Passive House Quality
Police Administrative Building

- short version -

Passive House Institute Darmstadt
July 2017

Commissioned by:
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HESSEN

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Police Administrative Building

- short version -

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Title of the Research Project:

"Passive House Construction Pilot Project", Scientific Monitoring of the New Office Building with Garages for the Nordhessen Police Headquarters in Baunatal.

We would like to thank the Police services in Kassel/Baunatal for making it possible for us to conduct the measurements. In particular, we would like to express our special thanks to Mr. Kanngießer, in-house technician, for his constant assistance.

All illustrations and images belong to the Passive House Institute unless otherwise stated.

Contents

1 Introduction

The Ministry of Finance for the German State of Hesse is responsible for the planning, construction and operation of buildings belonging to the regional government. For this reason, there is a natural sensitivity with regard to the overall cost burden for buildings during their life cycle. As its contribution to climate protection, the Hessian government intends to become CO_2 neutral by the year 2030. This decision was taken by the government of Hesse, thus also specifying new energy-related construction standards for government buildings. In 2007, a pilot project for the Passive House construction method was therefore initiated by the Ministry. The findings of the scientific monitoring of the building in its first years of operation will be presented below.

Since then, the government in Hesse has decided that in future, all new constructions will be built according to a building standard that significantly exceeds the currently applicable energy-relevant requirements, anticipating the provisions of the European Building Directive for 2019. A Passive House extension for the Ministry of Finance was also built based on the positive experiences gained with this pilot project and serves as an exemplary model for future government buildings in Hesse.

2 The building

The "Passive House Construction Pilot Project – New office building with garages for the Nordhessen Police Headquarters", which is the actual full project description, comprises an administrative building with a length of about 80 m and a width of 30 m implemented as a three-storey building with a flat roof.

The treated floor area based on the PHPP is 3870 m², with an additional area of approximately 1600 m² for the large garage on part of the ground floor.

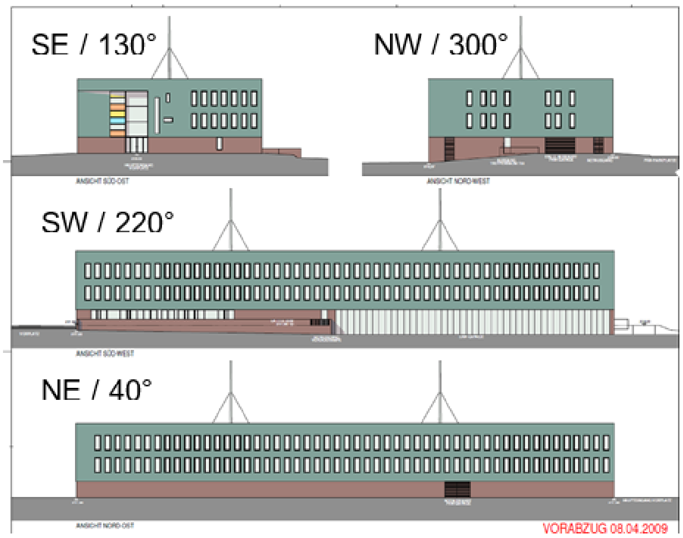

Fig. 1: Views of the office building

Since the building was to be built for the government of the State of Hesse, substantial parts of it were planned by the Hessian construction management department itself, with the involvement of a number of independent engineers. The Passive House Institute provided advisory support for the project and carried out the present study after completion on behalf of the Hessian State Ministry of the Environment, Energy, Agriculture and Consumer Protection.

**Fig. 2: Left: South-Western façade and entrance area on the South-Eastern side
Right: Façade detail**

2.1 Building envelope

While the heated zone of the ground floor has been implemented as a solid concrete construction with brickwork veneer and cavity insulation, the rest is a reinforced concrete frame structure with reinforcing stairwell cores. This is enclosed by prefabricated lightweight timber elements. Large span widths were achieved with the 50 cm thick hollow block ceilings. In-situ concrete was used for almost all concrete work.

