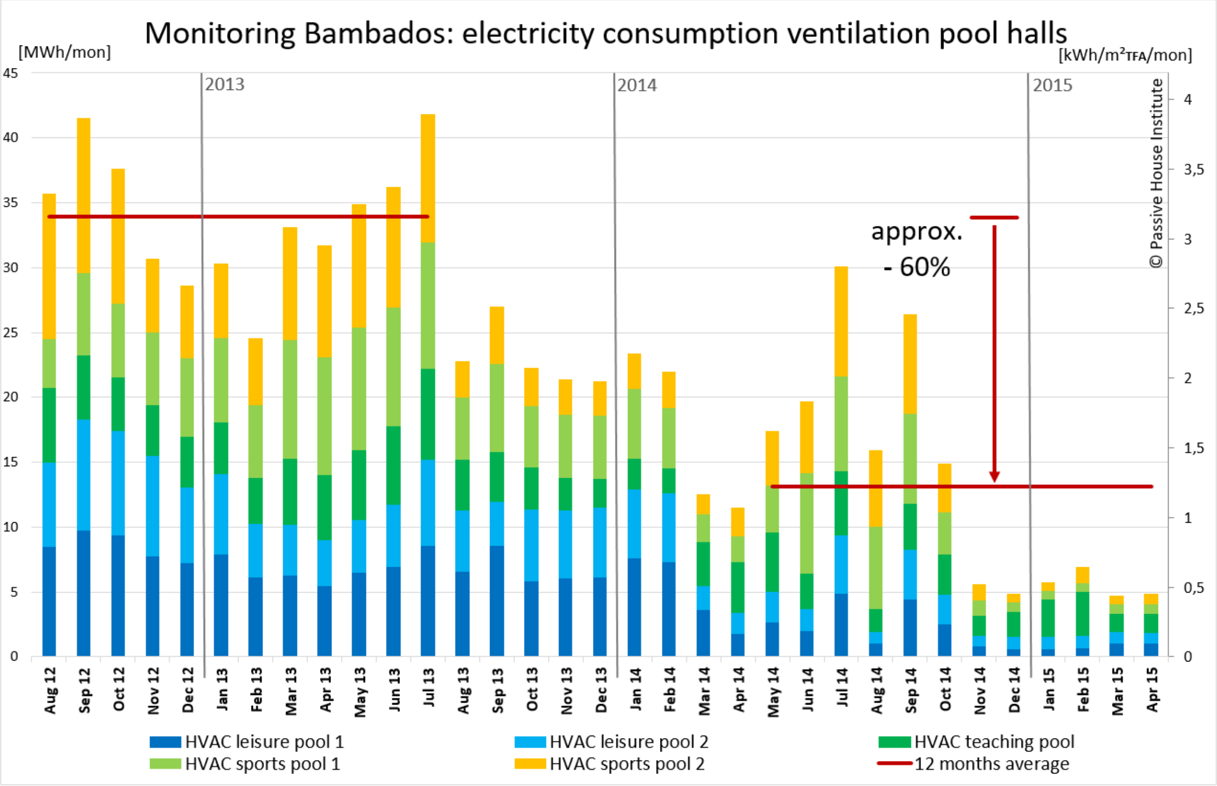


Fig. 38: Example of the indoor pool Bambados: reduction in the electricity consumption through optimised operation (without additional investment)

Operations optimisation is extremely economical because it does not require further investments (structural measures). The necessary technology usually exists already but is not utilised accordingly. Despite this fact, optimisation is not self-evident because operations managers usually have to fulfil many other sometimes more important tasks (compliance with hygiene-related requirements, organising personnel). Some examples of approaches which help optimise operation include:

- training personnel
- aids such as pre-configured control schemata ("recipes") on the BAS, checklists (see Fig. 40 and Fig. 41), high quality measuring device (relative humidity)
- fixed or extra time and/or staff for energy-relevant checking of operation (including documentation)
- clarification of the considerable financial extent of realisable savings
- possibly motivation through participation in the cost savings
- specification of control intervals
- regular exchange of information in the team and ideas for optimisation

Predictive/forward-thinking operations management

In order to realise predictive/forward-thinking operations management, it is fundamentally important to be aware of interactions and to have an understanding of the mode of operation/events which lead to increased energy consumption. In doing so, it is also helpful to be able to estimate the extent of energy consumption caused by a change so that the required effort and achieved benefit of a measure can be assessed.

