PERFORMACE OF AN ENVIRONMENTAL BUILDING DESIGN - LEARNING FROM A MONITORING PROJECT

M. Oetzel[1], C. Brach-Annies[2], P. Kaul[3], U. Schmitz[3], Dr.-Ing. A. Kerschberger[4]

[1]University of Dortmund, Dpt. of Environmental Architecture and Building Physics,
Prof. Dr.-Ing. H.F.O. Müller, Baroper Str. 301, 44227 Dortmund,
phone: (+49)231/755-5426, fax: (+49)231/755-5423, email:oetzel@klima.bauwesen.uni-dortmund.de
[2] Brach-Annies + Annies GbR, Berlin on behalf of Assmann Beraten + Planen GmbH, Dortmund
phone: (+49)30/47488848, fax: (+49)30/47488849, email: annies-fm@t-online.de
[3] University of Applied Sciences, Grantham-Allee 20, 53757 St. Augustin,
phone (+49)2241/865-515, fax -(+49)2241/865-795, email: peter.kaul@fh-bonn-rhein-sieg.de
[4] RK Architekten, Pflasteräcker Str. 88, 70186 Stuttgart,
phone: (+49)711/285-1613, fax: (+49)711/285-9990, email: RK-Stuttgart@t-online.de

ABSTRACT

For the new building of a University of applied sciences a comprehensive ecological concept was developed with the aim to create an environmental adequate building with low overall energy demand. A monitoring program was started to investigate the total energy consumption, the performance of systems and the resulting user comfort. The monitored performance of an earth heat exchanger and an adiabatic cooling system are presented. The results show the energy saving potential and necessary modifications.

INTRODUCTION

In September 1999 the new building for the University of applied sciences, located in St. Augustin, Germany, was completed and handed over to the user (Figure 1). Situated on an green field site field almost no overshadowing from trees or surrounding buildings exists. A usable area of about 16.000 m² covers auditoriums, administration rooms, laboratories and libraries. Table 1 shows the main data of the building.

Figure 1: Aerial photograph of the building

TABLE 1
MAIN DATA OF THE BUILDING

Net floor area:	27.000 m²
Usable Area:	16.000 m²
Volume:	124.000 m³
Number of user:	1.700
Number of floors:	2-3, no cellar
Area to Volume ratio	0,32
Proportion of windows	23%

Ecological Design

From an early stage of planning a comprehensive ecological concept was developed by an interdisciplinary planning team consisting of architects and engineers specialised in service engineering and environmental friendly building design. The following features were finally implemented:

- Use of environmental adequate building materials, considering toxicology and embodied energy
- Improved thermal insulation of the building
- Activation of thermal mass for heating energy storage and passive cooling. Thermal mass as ceilings and walls are only partly covered
- Improved usage of daylight by overhead lights with transparent thermal insulation and light-directing louvres
- Passive cooling of classrooms by automatically controlled cross-ventilation and use of thermal mass
- Earth duct for preheating (winter) and precooling (summer) of incoming air
- Passive air conditioning of the auditoriums by earth duct, adiabatic cooling and highly efficient heat recovery system.
- Roof gardens for retaining rainwater and improvement of local climate
- Use of rainwater for toilettes
- Photovoltaic plant
- Combined heating and power station (in addition to the main heating system)
- Intelligent facility management system for the regulation of heating, cooling and lighting.

Figure 3 gives an overview about the energy flow within the building:

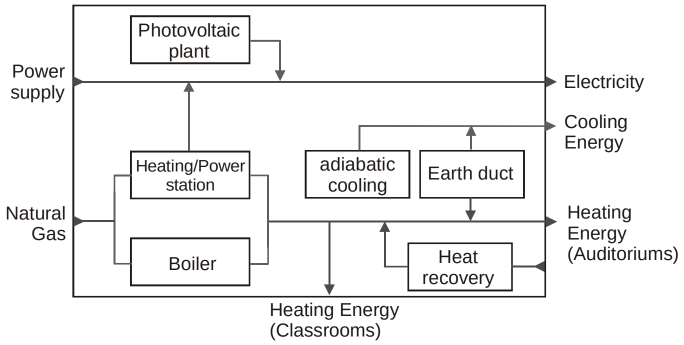

Figure 2: Energy flow of the building

Monitoring Program

To evaluate the benefits of the ecological concept an extensive measuring system was installed. A monitoring period of two years started on the 1. January 2000. Being part of a research- and demonstration project of the German Ministry for Education, Science and Technology, the building has to meet certain standards concerning the planning, environmental aspects and the resulting energy consumption. The total energy consumption for heating, hot-water supply and electricity has been monitored. In addition, the energy efficiency of the systems and the resulting user comfort was investigated.

EVALUATED SYSTEMS AND RESULTS

Representing only some of the evaluated systems detailed results will be given about the passive air conditioning of the auditoriums, including the earth heat exchanger, adiabatic cooling system and heat recovery. The analysis covers data from the year 2000 and 2001.

Earth heat exchanger

Auditoriums, library and some other highly frequented areas are supplied with fresh air and heating by ventilation plants. For preheating (winter) and precooling (summer) of incoming air an earth duct has been installed. Table 2 shows the technical data of the earth heat exchanger:

TABLE 2

TECHNICAL DATA OF THE EARTH HEAT EXCHANGER

Number of pipes:	3	Depth under building:	3,8 m
Material:	Reinforced Concrete	Nominal air flow (planned):	86755 m³/h
Nominal width:	1700 mm	Surface:	1202 m²
Length:	75 m each	Specific surface:	0,014 m^2/m^3h^{-1}

The implementation using only three pipes with a diameter of 1.7 m was chosen to enable trafficability for maintenance and cleaning. In addition the duct had to be laid below the building and therefore had to meet static requirements. As a result the specific surface defined as the ratio of surface and airflow is relatively small; earth heat exchangers with a large number of small pipes show in contrast a specific surface of up to 0.15 m^2/m^3h^{-1}.

To evaluate the energy flow of the system the ambient temperature, the air temperature on the outlet and the air flow is monitored.

The amount of heating and cooling energy supplied by the earth heat exchanger varies in a wide range according to the outdoor temperature, the air flow and soil temperature. In figure 3 the achieved temperature difference and corresponding outdoor temperatures are plotted. Each dot represents one quarter of an hour while the earth heat exchanger was in use (year 2001). A maximum temperature difference of 9 K for preheating and 7 K for precooling was reached.

In order to avoid heating in summer and cooling in winter, the system is equipped with a bypass, taking in fresh air directly while the earth heat exchanger is closed. The controlling system regulates the air flows, using a target value of 17°C for the air temperature. Figure 4 shows the resulting air temperatures behind the bypass and the corresponding outdoor temperatures. The bypass effectively prevents the cooling of outside air with temperatures below 17°C and the heating of outside air with temperatures above 17°C although some data points are slightly outside the desired range for cooling and heating due to the inertia of the controlling system. The controlling strategy had to be modified completely since the results of the year 2000 have shown a very inefficient use of the bypass.