Due to the unfavourable conditions at the building site, together with the use of the slightly sloping location for two different levels of the flooring on the ground floor, a 50 cm thick floor slab passing between the heated and unheated areas had to be used.

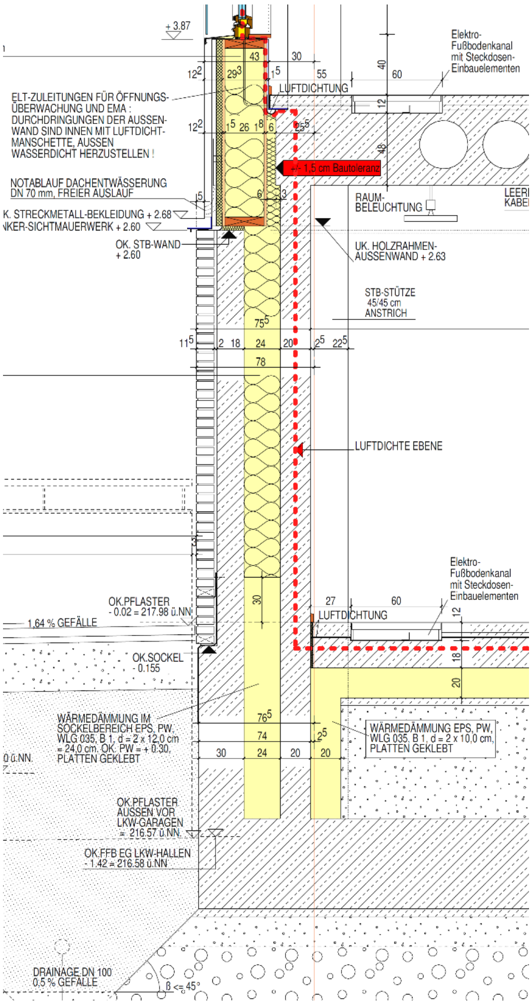

Fig. 3: **Cross-section showing the base point of the wall/foundation, and the airtight layer as a dotted red line**

The thermal bridge effect of the ascending load-bearing garage walls adjacent to the heated areas is limited by means of flanking insulation on both sides. However, the thermal bridges in the foundation area and due to the columns in the unheated garage area, contribute significantly to the transmission heat losses of this large building, accounting for 5 % of the total heat losses. In order to avoid other thermal bridge effects due to the brickwork of the ground floor façade, and create a foundation appropriate for the loads, the facing brickwork wall was implemented as a free-standing structure in front of the load-bearing wall that was clamped to the floor slab. (Fig. 3).

All façades on the upper floor were created using prefabricated timber structures. Windows and airtight inner planking as well as the thermal insulation were already installed by then, in this way it was possible to complete the building shell in a very short time. The timber elements are suspended from the top floor ceiling and are only fastened at the intermediate ceilings against horizontal forces.

Fig. 4: Assembly of the prefabricated façade elements

The U-values of opaque building components with ≤ 0.15 W/(m²K) are in the normal range for Passive House buildings in cool, temperate climates. This quality was achieved for all standard assemblies without issue, simply by slightly increasing the already foreseen insulation thickness.

The selected façade layout led to a high number of identical punch windows. This fitted in with the optimised detail design. Mullion and transom facades in the entrance area and for the ribbon windows on the ground floor were largely created from certified systems. Even so, this required some attention in order to achieve the necessary quality in these areas. Fortunately, since then the number of Passive House suitable systems available on the market has significantly increased.

Protection against the sun takes place by means of conventional venetian blinds on the outside, with daylight utilisation through divided blinds in the upper 50 cm (see Fig. 2). Large roof areas with skylights were equipped with fabric blinds on the outside to limit heat gains in summer and still allow the utilisation of solar incidence in winter.