The following examples usually contribute to higher energy consumption:

- Heat losses towards the outside (e.g. open door/window in the basement plant room)
- Heat losses towards colder temperature zones (e.g. permanently open door between a warm area and colder office portion or a cooled kitchen or sport area)
- Shading with simultaneous heating operation (e.g. lowered solar shading elements)
- Increased pressure losses in ventilation ducts (e.g. half-closed outdoor air valves, clogged filters)
- Increased pressure drops in water circuits (e.g. throttle valves, clogged filters,)
- Increased evaporation (e.g. splash showers and bubble loungers without users)
- Increased electricity consumption (e.g. operation of pumps for slides without users)
- Unnecessarily high ventilation volume flows
- Too frequent backwashing of filters
- High set points for temperature and low set points for humidity

It is helpful to consistently raise awareness of the staff so that they can attentively follow daily operations and counteract any irregularities/discrepancies.

Checking energy consumption

Unwanted changes and increased costs associated with these can be detected through regular checking of the energy consumption. This can be performed with varying levels of detail. The most important thing is to keep an overview of the total energy consumption. For this reason the analysis starts with the central consumption meters at the house connections. After that, in the case of unwanted changes one can go into more detail step by step and analyse the consumptions and interrelationships.

First of all the consumption of energy (electricity, heat, gas, water) should be evaluated. The depiction of monthly consumptions in the course of the year is appropriate for this, so that electricity consumption in January can be compared with the electricity consumption in January of the previous year (see example in Fig. 39). In this way it can easily be seen whether there are any major differences. Apart from this, it can be assessed whether the annual consumption has remained constant or whether there is a seasonal fluctuation (e.g. lower space heating consumption in summer compared to winter).

More exact evaluation of the consumptions is possible if electricity and heating energy consumption are recorded separately using sub-meters according to utilisation areas (e.g. swimming pool hall, changing rooms etc.). Depiction as described above is recommended here also. If there are any unusual developments then more exact depictions, such as weekly or daily profiles should be used instead. In this way, in case of problems one can find the cause by working step by step through individual areas.

