ESL-IC-08-10-73

LOW ENERGY OFFICE: DESIGN AND EVALUATION

Dr. Ing. Tobias Schrag
Prof. (FH) for Building Service Engineering,
Dep. of Facility Management,
University of Applied Science Kufstein
A-6330 Kufstein,
tobias.schrag@fh-kufstein.ac.at

Dipl. Ing. Christian Waldhoff, Dipl. Ing. Jörg Rädler,
Prof. Dr. Birgit Lenzen
dezentral GbR.
D-49076 Osnabrück
waldhoff@dezentral.de

ABSTRACT

The new government building with ca. 14.000 m^2 gross floor area in Innsbruck/Tirol was designed as a low energy office building.

As little technical installations as possible and as much room comfort as achievable: These were the two goals, set by the builder and user. An interdisciplinary team of architects, HVAC-planners and energy designers had already developed an integrated concept for the architectural competition. This was altered and adapted during the realization phase of the building.

Detailed building simulations were used to determine the interactions of building, climate and users. The integration of three glass atria into the concept, unheated and naturally ventilated, was one of the main challenges in this planning process. These atria serve as thermal buffers and use the passive gains of solar energy. Only the internal areas are ventilated mechanically.

The facades were optimized to combine daylighting and protection against high solar irradiation. Reduction of the cooling load, night ventilation of the atria and groundwater cooling in the offices secure moderate temperatures without any mechanical cooling. Despite a dense utilization the building offers attractive workplaces with a comfortable room climate. The energy consumption for heating in the first fully measured year was 35 kWh/m^2, which is very close to the prediction.

The consumption of primary energy is low also. The measured atria air temperatures comply in general with the simulated ones. A direct comparison of simulation and measurement is planned for the future.

INTRODUCTION

The builder wished a flexible building having an important role in the city planning for the center of the Austrian provincial capital Innsbruck. It should combine engaged architecture and energy-saving design with strict respect to limited costs. On this basis the architectural competition for the new administration building was announced in spring 2001. It was important, that the ecological criteria were not formulated as fashionable ad-ons without relevance. But their importance could be recognized in the evaluation scheme for the architectural biding.

In order to prevent the well known poetry of architectural competitions, the integration of an energy expert in the planning team was required and the submitted designs were checked by the state owned Tyrolian energy-agency.

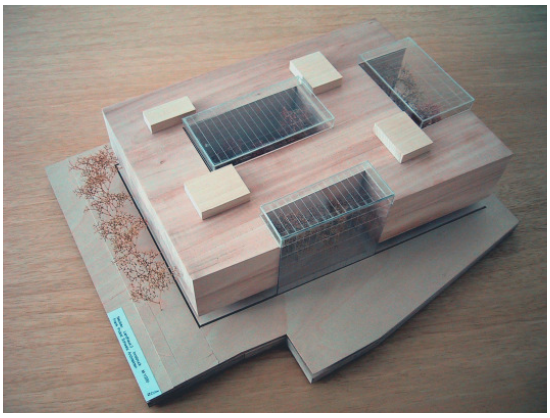

Figure 1 Architectural Model with 3 Glassatria, Photo:fpa

Builder: L2 Errichtungsgesellschaft Hypo Tirol Leasing, Innsbruck Österreich

User: Tyrolian Government

Architects: frank & probst architekten, München mit Walter Schwetz Architekt, Passau

HVAC: Dreyer & Jakob, München

Energy concept and building simulation: dezentral GbR

A maximum of heat energy consumption and the relinquishment of mechanical cooling were required. An ecological administration and office building with low operating costs should be built: A public building that can serve as a model.

The competition team consisted of the architects, the HVAC-engineers and the designers of the energy concept. It convinced the jury with their conclusive concept and was assigned with the realization of their design. Now, the building is ready and operating. The early team-oriented cooperation of all participants, involved in the process, paid off in every sense. At first the structural shell was optimized and a compact building with sufficient daylight was designed.