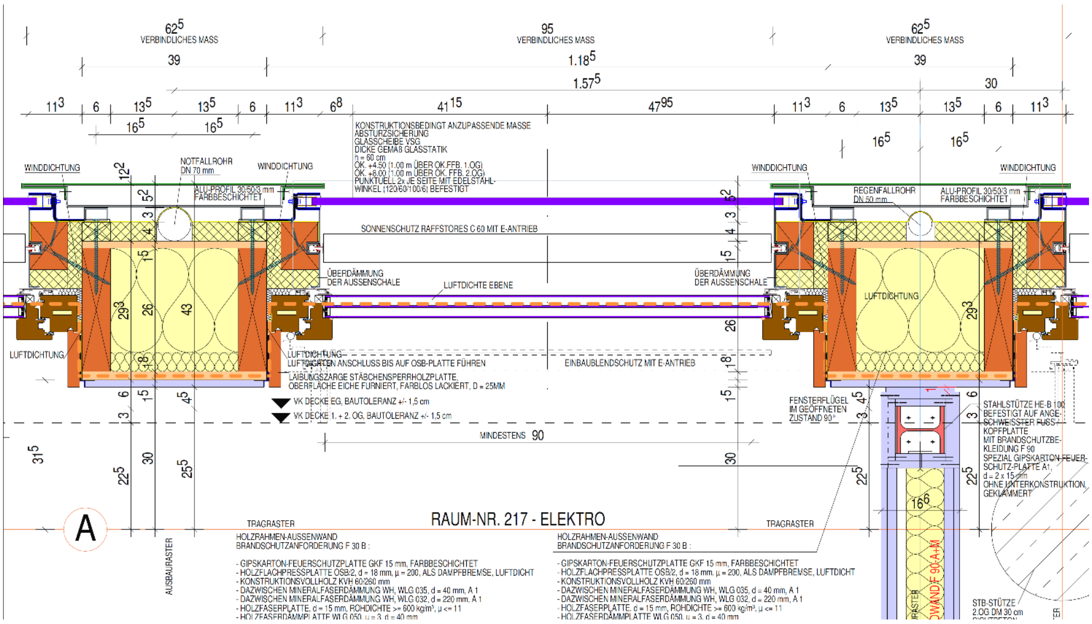

Fig. 5: Details of the prefabricated wall elements with window installation

The roof consists of a slightly inclined timber construction directly above the top floor ceiling. The roofing membrane layer applied to the formwork as a vapour barrier for the warm roof assembly creates the airtight layer and joins to the roof parapet consisting of the curtain-wall timber elements. The insulation layer consisting of PU rigid foam panels and finally the sealing membrane are applied over this.

2.2 Building services

It was possible to realise a ventilation concept with directed air flow due to the coordination of fire safety requirements and ventilation planning at an early stage. Doors situated in the corridors are constantly kept open during normal operation and the air can flow freely out of the offices into the corridors. The building is monitored by a fire alarm system and shuts these doors when necessary. Fresh air is introduced into the offices located along the façades and air is extracted in the central zone with the sanitary areas and store rooms. Presence detectors control the artificial lighting as well as the air demand. The total air quantities that are transferred can be kept small with this planning concept. The ventilation unit with high quality regenerative heat recovery is located on the top floor, so that the outdoor air and exhaust air ducts can be routed towards the outside through the roof along the shortest path.

To secure summer comfort during temporarily increased internal loads, cooling through concrete core temperature control was foreseen which can also distribute heat during the winter in Passive House buildings. On account of the very small temperature differences in each case, supply systems with a high level of efficiency can be used: a borehole heat exchanger system supplemented by a heat pump serves to remove heat in the summer, and heating can be provided in the winter through reversible operation of the heat pump system.

Surplus heat in the summer can be accessed via concrete core temperature control and transferred into the ground under the building via borehole heat exchangers whenever possible. In the case of an extra demand, this process can also be actively initiated by means of a heat pump system; alternatively, a recooling plant installed on the roof can be used as a heat sink (active or passive). The same heat pump system also meets the complete heating demand of the building for hot water for showering (all the year round) and space heating in winter, for which favourable working temperatures can be expected due to low forward flow temperatures of the concrete core temperature control.