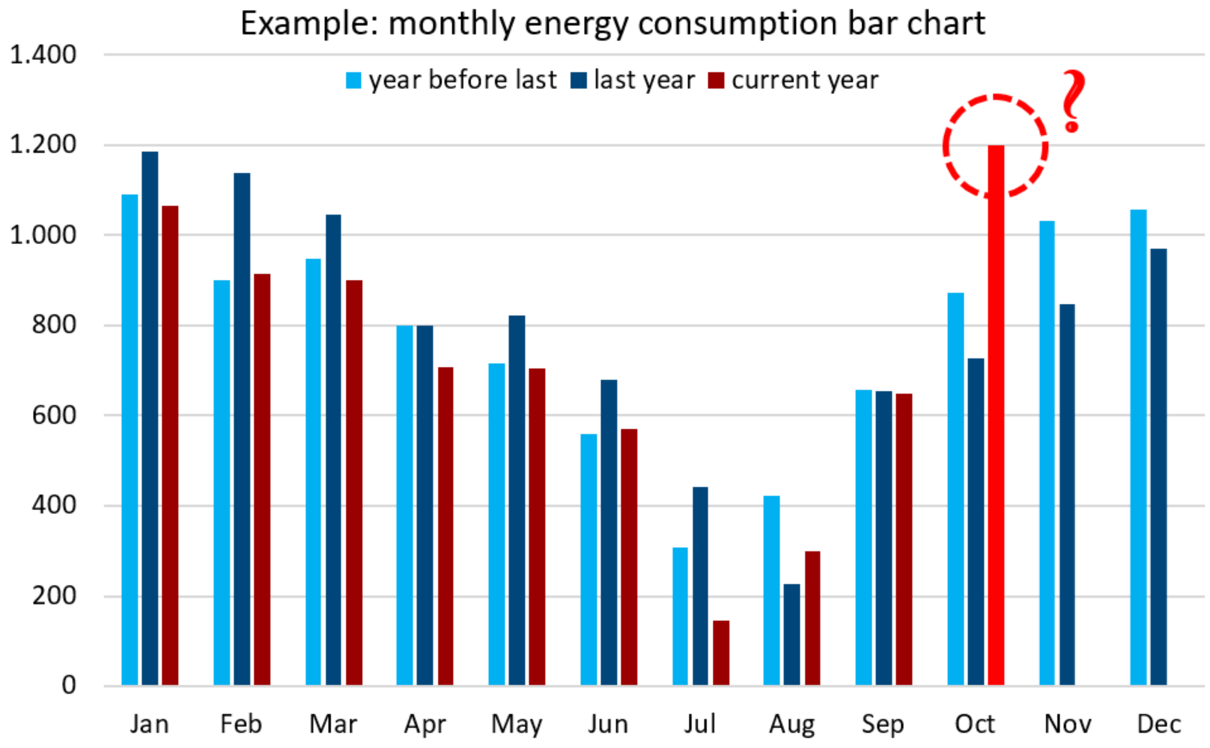


Fig. 39: It is easy to find changes in a depiction of monthly consumptions in the course of a year; evaluation: all three years show seasonal fluctuations; the current month (October) shows a significant irregularity. It is worth identifying the cause.

Other measured values may be helpful for the actual analysis of the energy consumption and interrelationships. For example, if one can display the controls (dehumidification, heating etc.) for a ventilation unit from the programming, then it is easy to track which "task" the device had performed at a certain point in time. Thus for example, it can be tracked how often during the course of the day the control unit for heating is active, and whether it is active at all on a warm spring day. The need to heat and cool in a short time interval (clocking) or in two adjacent areas without adequate thermal separation for instance would be undesirable. Temperature or humidity profiles inside the building as well as outside conditions may also constitute a useful basis for the evaluation.

After commissioning of an indoor pool the data should be analysed in detail for at least one year (after completion of any remaining work) in order to understand interactions during operation and find opportunities for optimisation. After successfully completed operations optimisation, it is enough to make monthly comparisons with little effort. In order to be able to assess deviations, it is important to keep an operations calendar/log in which changes, maintenance, special uses etc. can be noted. If differences are found during monitoring of the monthly energy consumptions, then the operations calendar/log can be consulted in order to see whether there are plausible reasons for these deviations (e.g. change in the set points). This will save time when searching for possible errors in case e.g. settings have been made inadvertently.