GLASS ATRIA AS DETERMING ELEMENT

Three unheated glass atria were integrated into the building and serve as areas for communication and zones of sojourn. They also grant a gaze into the green all the year. The accouterment of the atria with natural plants is a central idea of the architectural concept. Acute coordination between

Figure 2 Green Appearance of the eastern atrium
Photo: Tobias Schrag

plant planning and energy planning was necessary as the offices conjoining the atria are naturally ventilated also. The captured solar radiation reduces the heat losses and benefits the natural ventilation of the offices. The halls are equipped with a heat protection glazing (U-Value of the glass: 1.1 W/m²K, g-value: 0.62) as well towards the building as toward the outside. Therefore the temperature in winter is normally 10 K above the outside temperature.

Energetic Optimization of the Airflow

The advantages and disadvantages of the inclusion of the glass atria in the ventilation-concept were examined more exactly. As analysis tool, the dynamic building simulation environment SMILE with its multizone building model was used [1, 2]. In a first examination different possibilities of a principal integration of large unheated spaces into the ventilation concept with a heat recovery system were compared. The type of the airflow between surroundings, buildings and atrium was varied as well as the thermal quality of the glazing. The aim was to quantify the lowering of the heating energy and the resulting temperatures in an atrium.

For an energetic classification of different designs for atria, the relation of the transmission heat losses of the atrium to the surroundings to those of the building into the atrium is crucial [3,4]. The best energetic qualities are normally offered by atria, which are completely surrounded by the building, followed from atria that are framed at three sides of the building (U-Atria). Such an atrium was examined here in order to compare conceptual solutions. The heat-recovery of the ventilation was estimated with an efficiency of 65 percent. The ventilation was chosen so that the surrounding offices were ventilated with a twofold hourly airchange during the day.

Analysed airflow variations

The illustrations in Figure 3 show the concepts A-E with different airflows, that were simulated for a cold central European winter period.

The outside-façade of the glass-atria was varied between:

Simple-glazing
(1:U-value 5,8 W / m²K)

Heat-protection-glazing
(2:U-value 1,1 W / m²K)

Airflow:

A, B: Supply air over the atrium with heat recovery

C, D Supply air with heat recovery directly into the building

C, E Exhaust air into the atrium

D Atrium and building independent

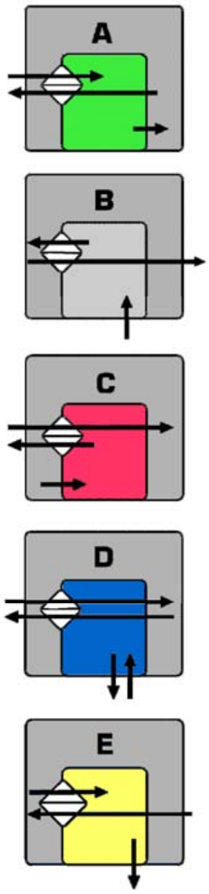

Figure 3: Variation of the Airflow into an Atrium

The different concepts were compared on the basis of the resulting temperatures in the atrium and the required heating energy for the surrounding building.

Temperatures in the atrium

In Figure 4 the air temperatures of the atrium during the coldest winter week with simple glazing are displayed. The temperatures are clearly always above the ambient temperature. In all variations however temperatures below the freezing point during the night could not be avoided. A clear increase in temperature can be achieved (concept A) by blowing the supply air into the atrium after the heat recovery. However, this is like an indirect heating of the atrium since the supply air cools down considerably in the atrium. Clearly the warmest temperatures are reached by an exhaust airflow over the atrium before the heat-recovery. This however also resembles an indirect heating of the atria since the exhaust air cools down here and can hardly be used anymore in the heat-recovery.