3 Summary of findings

In the context of efforts by the State government of Hesse to achieve CO_2 neutral regional administration, the monitored building was built as a "Passive House Construction Pilot Project". The results of the study clearly prove that a significant contribution was made to the reduction of energy use and CO_2 emissions. Even before its completion, the Passive House pilot project gave a significant impetus to new requirements for energy efficient construction of government buildings in Hesse. Future projects of the regional government will profit from the insights gained with this pilot project. From these insights, government buildings in Hesse can be realised more easily and more economically in a sustainable way using optimised planning approaches.

The economic efficiency of this building was already examined previously in a study in 2009. [Huse 2010] summarises it thus: *"As a result of this analysis, here it can be stated that the office building constructed according to the Passive House method has definitely proved to be an interesting measure in economic terms. The PASSIVE HOUSE incurs such low operating costs and emissions compared with the reference buildings E07 and E09* [note: according to the German energy savings ordinance] *with a simultaneous improvement of thermal comfort that the higher investment costs for more energy efficient measures can be refinanced. Furthermore, the cost and supply risk is significantly smaller."*

The building with a treated floor area of 3870 m² is equipped with modern supply technology with two central heat pumps (connected to a borehole heat exchanger field and a cooling tower) for heating and cooling. Energy supply thus takes place monovalently with electricity and fits in very well with the sustainable future supply system based on fully renewably generated electricity. A concrete core temperature control (CCTC) system is used for heating and cooling all rooms.

Heating energy

The building was put into operation at the end of August 2014, and evaluation of the measured values started at the beginning of 2015. In particular, the measurement year May 2016 to April 2017 with a comparatively cold winter was evaluated in detail. The measured heating energy consumption of the building with just 19.2 kWh/(m²a) is very close to the calculated value of 18.3 kWh/(m²a) (after adjustment of the conditions of the operating year), which is considerably below the consumption values of ordinary office buildings. The slight increase is explained by the higher indoor temperatures (23 °C), the weather conditions and the increased air volume flow during the study period. This attests to the functioning of the high quality building envelope of this building. Thermographic images of the outside of the building envelope also demonstrate this in addition. The heating demand is divided into the dominant part of the heating via CCTC (18.8 kWh/(m²a)) and for post-heating of the ventilation with just 0.5 kWh/(m²a)(equating to 2.4 %). The energy expenditure for hot water consumption is secondary to this due to the largely office use and amounts to 6.6 kWh/(m²a).

Cooling energy

Cooling of the building takes place primarily via CCTC. Additionally there is the possibility of cooling of the server rooms and briefing rooms by means of ceiling-mounted circulating air coolers. The total cooling energy consumption of 39.4 kWh/(m²a) is higher than the planned amount. For the major part this can be attributed to unscheduled operation: it was discovered that heat recovery of the ventilation system was activated throughout the whole summer, due to which heat from extract air remained in the building (causing an additional cooling demand of ca. 10 kWh/(m²a)). In addition, reduced use of exterior shading elements generated an extra cooling demand (3 kWh/(m²a) with a variation in utilisation of 60 % instead of 70 %). However, there is no data available for the exact use of shading. In particular, it was found that cooling energy was required all year round which was principally used for cooling of the server rooms. If electricity is converted to heat inside a room and then actively removed by means of a cooling device. This process is purposely not included in the PHPP space cooling balance (but it is included in the electricity and primary energy balance), but because the waste heat from server rooms is removed via the building's cooling system, here this cooling amount must be taken into account separately in the cooling balance. The useful cooling that is required is thus increased by approximately 17 kWh/(m²a). The largest share of the additional consumption for cooling energy can be explained by these three effects. Further optimisation potential is therefore available in the area of useful cooling. The results also show that if active cooling is operated in non-residential buildings, the danger of achieving the desired level of comfort by means of further energy use rises although the full potential of passive measures (e.g. sunshades) has not been exploited.

Heat and cold supply

For the heat supply, 9.9 kWh/(m²a) of heat are taken from from the borehole heat exchangers. An electricity consumption of 10.9 kWh/ (m²a) for the heat pump is also introduced into the building as heat. For the cold supply, 26.9 kWh/(m²a) are removed via the cooling tower (equating to 78 % of the cold supply) and only 7.5 kWh/(m²a) are removed via the (shallow) borehole heat exchangers (equating to 22 %). For heat removal, the planning objective was to use primarily the cooling tower and then the borehole heat exchangers. This was successfully realised. The annual balance of the borehole heat exchangers is approximately equalised, therefore there is no reason to worry that the borehole heat exchangers could become depleted in the long term.