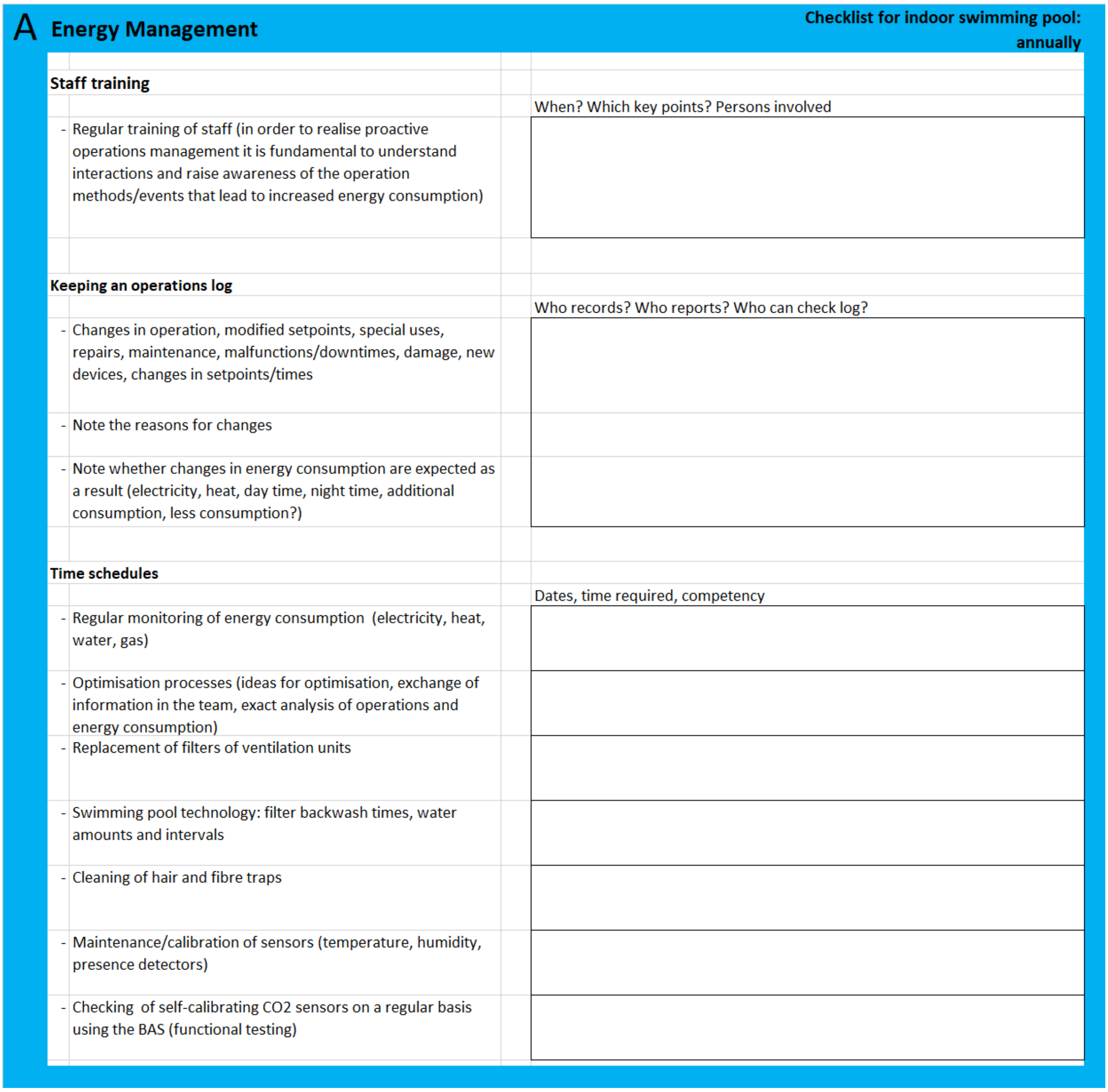
Specifying time periods in which the initial operations optimisation is repeated on a smaller scale is very effective. This serves for checking the current status and for identifying further optimisation potentials. Fixed times or set points may be obsolete. If all the staff is involved, it is possible to take into account additional feedback from daily operations and incorporate other ideas which will assist with the optimisation process. As a result of their involvement, the staff will be motivated to work together in the implementation and monitoring of measures.

Energy-relevant monitoring not only detects higher energy costs, it can also have positive effects on the operation. It often happens that irregularities in the energy consumption point to disruptions in operation which may have consequences, for example in relation to hygiene or stability/durability. Thus a high electricity consumption for example will indicate reduced cleaning performance due to clogged filters.

