MONITORING OF AN ECOLOGICAL BUILDING DESIGN CONCEPT-
THE BUILDING OF THE UNIVERSITY FOR APPLIED SCIENCES IN ST. AUGUSTIN, GERMANY

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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 results show the energy saving potential and necessary modifications.
Conference topic: 3.4 Monitoring

1 BUILDING AND ECOLOGICAL CONCEPT

1.1 Building

In September 1999, the new building for the University of applied sciences, situated in St. Augustin, Germany, was completed and handed over to the user (Figure 1). Situated on an open, plane field almost no shadowing from trees or surrounding buildings exists.

Figure 1: Aerial photograph of the building

A usable area of about 16.000 sqm covers auditoriums, administration rooms, laboratories and libraries. The building is structured in three main zones (Figure 2):

- Zone A: Main entrance hall, Auditoriums, library, administration offices, student restaurant, workshop and facility management.
- Zone B and C: Different departments with classrooms and offices, laboratories, computer pools.

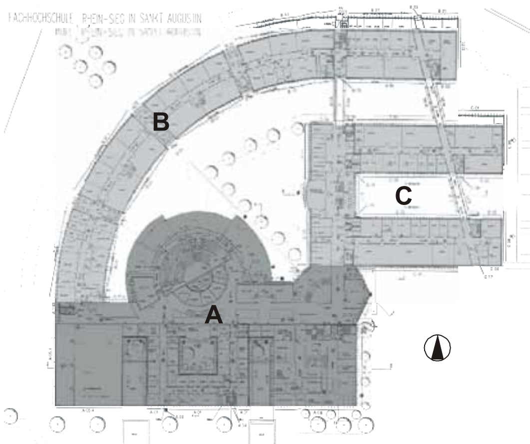

Figure 2: Floor plan and main zones

In table 1, the main data of the building are shown:

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%

1.2 Ecological Concept

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 heat energy storage and passive cooling. Massive construction 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 regulated 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:

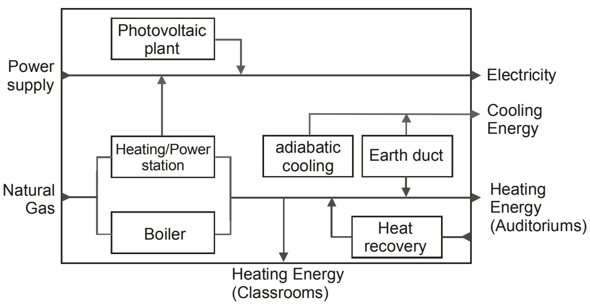

Figure 3: Energy flow of the building

2 MONITORING PROGRAM

To evaluate the benefits of the ecological concept, an extensive measuring system was installed. A measuring project of two years started on the 1. January 2000.

2.1 Objective of total energy consumption

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 energy consumption. Figure 4 shows the target values for energy consumption for heating, hot-water supply and electricity [1]. The value for heating energy demand is about 35% below the german design code [2].

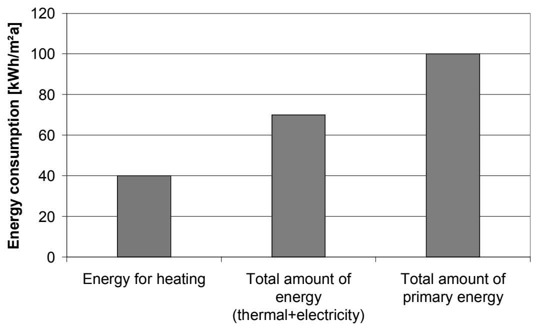

Figure 4: Target values for energy consumption

To calculate the total primary energy consumption, electricity is multiplied by 2,8 considering the average efficiency of power plants. Consumption of electricity only depending on the user, e.g. computers or radios are not considered.

2.2 Monitoring of systems and user comfort

In addition to the monitoring of the total energy consumption, the energetic efficiency of the systems and the resulting user comfort is investigated. Three representative classrooms and the main auditorium were chosen to asses the indoor climate and user comfort by monitoring temperatures, humidity and air quality (CO_2)

3 EVALUATED SYSTEMS AND RESULTS

3.1 Earth duct

Auditoriums, library and some other areas which are highly frequented, 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. Three concrete Pipes with a diameter of 1,6 m and 75 m length were laid 4 m underneath the building. Providing the three main ventilation plants with air, the maximum air flow can reach 84.000 m³/h. In order to avoid inefficient conditions in spring and autumn, the earth duct can be bypassed and outside air can be taken in directly. Figure 5 shows the achieved temperature difference at a given outdoor temperature. Each dot represents one quarter of an hour while the earth duct was in use (year 2000):