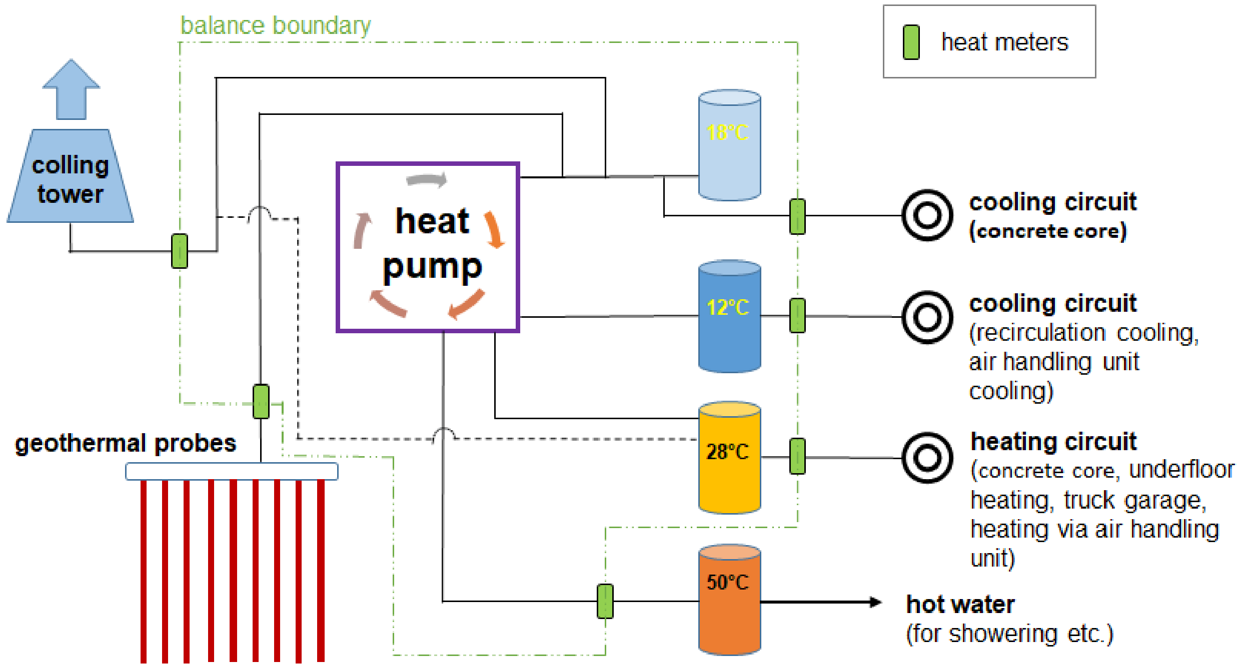

Fig. 6: **Schematic diagram of a hydraulic system of the building, simplified to a minimum, with the supply side and the four energy storage tanks with different temperature levels. The forward flow and return flow pipes are only drawn as simple connecting lines; heat exchangers between separate circuits are not shown. Downstream heat meters also aren't shown.**

Ventilation system

As is common for Passive House buildings in cool, temperate climates, this office building also has a ventilation system with heat recovery. A single central system was chosen for this, situated in a plant room on the top floor. This enabled the outdoor air and exhaust air ducts to be routed directly towards the outside through the roof along the shortest possible path. The central unit works on a renewable energy basis using two fixed heat storage blocks. The air route is cyclically switched every 60-90 seconds by means of louver dampers. By specifying longer cycle times, the heat recovery can be reduced as required. A design air quantity of 4200 m^3/h was planned for the project, whereby a considerably lower volumetric flow was expected most of the time. Controlled shut down with filter drying routine was foreseen outside of usage times, at night and at weekends.