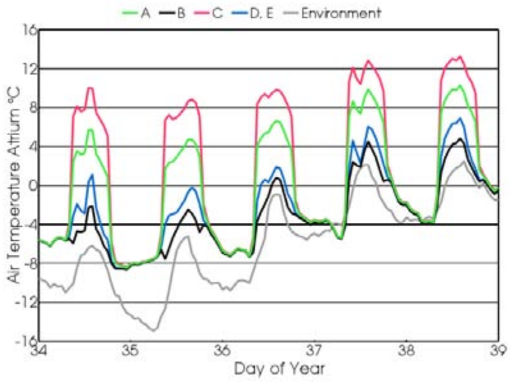

Figure 4 Atrium Temperatures with Single Glazing

In figure 5 the temperatures for an atrium with heat protection glazing are shown. The improved glass quality results in an increase of the atrium air temperatures for all concepts of about 5-7 K. Temperatures below 0°C are almost avoided, with an exception for the direct inflation of the outside-air into the atrium (B). The relation between the temperatures of the concepts is comparable to those of the single glazed variations.

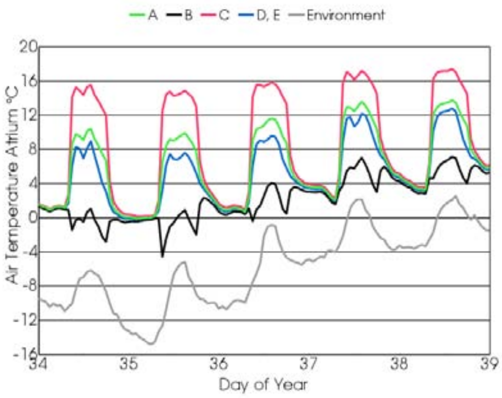

Figure 5 Atrium Temperatures with Heat Protection Glazing

Effects on the consumption of heating energy

In figure 6 the heating energy consumption for the offices confronting the atrium is shown. A decline of the relative demand by almost 30 percent through the better glazing can be seen. In variation B cold outside air is blown into the atrium. This lowers the temperatures in the atrium and can create airdraft also. This is unpleasant for users and might be damaging for the plants.

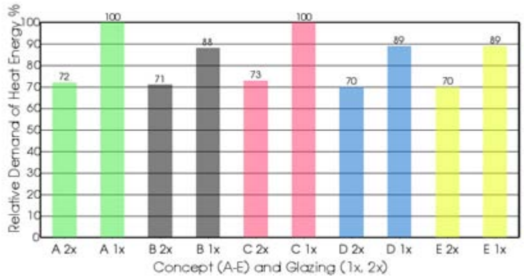

Figure 6 Heating Energy Consumption of the Adjoining Offices for Different Concepts (A-E) and Glazing (1,2)

Through glass atria that are integrated carefully into a building system, the energy consumption of a building can be lowered and the application of different ventilation concepts is enabled. However, a purely energetic approach still not results in an economic solution. Here the quality enhancement of the building must be taken into consideration through attractive medium climate zones as well. Besides the temperatures and the energy consumption, also the air quality is important for the judgment of the winter-situation

In the variations C and E CO_2-enriched and moist exhaust air is led into the atrium. This is especially problematic if the exhaust air is olfactory incriminated and the windows of the offices facing atrium can be opened. The problem of the dew water formation for the facade of the atrium particularly in the cases C and E is only mentioned. Further examinations about it are not explained here.

Minimization of the Installation

The theoretical studies shown above are based on a mechanical ventilation system in the offices around the atrium. But a high quality of the atrium glazing leads to a very mild climate in the atrium. Therefore mechanical ventilation can be omitted and a natural ventilation of the offices does not lead automatically to higher heating losses. A further simulation study was carried out in which the planned building was simulated with and without the atria. Figure 7 shows the results of this study, where the energy balances with and without the atria as well as with natural or automatic ventilation in the offices around the atria are compared. For the realized variation with integration of the three atria and free window ventilation in the offices connected to the atria a heating energy demand of 33 kWh/(m²a) was calculated. The users wanted window ventilation into the atria and also window ventilation at the exterior facades. Only the interior combizones are mechanically ventilated. In contrast to completely mechanically ventilated buildings, installation, maintenance and electricity costs were saved,