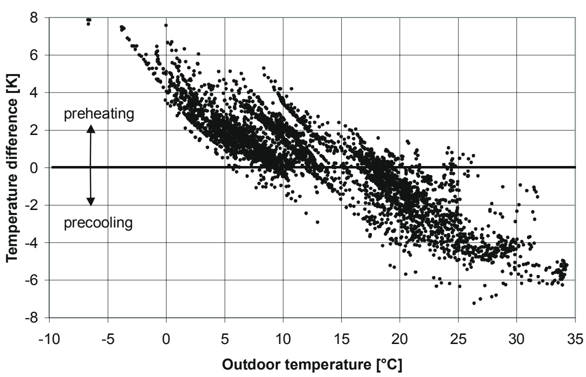

Figure 5: Temperature difference achieved by the earth duct

A maximum temperature difference of 8K for preheating and 6K for precooling is reached. The value of temperature difference is highly dependend on the air flow, therefore the values spread in a wide range. Air flow is measured at the main intake channel to calculate the energy flow. Figure 6 shows the monthly gain of heating and cooling energy (year 2000).

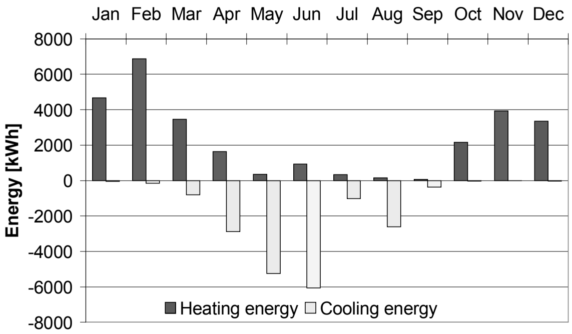

Figure 6: Monthly heating and cooling energy supplied by earth duct

With a total of 28 MWh heating energy, about 15% of the total heating energy demand for the ventilation plants is supplied by the earth duct.

3.2 Adiabatic cooling

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.

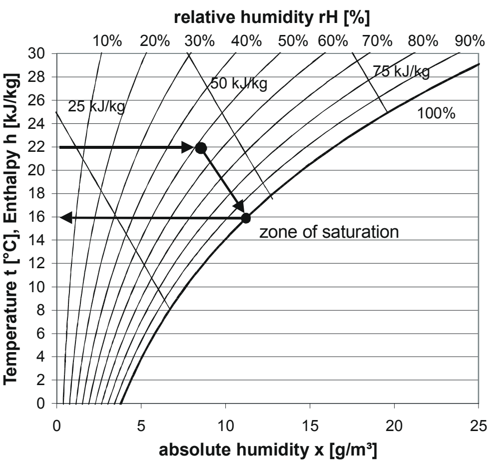

Figure 7: Psychrometric diagram with adiabatic change of air condition

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.

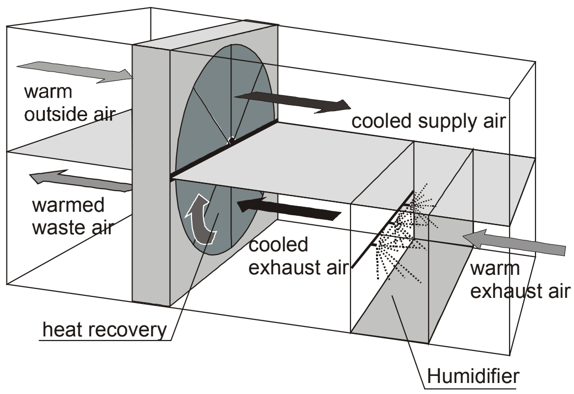

Figure 8: Adiabatic cooling system

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 9 shows the outside air temperatures and the temperature difference achieved by the adiabatic cooling. Each dot represents the average value of one quarter of an hour while the system was in operation. Line “1” marks a constant supply air temperature of 18°C, Line “2” of 22°C. The temperature of incoming air, pre-cooled by the earth-duct, does not exceed 29°C.

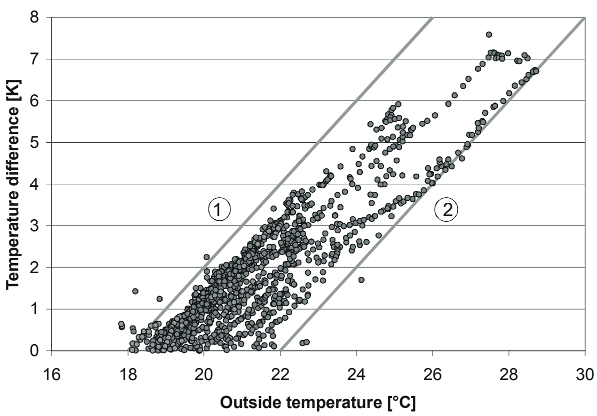

Figure 9: Cooling performance of adiabatic cooling system

The supply air temperature does not exceed 22°C, which constitutes a positive result. As shown in figure 7, the potential of adiabatic cooling is limited.