Checklist

The provided checklist (also available in the form of an Excel file on www.passiv.de) serves as an aid for monitoring and optimisation of operation. It can also be adapted and amended for the respective pool. The list is divided into three parts:

- **A: energy management** (see Fig. 40): clarification of the general procedure and specification of dates and competencies.
- **B: monitoring of energy consumption and operations optimisation** in 2 steps (see Fig. 41): this part of the checklist is suitable for monthly checks when the pool has already been in operation for some time and consumption values are available for comparison
- **C: detailed analysis in sub-sections:** if the monthly check shows any irregularities then the relevant area can be used for more exact examination in Part C. Part C is also suitable for operations optimisation (without illustration).



A Energy Management

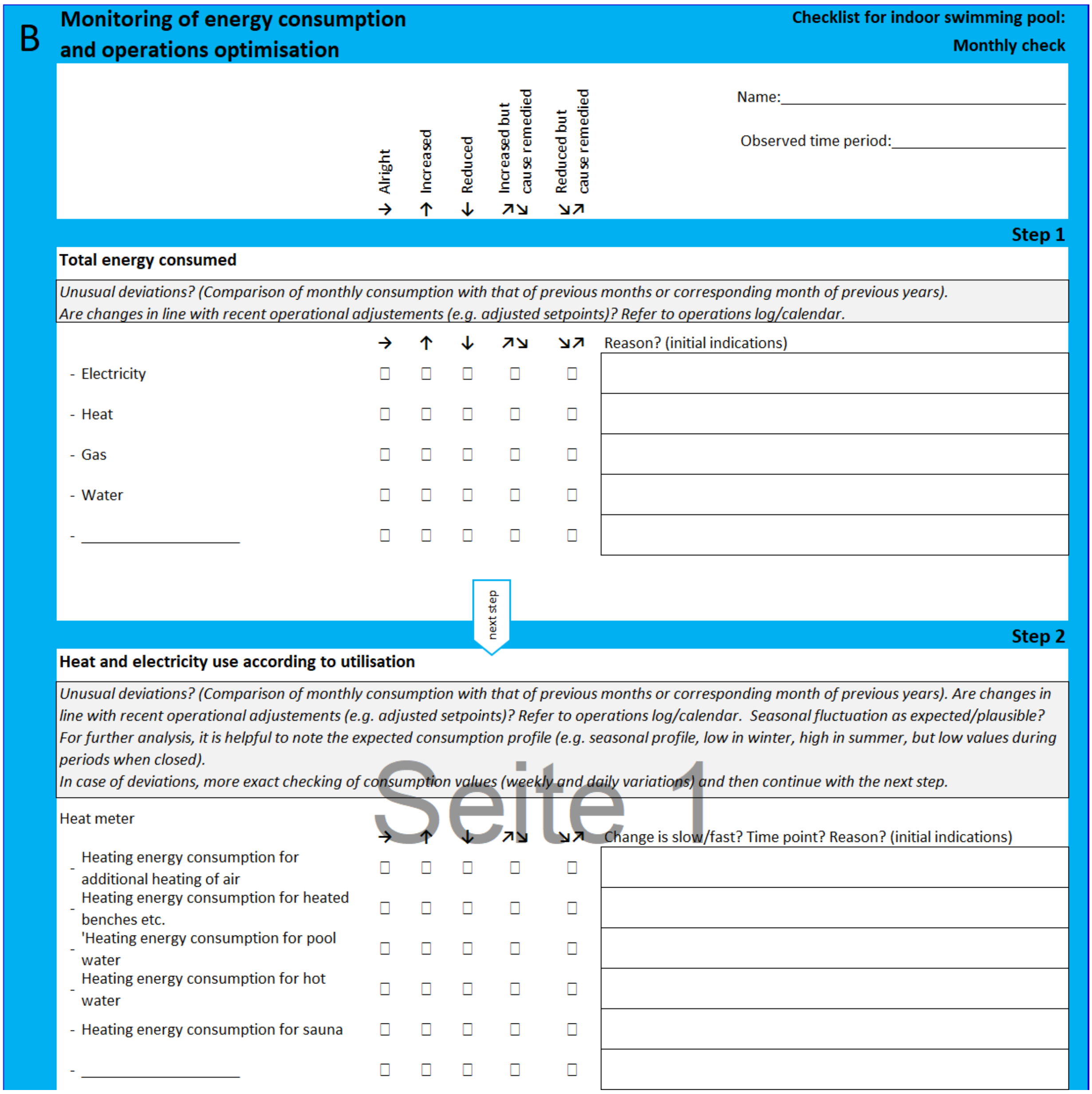
Checklist for indoor swimming pool: annually