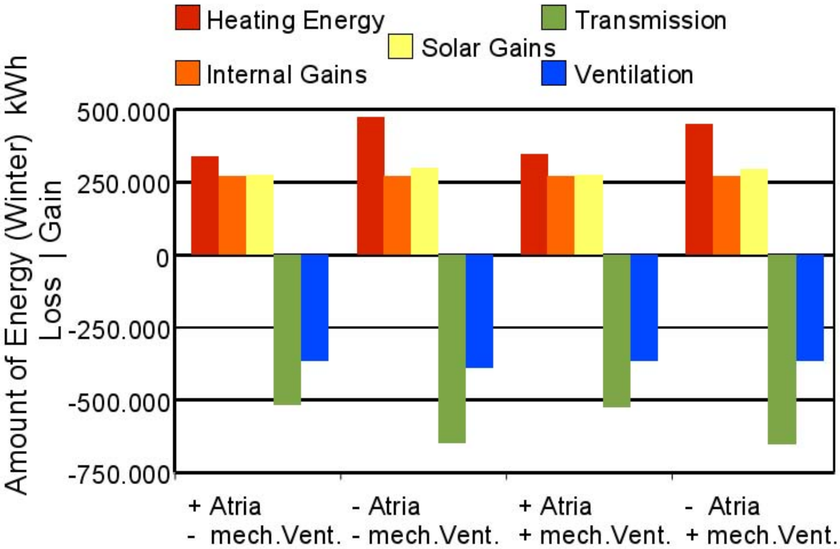

Figure 7 Energy Balance for the Winter Period of the Building with/without Atria and with/without Mechanical Ventilation

whereas the reduction of heating energy is achieved through the solar preheating of the air in the atria instead of a heatrecovery system.

FUNCTIONAL FACADES

Since the adjoining offices get fresh air directly from the glass-halls, particular care was taken, to avoid extremely high temperatures. This problem has to be avoided especially in the upper floors. Normally glass atria require an intensive sun-protection. After comparative examinations respecting the facade of the eastern atrium, the planning team decided in favor of a less costly but also efficient interior sun protection.

Simulations showed that more favorable temperature and ventilation circumstances can be obtained with a sun protection at the atrium wall compared to individual sun protection at the office facade inside the eastern atrium (see figure 11). Here and in the northern atrium additionally fixed grid elements in the roof fade out excessive direct solar radiation. For the central atrium, a special solution was realized: Movable, deflecting prisms direct the diffuse sunlight deep into the building and shield unwanted direct irradiation.

On grounds of the scarce building site only an insulation of 12 cm was feasible in the opaque parts of the façade. But the combination with roof and ground floor insulation of up to 30 cm reduced the transmission losses. Care was taken to avoid thermal bridges at the suspension for the paneling of the outside façade. The perforated facade represents an optimum for architecture, daylight-utilization and energy efficiency.

Figure 8 Glasprism in the middle atrium
Photo: T. Schrag

The glass area represents less than 50 percent of the facade. The sun protection at the exterior office facades is positioned at the outside and individually controllable. The venetian blinds are divided in two parts. So that the upper part can be permeable for sunlight while the rest of the window is dimmed. Therefore glare is prevented and enough daylight reduces the use of electrical illumination.

The exposed concrete ceiling with its high mass and heat capacity can absorb heat during the day and therefore lower the maximum temperatures.

All these measures reduce temperatures during the summer and contribute to a comfortable indoor-climate.

The facade between the offices and the atria has glare and view-protection and is designed for a maximum utilization of daylight. (wooden windows Total U-value: 1.44 W / m²K, g-Value: 0,6).