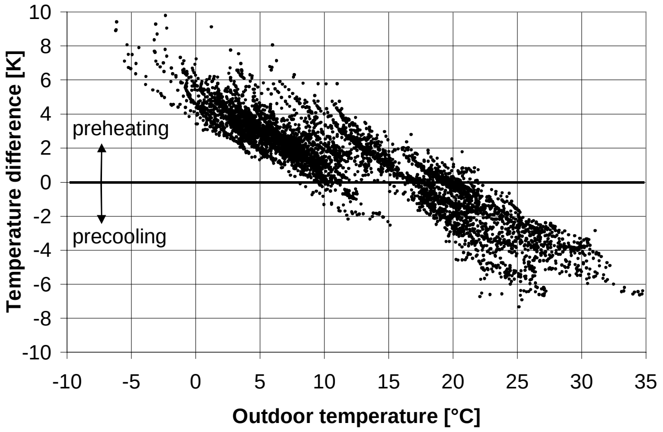

Figure 3: Temperature difference achieved by the earth heat exchanger

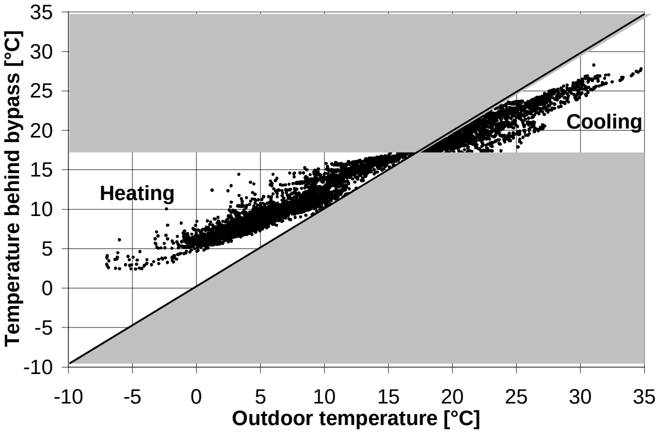

Figure 4: Regulation of air temperature with Bypass

Figure 5 shows the distribution of cooling and heating energy gains within intervals of outdoor temperatures. Each bar represents the accumulation of the supplied heating or cooling energy within an interval of 1°C of the year 2001. The highest amount of heating energy was achieved between 4 and 5°C outdoor temperature, the highest values for cooling energy between 22 and 24°C. This result corresponds with the frequency in which certain outdoor temperatures occurred during the year.

Table 3 summarises the monitored characteristic values of the earth heat exchanger of the years 2000 and 2001. The monitored average airflow reaches only 29 – 34 % of the nominal airflow. Therefore, the specific surface area becomes more advantageous. The achieved specific energy per m² surface area of the heat exchanger can be regarded as a positive result, though a higher number of small pipes would promise a better efficiency.

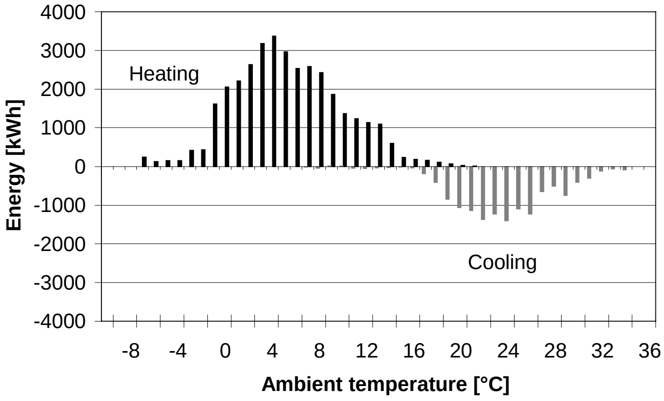

Figure 5: Distribution of energy gains for outside temperatures intervals

TABLE 3

MONITORED CHARACTERISTIC VALUES OF EARTH HEAT EXCHANGER

Year	2000	2001
Heating Energy [kWh]	27.911	32.173
Cooling energy [kWh]	19.280	12.245
Spec.heating energy [kWh/m^2]	23,2	26,8
Spec. cooling energy [kWh/m^2]	16,0	10,2
Average air flow [m^3/h]	29.422	25.273
Spec. Surface area [m^2/m^3h^{-1}]	0,041	0,048

Adiabatic cooling system

Instead of a usual cooling plant, an adiabatic exhaust air cooling system combined with a highly effective heat–regainer was installed to cool the auditoriums and other frequented rooms. In Principle, a pump sprays water under high pressure into the outgoing air stream. The humidity of the air is increased up to 95 – 100% RH. To evaporate the water a certain amount of energy is used. Because the total energy content (enthalpy) of the air stays constant, thermal energy of the air is taken and the air temperature drops.

An example for the adiabatic cooling effect is given in Figure 7, showing the changing air condition in the psychrometric diagram. Air with a temperature of 22°C and 50% RH is humidified to 100% RH, cooling down to 16°C. The diagram shows that there is a natural limitation for the potential of adiabatic cooling, depending on the current air condition.