For determining the heat recovery efficiency of the unit, in the main winter period of 2016/2017 the Passive House Institute carried out a more in-depth measurement using calibrated data loggers. The characteristic values of the ventilation unit that were obtained from the certification (86% effective efficiency) were confirmed with a heat recovery efficiency of 82 % under field conditions. The deviation is within the scope of measurement uncertainty. The highly efficient ventilation unit with heat recovery proved successful in actual practice even under unfavourable boundary conditions, and the characteristic values determined realistically in the context of certification turned out to be adequate for accurate planning of future objects**.**

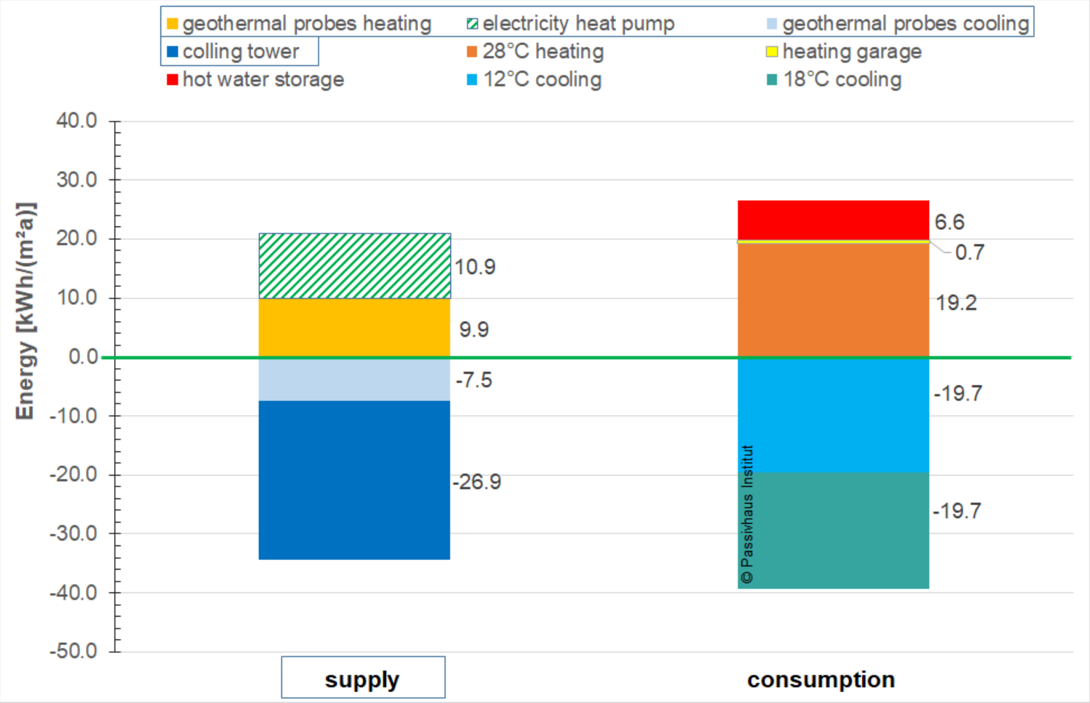

Fig. 7: **Supply-consumption balance of the building for the one-year period 01.05.2016 to 30.04.2017. Treated floor area (TFA): 3870 m².**

PHPP balance

During the planning, the PHPP calculation was continually adjusted for the structural conditions. For a suitable comparison with the planning data, the boundary conditions of the measurement (weather, indoor temperature, operating times and volumetric flow of the ventilation unit, occupant density, internal heat gains) must be taken into account in the balance calculation (PHPP). The results of the energy balance with the PHPP changed due to these adjustments. The measured **heating energy consumption** of 19.2 kWh/(m²a) was thus only 0.9 kWh/(m²a) higher than that obtained with the adjusted PHPP calculation, which can be assessed as a very good correlation. As mentioned above, a very high additional consumption compared to the planning was observed for the **cooling**. This was explained by the monitoring (use of heat recovery system all through the year, and server cooling).