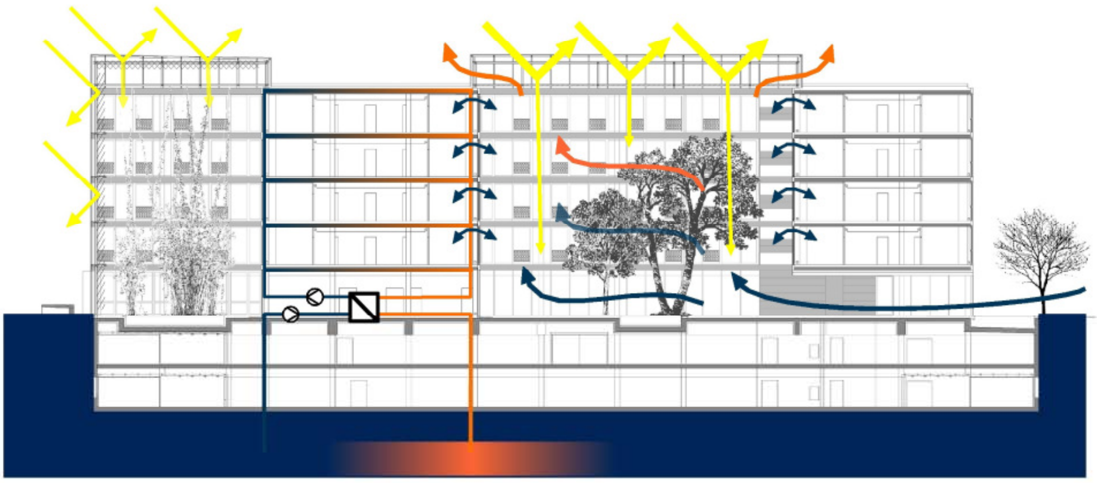

Figure 9 Schematic Drawing of the Energy Concept of the Government Building L2 in Innsbruck with Sunshades, Daylighting, Natural Ventilation and Ground Water Cooling

The office concept is based on single offices and a generous combizone. The transparent inner-walls transmit light into the interior building parts. The combination of maximum daylight, agreeable colours and much wood create a stimulating work-atmosphere. The green glass atria are visible far in the building and award also the stony neighborhood of the city center with color.

COOLING WITH AIR AND WATER

Natural night ventilation in the atria removes the heat stored in the building masses during the day without additional electricity consumption for fans. Controlled opening of the supply and exhaust air shutters and the chimney effect provide the necessary airflow by means of thermal buoyancy. Through opening of the windows during the night, a partly cooling of the offices can also be achieved.
However, the dense utilization of the offices with a high occupancy of computers and people make an additional active cooling of the offices necessary. This is achieved with capillary-tube-mats embedded in plaster on the ceilings. The otherwise usual combination of a cooled ceiling with an air conditioning for dehumidification offers higher cooling capacity than without air conditioning. The prevention of the dew point reduces the cooling-capacity. A radiant cooling system combined with a natural ventilation system has to avoid conditions close to the dew point and therefore can not guarantee a fixed maximum temperature inside the office e.g. 24°C especially in hot and humid weather periods. However, simulations showed that overheating of the offices can be avoided by the coordination of different measures like reduction of the cooling loads, night ventilation and the cooling capillary-tube-mats.
The surface cooling also creates a comfortable climate so that up to 2°C higher air temperatures can be tolerated in contrast to pure air conditioning systems. The interior combizones are chilled only over the ventilation system with cooled minimum-airchange.
For both cooling applications the groundwater is used as regenerative source. It is a seasonally independent cooling source, which was available, as the neighboring hotel, that already uses groundwater for cooling, permitted a further exploitation of this source. This kind of cold generation has not only substantial advantages regarding the costs, but leads also to a minimal primary energy impact as only little electricity is necessary for the two pumps supplying the cold water and pressing it back again into the ground.
Unfortunately the counterpart to this regenerative cooling technique, an already planned pellet heating system was not realized. High investment costs compared to conventional gasburners were one of the reasons for this failure. More competition of producers in the capacity area beyond the 250 kW could have helped opening inner city office buildings as a new market for pellet heating.
Bigger objects in rural areas frequently are heated with wood chip burners already today. A delivery of wood chips in inner urban situations however is not possible. Pellet heating systems could be used for the groundload ideally.

FIRST RESULTS OF THE OPERATION

There are no proper recordings of weather data and no data of the building controlling unit at the moment, so that a detailed comparison of simulated data and measurements cannot be done. Also no data of the indoor climate in the offices are available.