In Figure 8, the principle of the adiabatic cooling system is shown. The warm exhaust air is humidified and cools down. By passing the heat recovery, which operates as a rotating storing mass, the warm outside air is cooled down and the waste air warms up. The heat recovery has an efficiency coefficient of about 80% and does not transfer humidity.

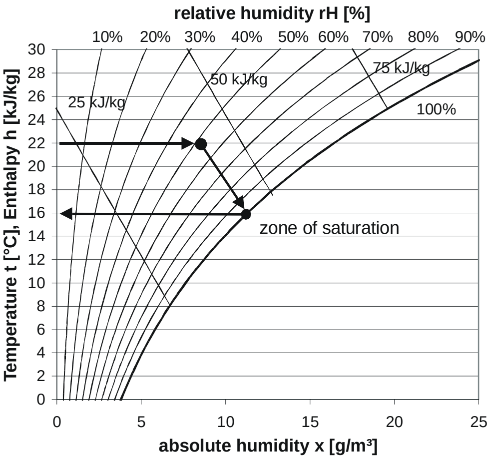

Figure 7: Psychrometric diagram with adiabatic change of air condition

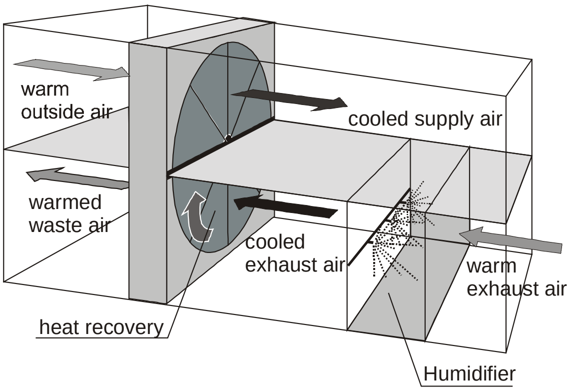

Figure 8: Adiabatic cooling system

Sensors for temperature, relative humidity and air flow are installed are installed in all in- and outgoing air flows to calculate the energy balance of the entire system.

The efficiency of the adiabatic cooling system does depend on a number of variables, which are changing and interacting constantly, as the in- and outgoing air velocity, temperatures, relative humidity and efficiency of the heat recovery. Figure 9 shows the range of temperature difference (cooling) and increase of relative humidity achieved by the humidifier while the system was on duty. While the relative humidity increased between 20 – 65%, the air temperature decreased between 3 and 9 K. Due to the variability of the fresh air temperature, only a fraction of the cooling energy attained in the exhaust air flow by the humidifier can be transferred to the supply air by the heat recovery. Figure 10 shows the cooling of both air flows. Though the monitored efficiency of the heat recovery itself had an average of 78%, the attained cooling of fresh air was often low. At some times an insufficient controlling strategy forced the system to work even when cooling of fresh air was impossible.