Staff training	
	When? Which key points? Persons involved
- Regular training of staff (in order to realise proactive operations management it is fundamental to understand interactions and raise awareness of the operation methods/events that lead to increased energy consumption)	
Keeping an operations log	
	Who records? Who reports? Who can check log?
- Changes in operation, modified setpoints, special uses, repairs, maintenance, malfunctions/downtimes, damage, new devices, changes in setpoints/times	
- Note the reasons for changes	
- Note whether changes in energy consumption are expected as a result (electricity, heat, day time, night time, additional consumption, less consumption?)	
Time schedules	
	Dates, time required, competency
- Regular monitoring of energy consumption (electricity, heat, water, gas)	
- Optimisation processes (ideas for optimisation, exchange of information in the team, exact analysis of operations and energy consumption)	
- Replacement of filters of ventilation units	
- Swimming pool technology: filter backwash times, water amounts and intervals	
- Cleaning of hair and fibre traps	
- Maintenance/calibration of sensors (temperature, humidity, presence detectors)	
- Checking of self-calibrating CO2 sensors on a regular basis using the BAS (functional testing)	

Fig. 40: Part A of the checklist is used for specifying dates and competencies

The checklist assumes that a large number of meters and measuring points are connected to the BMS and can be analysed in the course of time. If this is not the case, then manual reading of meters can help. If the reason for an increase in energy consumption still remains unclear, then further temporary measurements in that area can be initiated, connection of other measuring points to the BMS can be considered or more exact investigations can be assigned to specialist companies. It is not possible for the operations manager to immediately find answers to all questions in the checklist, but if they appear to be relevant, then a closer examination can be conducted.

The checklist may also be helpful for a potential energy audit.



B **Monitoring of energy consumption and operations optimisation**

Checklist for indoor swimming pool:
Monthly check

Name:____________________

Observed time period:____________________

→ Alright
↑ Increased
↓ Reduced
↗↘ Increased but cause remedied
↘↗ Reduced but cause remedied

Step 1

Total energy consumed

Unusual deviations? (Comparison of monthly consumption with that of previous months or corresponding month of previous years).
Are changes in line with recent operational adjustements (e.g. adjusted setpoints)? Refer to operations log/calendar.

	→	↑	↓	↗↘	↘↗	Reason? (initial indications)
- Electricity	☐	☐	☐	☐	☐	
- Heat	☐	☐	☐	☐	☐	
- Gas	☐	☐	☐	☐	☐	
- Water	☐	☐	☐	☐	☐	
- ________________	☐	☐	☐	☐	☐	

next step

Step 2

Heat and electricity use according to utilisation

Unusual deviations? (Comparison of monthly consumption with that of previous months or corresponding month of previous years). Are changes in line with recent operational adjustements (e.g. adjusted setpoints)? Refer to operations log/calendar. Seasonal fluctuation as expected/plausible? For further analysis, it is helpful to note the expected consumption profile (e.g. seasonal profile, low in winter, high in summer, but low values during periods when closed).
In case of deviations, more exact checking of consumption values (weekly and daily variations) and then continue with the next step.