<u>Summer</u>

In principle the combination of natural ventilation via atria combined with radiant cooling achieved by the capillary tube system in the ceilings functions well. The indoor climate in the atria and offices has been very comfortable during the first years of use. This is confirmed by the users. Some problems with air draught in the northern atrium had to be eliminated by a different controlling.

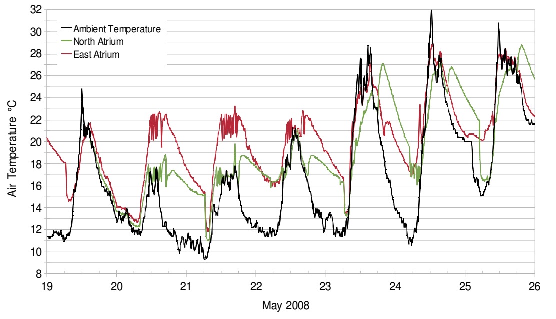

Figure 10: Air Temperature in northern and eastern Atrium at 3rd Floor Level

As in many similar projects the automatic sun shading system is not enjoyed by all users but avoiding overheating in summer means a restricted regulation in certain points.

There are no measurements of the indoor climate of the offices available at the moment but the atria temperatures were measured in a warm summer week shown in figure 10.

During the cold nights at the beginning of week the atria are kept warm due to reduced ventilation. At higher ambient temperatures of 28-32°C the atria are protected against overheating by passive cooling and maximum ventilation.

Comparison with the simulation

In the early design process a simple model of the whole building was used to evaluate the main characteristics of the building, especially concerning heating and ventilation. This was also used to optimize the building structure itself and to place the atria within the building. For analyzing the atria and the indoor climate each of the three glazed spaces was simulated with a simple and a complex model, the latter with the air volume of the atrium divided in six different layers (naturally ventilated).

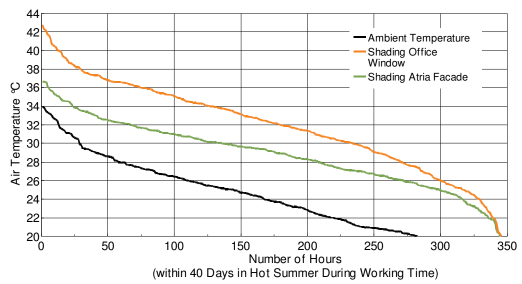

Figure 11: Simulated Duration Curve of Atria Temperatures in a Hot Summer Period with Different Shading Systems

With this complex model different types of sunshading devices and openings for ventilation were compared. As an example figure 11 shows the duration curve of the air temperatures during a hot summer period in the eastern atrium (level 4th floor). It shows that shading the atrium at the outside facade results in lower air temperatures than shading the office window itself. For this configuration the atrium temperatures is expected to be about max. 4-5 K higher than ambient temperature at 4th floor level. At high ambient temperatures the offset is only about +2,5 K, which means that the passive cooling at night and the ventilation of the atrium is doing well.

A comparison of the simulation with the measured temperatures in figure 10 is not possible as the simulation was done for a very sunny period and for the measured temperatures no irradiation data or temperatures of the surrounding offices are available yet. Most notably the simulation results led to an enlargement of the ventilation shutters, that now ensures, that at high ambient temperatures the atrium temperatures stay moderate.

The enlarged area of ventilation shutters might also be the reason, that the predicted higher temperatures in offices facing the atria compared to offices facing the outside, that are shown in figure 12 can not be confirmed, although detailed measurements have to be carried out yet.

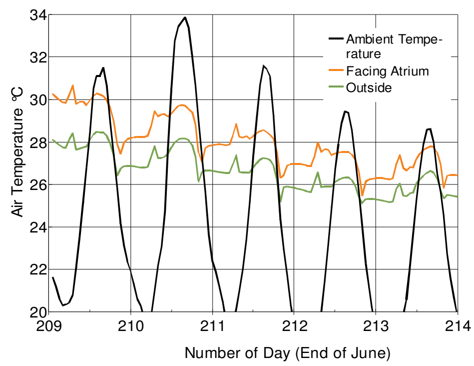

Figure 12:Temperature of an Office facing the Atrium and an Office facing the Exterior during a Hot Summer Week

Figure 12 shows, that the offices at 4th floor level, which are facing the eastern atrium are expected to be up to 2 K warmer than offices to the outside in an extremely hot period. The cooling system is at its limit so that the higher fresh air temperature of the atrium causes lower indoor comfort in the office. During average summer periods this effect is less important.