Thus further potential is available in the area of useful cooling. What matters is that the counterproductive use of HR in the summer is deactivated (adjustment of control units). Activation in summer should only take place during hot periods (reduction of the heat load introduces by ventilation). Again, the results also make it clear how useful and necessary the use of energy-efficient IT technology is, particularly also in server rooms. Attention should always be given to this area during the planning.

Electricity

The building is entirely supplied with electrical energy, which is why the consumption values are of particular interest. The specific total electricity consumption of the building with 47.9 kWh/(m²a) includes all energy applications of the building, also those relating to police work.

The areas "lights + power sockets" and the separate data processing network "IT + IT power sockets" were assessed separately as a partial measurement. About 5 kWh/ (m²a) were used for the data processing, the remaining approximately 20 kWh/(m²a) were used for the area "lights + power sockets". The annual consumption for the entire MCR (measurement/control/regulation) applications was 13.9 kWh/(m²a). This supplies various control units and devices on all floors and rooms, including e.g. sensors, (temperature, humidity), actuators for e.g. dampers, presence detectors, window contacts, volume flow controllers, motorised fire dampers (permanent performance requirement against spring load), control measurements of filters, differential pressure measurement devices, cooling tower including water treatment, several pipe heating systems (for preventing freezing), pumps, thermostats and control valves.

In the area of building services, electricity for the hydraulic pumps (water circulation) was measured and studied separately. This was already included in the electricity for the measuring and control technology. For operation of the network with borehole heat exchangers, cooling tower and the four cold and hot water storage tanks including the concrete core temperature control (CCTC), four central pumps were measured and extrapolated to the 9 pumps used in total (6 CCTC pumps). This resulted in a total annual consumption of 2.3 kWh/(m²a) for all 9 pumps.

The ventilation system would need about 1.4 kWh/(m²a) (extrapolated) for operation according to the planning. The measurement of the ventilation system shows a higher consumption of 5.0 kWh/(m²a) for this one year period. The reason for this lies in the initial incorrect operation with much too high volumetric flows (also at night and on weekends). It turned out that since August 2016, the programming of the building management system was altered on account of excessively high humidity values in the showers, so that the device was operated at a very high level almost permanently. The time limit (post-run time/shut-off delay) for drying of the showers and washrooms was lifted, which led to operation with a constant demand of approximately 1600 m³/h just for the showers and washrooms. Due to the insistence of the Passive House Institute, the cause of this was discovered to be due to the programming of the BMS company. The programme was reset to the original operating mode with post-run times/shut-off delays on 09.06.2017, due to which the air flow of 4260 m³/h on average suddenly decreased to 1660 m³/h – that is, reduced by a good 60 %. Now the value of 4000 m³/h is only achieved infrequently as a peak demand. This change accordingly had a positive impact on the electricity consumption: the required electrical power decreased from an average of 3 kW to just 0.6 kW. This equates to an 80 % reduction. If this operation method is maintained, the monthly consumption will decrease by more than 1700 kWh/month.

If the reduction in the volumetric flows is maintained, the unwanted effects on the heating energy consumption, air humidity, electricity consumption and also mechanical stress on the duct system can be successfully stopped.

In the area of building services, the third biggest electricity consumption that was identified was the total consumption of the two **heat pumps** and their control units with almost 11 kWh/(m²a). The consumption of the control unit and two pump circuits is already included in this.

Heat pump

As the only heat supply system in the building, the heat pump plant (connected to a borehole heat exchanger field and cooling tower) is of particular interest. The heat pump supplies four cold and heat storage tanks with the temperature levels 12, 16, 28 and 50 °C. The COP of the facility was determined using the heat meters of the main areas with the cooling tower, borehole heat exchangers and the four storage tanks including the line losses and storage losses. Excellent results were achieved with COPs of 3.2 in the summer and even 4.9 in the winter. If also the electricity consumption of the circulation pumps is taken into account, these values decrease to 2.8 and 4.6 respectively and are thus still good considering the fact that line losses and storage losses are also included in these. COPs of 4.2 and 3.5 respectively (including electricity for feed pumps) resulted as overall annual values. Optimal operating conditions for the heat pump arose in the main winter period with heating operation and simultaneously a cooling demand for the server rooms, when COPs of 5.1 and 4.7 respectively (including electricity for feed pumps) were even achieved. This clearly shows that heat pump operation is successful and is functioning as intended.