Heat meter

	→	↑	↓	↗↘	↘↗	Change is slow/fast? Time point? Reason? (initial indications)
- Heating energy consumption for additional heating of air	☐	☐	☐	☐	☐	
- Heating energy consumption for heated benches etc.	☐	☐	☐	☐	☐	
- 'Heating energy consumption for pool water	☐	☐	☐	☐	☐	
- Heating energy consumption for hot water	☐	☐	☐	☐	☐	
- Heating energy consumption for sauna	☐	☐	☐	☐	☐	
- ________________	☐	☐	☐	☐	☐	

Fig. 41: **Excerpt of Part B of the checklist for monthly energy consumption monitoring. The whole list is available as an Excel file on www.passiv.de.**

9 Conclusion and further information

The Passive House concept works for indoor swimming pools, saves operating costs to a significant extent and is therefore capable of substantially relieving the burden on municipal budgets. This is a decisive argument for keeping this kind of facility open for citizens. The recommendations in this guideline document provide important guidance which should be incorporated into meticulous planning.

Further background information can be found in the publications made available by the Passive House Institute on the subject of Passive House swimming pool buildings. All reports can be downloaded free of charge from the website (in German): www.passiv.de/hallenbad

Grundlagenuntersuchung der bauphysikalischen und technischen Bedingungen zur Umsetzung des Passivhauskonzepts im öffentlichen Hallenbad

Baseline study of the buildings physical and technical prerequisites for implementation of the Passive House concept for public swimming pool buildings

Study of energy-relevant interactions in swimming pool buildings and development of solutions for significant reduction of the energy demand

[Schulz et al. 2009]

Integrale Planung für die Realisierung eines öffentlichen Hallenbades mit Konzepten der Passivhaustechnologie

Integrated planning for realising a public swimming pool building using Passive House technology concepts

Documentation of the planning process for the Passive House indoor swimming pool in Lünen. Description of all relevant subsections of the integrated planned process from the building envelope , swimming pool and building technology, costs and energy balances to cleaning, acoustics and fire safety concepts.

[BGL 2011]

Monitoring Passivhaus-Hallenbad Lippe-Bad Lünen

Monitoring of the Passive House swimming pool Lippe-Bad Lünen

Documentation of detailed monitoring of the first 18 months of operation of the Lippe-Bad. The metrological analysis shows the operating conditions and the respective energy consumption values. The calculation methods were validated and refined through comparison with the predicted values and further savings potentials were identified.

[Peper/Grove-Smith 2013]

Passivhaus-Hallenbad Bambados Monitoring

Passive House swimming pool Bambados. Monitoring

Research report on the monitoring of the first few years of operation of the Passive House swimming pool Bambados, including operations optimisation and its effects on the operating conditions. Recommended actions on the basis of analysis of the measured energy consumption values.

[Gollwitzer et al. 2015]

Passivhaus-Konzept für Hallenbäder:
Datenauswertung und Empfehlungen

Passive House concept for indoor swimming pools: Data evaluation and recommendations

Analysis and amendment of the findings gained from the examination of indoor swimming pools and development of planning recommendations for subsequent projects. On this basis, energy savings potentials can be utilised in a targeted manner for future projects.

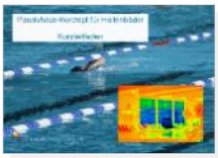
[Gollwitzer et al. 2018]

Passivhaus-Konzept für Hallenbäder:
Leitfaden

Passive House concept for indoor swimming pools: Guidelines

Compilation of recommendations for planning and operation based on the research report [Gollwitzer et al. 2018] as an aid for the construction and operation of Passive House indoor swimming pools.

Passive House Institute, 2018



Passive House concept for indoor swimming pools: Quick reference guide

Basic information about the most important points for the construction and operation of Passive House indoor swimming pools as extracts from the guidelines document.

Passive House Institute, 2018

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11 Imprint

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