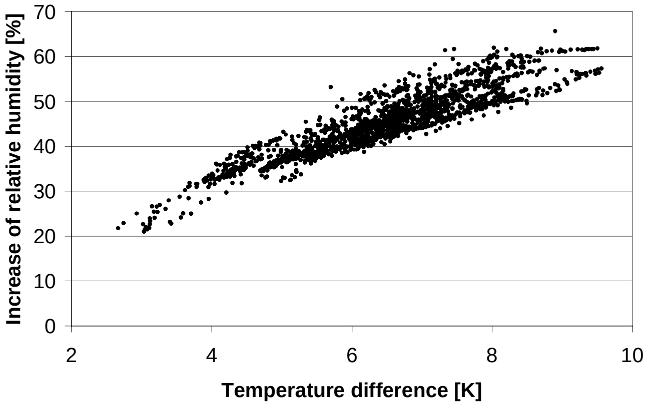

Figure 9: Increase of relative humidity and achieved cooling by humidifier

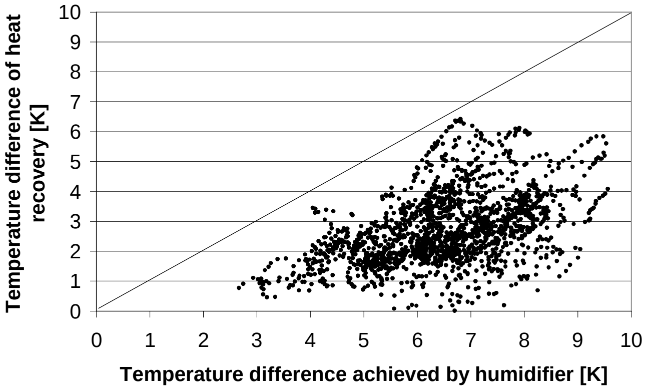

Figure 10: Cooling of waste air and transfer to supply air by heat recovery

The performance figure, defined as the ratio of gained cooling energy of incoming air and electrical energy consumed by the humidifier, varies for the same reasons as described above. In figure 11 the monthly cooling energy supplied for the fresh air, the consumed electricity and the resulting performance figure for the summer 2001 are shown. Because the system only works when there is a demand for cooling, the total monthly amount of energy does not necessarily indicate limitations of performance. The obtained average performance figure of 5,1 indicates a good energy saving potential of the system, which can be improved by better controlling strategies. It should be mentioned that due to the increased temperature of fresh air caused by the earth heat exchanger, the performance of the adiabatic cooling is reduced. Figure 12 compares the outdoor temperatures and the obtained supply air temperatures achieved by the earth heat exchanger and adiabatic cooling when the system was on duty (summer 2001). For all outdoor temperatures, the supply air temperature does not exceed 23°C.

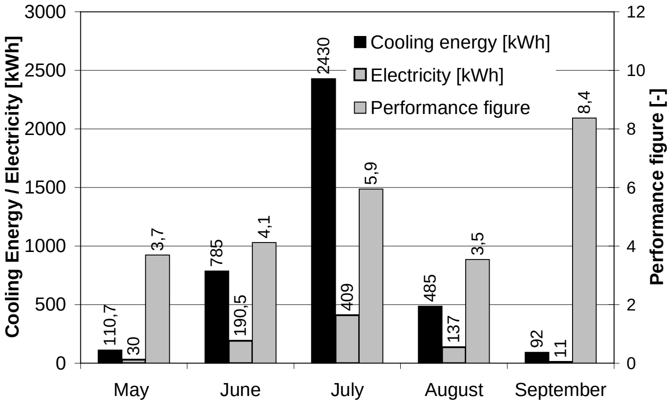

Figure 11: Cooling energy, used electricity and performance figure of the adiabatic cooling system

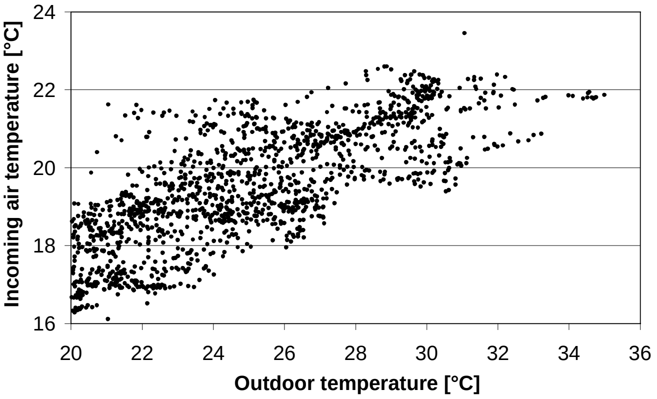

Figure 12: Outdoor temperature and obtained supply air temperature for 2001

CONCLUSION

Detailed results of the earth heat exchanger and the passive cooling system have been presented. Because of the dependencies on many variables the maximum performance can no be guaranteed at all times and conditions. Nevertheless, the systems show a high energy saving potential and are able to create an acceptable indoor climate. Controlling strategies have to be modified in order to improve the performance. The need for better controlling strategies was observed for most of the evaluated system.
The project shows that monitoring projects are an important tool to improve systems and regulation strategies. They help to take full advantage of energy saving potential of new systems and buildings.