Thermal comfort

In the winter, extensive tests relating to thermal comfort were carried out in four selected office rooms. These were all rooms which exhibited relatively unfavourable characteristics with reference to thermal comfort, such as having more than one exterior wall, or thermal bridges (e.g. towards the ground). For determining the operative indoor temperature, the radiation temperature asymmetry and air velocity, a measurement lasting approximately 30 minutes was carried out in all these rooms. In addition, thermographic examinations of the space enclosing surfaces were carried out.

In this test the rooms complied with the highest and the second highest category with reference to the operative temperature. The ascertained temperature stratification was extremely low, as expected for a well-insulated and airtight building. The requirement for the radiation temperature asymmetry was also complied with by a large margin in all rooms, a very homogeneous temperature range prevailed in each room. The measured relative air humidity levels were low and were below the 30 % r.H. that is recommended as an average value over longer periods. The cause was found to lie with the ventilation system which was operated with an excessively high volumetric flow. This operation mode was changed in the meantime, which is likely to result in higher air humidity values in the future. The measured average air velocities were very low. Even the peak values were below 0.1 m/s in all rooms. The average values were less than 0.07 m/s. Any impairment of thermal comfort by air movements can be excluded on this basis.

The summarised assessment indices PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) according to [EN ISO 7730] can be derived from individual parameters. Optimum thermal comfort according to category A was achieved in all rooms on the second floor, the PMV is clearly below the amount of 0.2. An even lower PMV can be expected for the less exposed rooms on the second floor and all rooms on the first floor. The conditions in about 90 % of the heated building area thus offer an optimal ambient climate even under the most stringent requirements.

Conclusion

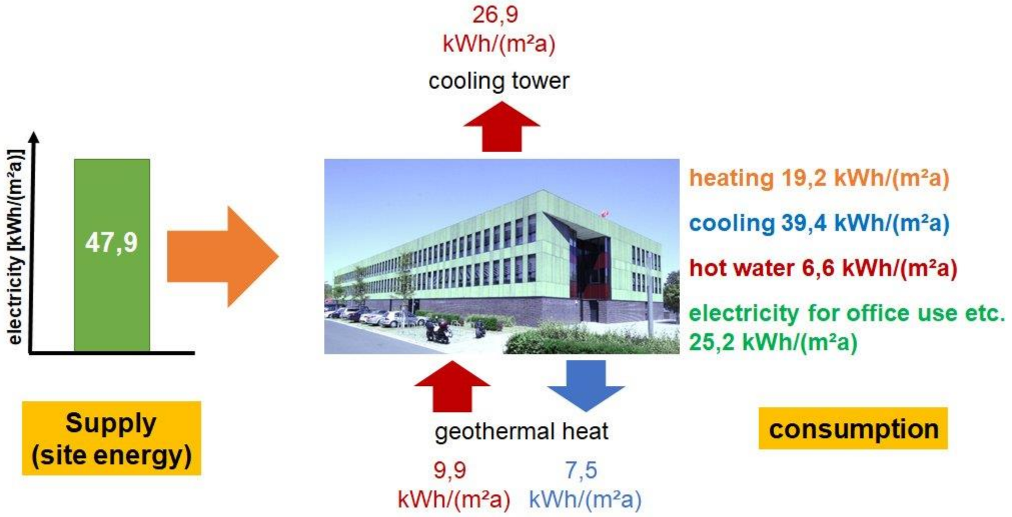

Fig. 8: Overview of results for the supply and use of the administrative building

As an overall evaluation, it can be stated that a functioning energy-efficient administrative building was realised, in which a high level of comfort has been verified. This was achieved with very low energy use on account of the extremely high quality building envelope and adapted building technology. The appropriateness of monitoring was again evident from the potential for improvement that was still available. The Passive House Standard once more has proven to be an easily implementable and practicable standard. It offers an excellent tried and tested solution for future building requirements, today.