Due to an inadequate regulating strategy, the system was forced to work in a very inefficient way, trying to cool when the current air conditions would not allow it. Figure 10 shows the monthly cooling energy supplied by the adiabatic cooling, compared to the hours on duty:

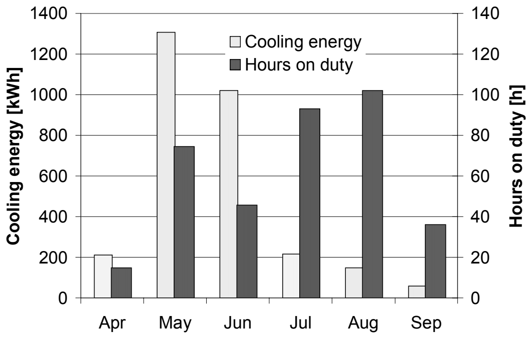

Figure 10: Cooling energy and hours on duty of adiabatic cooling system

This shows the need for developing regulation systems very carefully in order to use the full saving potential of a system.

3.2 Resulting indoor climate

Due to the fact that an adiabatic cooling system can not be compared to a usual cooling plant, the demands for the inside temperature in summer have been kept more tolerant allowing to rise above 26°C at some time. In Figure 11 the indoor temperature of the main auditorium is compared to the outside temperature. Indoor temperature is measured in the auditorium at head height. Each dot represents an average value of one hour while the room was in use:

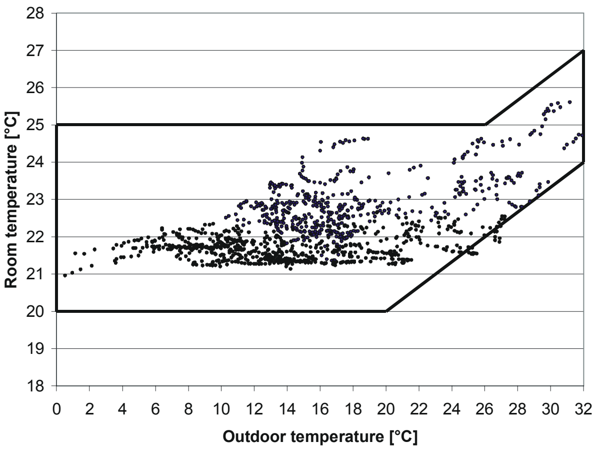

Figure 11: Indoor climate of the main auditorium

The black lines represents the recommended area for room temperatures according to german building standards. The figure shows that the indoor temperature does not exceed 26°C for all outside temperatures.

Concluding, the adiabatic cooling combined with the earth duct is able to create a comfortable climate with a low energy demand.

3.3 Passive cooling in classrooms

Zones with classrooms and offices are completely naturally ventilated. Cooling of these rooms is provided by a cross- ventilation system. At night-time, when the outside temperature drops below the inside temperature, top-lights in the facade and air ducts bridging the corridors will open automatically, establishing ventilation with cool air across the building. Thermal masses are activated by refraining from ceiling and wall covers. Therefore, the massive construction is able to cool down at night (figure 12).

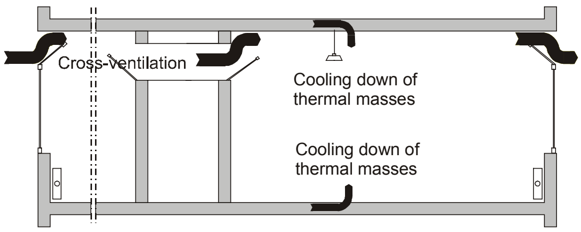

Figure 12: cross-ventilation in classrooms (night)

In the morning, Flaps and ducts are closed again automatically. The heating up of the room caused by solar gains and the user during the day delays due to the thermal mass. Figure 13 shows the measured development of the room temperatures during a hot period in August 2000. The outdoor temperature, room temperature and the surface temperature of the massive ceiling are plotted.