Winter

Although the operation of the building started in the winter 2004/2005 the first year with continuous documented heat energy demand is 2007.

The measured heat consumption is slightly below the simulated one of 33 kWh/(m²a), but taking the weather into account and adjusting the measurement with heating degree days the measured consumption is with 35 kWh/(m²a) slightly above the predicted value.

As only one year is measured yet, this close accordance might be incidentally, but according to the operator the heat demand was low also in the undocumented winters before.

The measured atria air temperatures in winter comply in general with the simulated ones. Only the minimal temperatures in one of the atria are below the prediction and endanger the growth of the plants. But this is due to a change in utilization, as a café was integrated into this atrium despite previous denial of this possibility. The odors of the gastronomic establishment led to a higher ventilation rate as calculated and therefore to lower minimal temperatures.

The measured consumption of electric energy with 44 kWh/(m²a) for the year 2007 is higher than expected. But this figure includes the continuous electricity consumption for the governmental data processing center located in the basement. Based on data from the building operator a rough estimation of more than 50% of the total electricity consumption is due to the data center. The remaining 20 kWh/(m²a) is a rather low figure for the electricity consumption of such a modern high quality administration building, which is also due to an comitted building operator.

CONCLUSION AND OUTLOOK

The integral design for the new governmental office building achieved a low energy standard.

Natural ventilation and daylighting are ensured by three glass atria. Compact structure and high insulation reduce the heating demand to 35kWh/m².

Cooling is realized via ground water cooling and night ventilation of the atria. The energy concept, stemming from an architectural competition had to be adopted several times during the planning process. But the strong commitment of the architects and the builder towards an ecological design and the integration of an energy expert into the planning team ensured the accomplishment of three goals:

1. Construction of a functional and aesthetical building that fulfills all requirements
2. High Comfort and low energy consumption at the same time.
3. Abidance of the strict cost limits.

Especially the abidance of the cost limits accounts for the model function of this building. This proves that ecological buildings do not have to be expensive. The HVAC expenses were reduced considerably by reducing the mechanical ventilation system, but other improvements with low life cycle costs like the wood pellet heating could not be realized because of the limited investment costs.

First comparisons of the planning with the measurement data taken from the memory unit of the HVAC control could be carried out and signal satisfactory accordance. But a proper measurement with several temperatures taken from different places in the building, exact weather data and recorded memory of the ventilation shutters have to be carried out before simulation results and operation can be compared directly.

Even more important and already in preparation is a detailed measurement of the electricity consumption to decide the proportion of the electricity needed for the data center, to calculate the coefficient of performance of the ground water cooling in combination with the capillary tubes and first and foremost to determine further energy reduction potentials.

LITERATURE

[1] C. Nytsch-Geusen:2001 *'Berechnung und Verbesserung der Energieeffizienz von Gebäuden und ihren energietechnischen Anlagen in einer objektorientierten Simulationsumgebung',* Fortschritt-Berichte VDI Reihe 6 Nr.472, VDI Verlag, Düsseldorf

[2] C. Nytsch-Geusen, G. Bartsch, 2001 *An Object Oriented Multizone Thermal Building Model based on the Simulation Enviroment SMILE*,. in: Proceedings of Building Simulation 2001, International Building Performance Simulation Association, Rio de Janeiro

[3] M. Wall: 1996.*'Climate and Energy Use in Glazed Spaces',* Dissertation Lund University

[4] IEA Report of Task 12: 1999 *' Atrium Modells for the Analysis of Thermal Comfort and Energy Use',* SINTEF, Trondheim