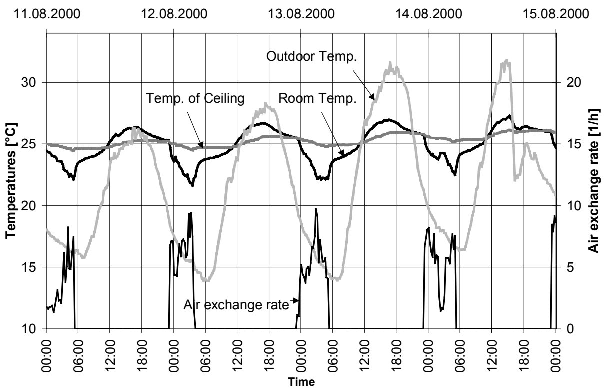

Figure 13: Room temperatures during a hot period in August 2000

The outdoor temperature in this period reaches 32°C. While the flaps are open and an air exchange establishes, the room temperature drops and the massive construction is cooled down. An air exchange rate up to 8/h is reached. During the day, the room temperature does not exceed 26°C.

Due to the fact, that the openings for incoming and outgoing air have the same level, airflow can not be thermally induced, therefore some outside air movement is necessary to establish the air exchange. Though the measured wind speed and direction have a strong influence on the air exchange, no direct relation can be obtained. Problematic is the fact that the flaps close automatically at 5:00 am, while the lowest outdoor temperatures occur about 6:00 am, when the system would have the best efficiency.

The opening time of the flaps will therefore be extended to 7:30 am for next summer.

3.4 Daylighting concept

With the aim of energy reduction for artificial lighting and the creation of good working conditions for the user, a concept for an improved use of daylight was developed. Due to the depths of 8 meters, all classrooms have room-high windows with top-lights. The top-lights of the south-facing facades are equipped with transparent thermal insulation (TTI) in order to reduce glare and to provide better distribution of light in the depth of the room (Figure 14).

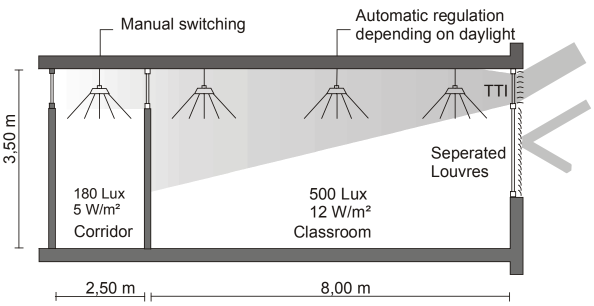

Figure 14: Daylighting concept of classrooms

The louvres can be controlled separately and can be used independently in the upper and lower part of the window. When the louvres at the windows are closed to protect from glare, the top-lights still provide daylight for the room. Top-lights between corridors and classroom allow some daylight to enter the corridors and reduce the demand for artificial lighting.

The artificial lighting in the classrooms is regulated automatically complementing the available daylight to the necessary 500 lx. An override by the user is still possible.

3.5 Total energy consumption

Figure 15 shows the monitored total energy consumption of the year 2000:

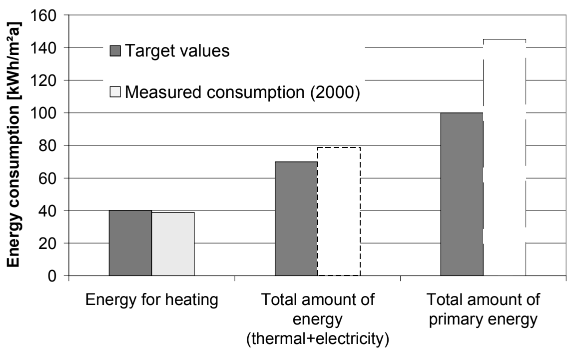

Figure 15: Total energy consumption (year 2000)

The target value for heating energy meets the requirements, while the total energy consumption and the total primary energy exceeds the targets. This is due to the individual consumption of the user which is still included in the calculation in contrast to the requirements. Due to the fact that the user consumption is not recorded separately, an investigation of the number and kind of individual devices will be done.

Considering a usual number of computers and similar devices the total energy consumption will most probably meet the requirement.

4 CONCLUSION

Monitoring results of systems and the overall energy consumption have been presented covering data from the year 2000.

The total energy consumption concerning the heating energy did meet the requirements, while further investigations are necessary to gain more detailed information about the consumption of electricity. Most systems were able to meet the expectations, though regulation strategies need to be modified in order to improve the performance. The project shows that monitoring programs are an important tool to improve systems and regulation strategies. They help to take full advantage of energy saving potential of new buildings.

Modifications have been made within the year 2000, which will show their results during the year 2001.

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http://www.solarbau.de
(28.03.2001)

[2] Wärmeschutzverordnung 95
Verordnung der Bundesregierung
vom 16.08.1994

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