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ENERGY EFFICIENT COMMERCIAL BUILDINGS IN GERMANY

Energy Efficient Commercial Buildings in Germany

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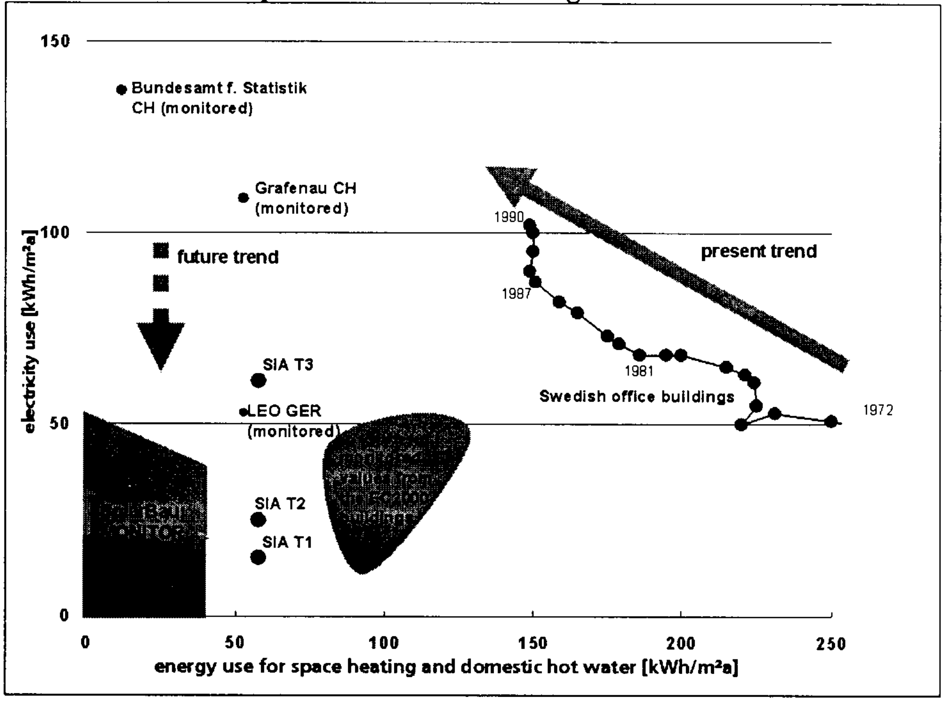
ABSTRACT

The paper presents the description and initial evaluation of a number of commercial large scale buildings (>1000m^2) situated across Germany. The study has been carried out within the framework of the evaluation program, SolarBau, which has been initiated and funded by the German Ministry of Economy and Technology. The program funds up to 25 demonstration buildings and their collective evaluation. Funding is only provided at the design stage of the buildings for additional investigations and simulations of variants, which feature elements of passive cooling, and after construction for a thorough monitoring of the finished buildings. The absence of investment subsidies ensured that all design solutions were realized under representative economic conditions. The technical requirements for admittance of a building to the program were an anticipated total primary energy use (heating, cooling and lighting) below 100 kWh/(m^{2}a) [31,700 Btu/(ft^{2}a)] combined with excellent visual and thermal comfort conditions. These ambitious goals can only be reached by a *lean building* featuring increased thermal insulation, intensive use of daylight and a strategy for passive cooling. The reduced HVAC-system relies heavily on a building whose design carefully considers the given climatic boundary conditions. In the moderate German climate, the focus usually lies on the avoidance of unwanted solar gains in the summer. The remaining internal loads can often be counterbalanced by controlled ventilation, additional nocturnal ventilation or by earth-to-air heat exchangers.

Background

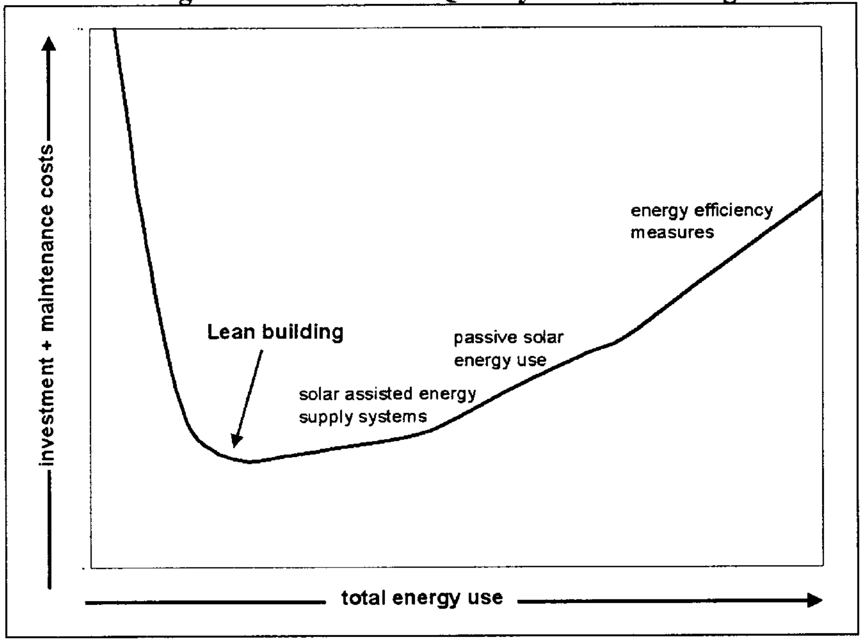
Buildings fulfill multiple proposes. They provide shelter and aim to create adequate working and living conditions for their inhabitants. Apart from these functional aspects, buildings serve as a mean of cultural identification and social representation. To satisfy all these diverse expectations, financial, material and energy resources are required to construct and maintain a building. The contribution of building-related energy use to the total energy demand is roughly a third across most Western societies despite the diversity of individual life styles. In Europe, the accompanying costs correspond to approximately 3.9% of the GDP of the EU (ESAP, 1998). Fig. 1 shows some recent trends in the European office-like building sector. Shown is the development since 1972 of the mean annual thermal and electrical energy demand per net floor area of new non-residential buildings in the Swedish building sector (Nilson 1997). Qualitatively, the data can be transferred to the German building stock. The data reveals that Swedish office buildings have experienced a continuous decrease in heating demand following the development of stricter building codes. This increased efficiency of the thermal envelope has been accompanied by higher electrical energy demands. Two prominent examples for this development are the two monitored Swiss buildings (Schweizer Energiefachbuch 1997) in the upper left corner of Fig. 1 which combine uncommonly high electrical energy demands with a thermal energy demand below 50 kWh/(m^{2}a) [15,850 Btu/(ft^{2}a)]. Several circumstances support the present trend:

Figure 1. Trends in the European office-like Building Stock



1. The majority of modern office buildings aim to create a time and site independent indoor climate which approaches a narrow, *trans*-global range for what are considered to be adequate working conditions (Baker 1999). As the tolerance range of the users diminishes, the need for powerful HVAC equipment rises together with the energy demand. The effect is pronounced if many work places are grouped together in large offices.
2. Commercial buildings communicate the corporate identity of the building inhabitants to the outside and place the buildings in context with their neighboring surroundings. This important function of buildings has lead to building examples which ignore their climatic boundary conditions for the sake of a desired visual impression.
3. As modern office buildings exhibit rising internal load profiles due to the explosive increase in the use of electrically powered office equipment like PCs, printers and other technical equipment, the cooling loads start to dominate the overall energy use even in moderate climates. The peak of this development seems to have been reached as more energy efficient appliances are finding their way into offices, e.g. LCD computer displays and fluorescent lamps. In Switzerland, the main motivation for purchasing these new appliances has been found to be often unrelated to the better energy performance of the devices. It is a mere positive side effect that new articles tend to have a lower energy demand (Weber *et al.* 1999). The tendency of electrically driven, cooling-dominated HVAC systems further boosts the overall CO_2 balance of a building.
4. Furthermore, energy saving measures and building energy codes tend to concentrate on the thermal envelope since the thermal energy demand dominated the total energy demand of a building in the past. An exception to this is the Swiss SIA building code which formulates energy bench numbers for thermal as well as HVAC and lighting electrical energy use. The SIA is the Swiss Society of Engineers and Architects. Fig. 1 shows the ambitious SIA energy benchmarks for office buildings with mainly single offices, a low technical standard and no air-conditioning

Figure 2. The Energy Concept of a *Lean* Building follows a Least Cost Planing (LPC) Approach without affecting the Architectural Quality of the Building



(T1), mainly group offices, an extended technical equipment and possibly air-conditioning (T2) and the same as under T2 with central computing facilities (T3) (SIA 1995).

The two former issues are related to the architect's understanding of the significance of the energy concept within the overall building design. Improvements could be realized by innovative educational colloquia. On the other hand, the two latter reasons mainly address the users and society as a whole and their consciousness towards electrical energy use.

Lean Buildings – a Step towards Sustainable Building Practices

To overcome both health problems related to unsuitable work conditions (Redlich et al. 1997) as well as the growing electrical energy use in the commercial building sector, a new class of buildings has been realized in the past decade. The *low energy office* (LEO, *see Fig.1*) in Cologne, Germany, is an example constructed in 1995 (Lohr 1998). The office buildings from the Energy Comfort 2000 (EC 2000) project also show the way to reduced specific electrical energy use. EC 2000 was a demonstration project on energy efficient non-domestic buildings funded by the European Commission (Esbensen 1998). These *lean buildings* harmonize with their given climatic boundary conditions and exploit naturally available energy sinks and sources in order to provide increased visual and thermal comfort for their inhabitants while reducing the energy demand. Lean buildings rely on both traditional energy conscious architectural practices and very recent developments which supply architects and HVAC engineers with an ever-increasing catalogue of components and concepts: solar cells and collectors, smart windows and better insulation materials, heat pumps, daylighting, integrated lighting and shading control systems, free nocturnal air cooling, pre-heaters like air heat recovery and earth-to-air heat exchangers for preheating in winter and cooling in summer, phase change materials... . Some concepts convince through their simplicity, others impress by their technical sophistication. New powerful simulation methods allow modeling of the interplay between these components in the design phase of a building. It is worthwhile to mention that in the age of powerful, *quasi* climate-independent HVAC systems and falling energy prices, the construction of a lean building marks the conscious decision to find individual solutions where conventional practices lack a sustainable dimension.

To realize the ambitious goals of constructing a lean building under economic conditions, the design process of a lean building requires a more thorough plan compared to a conventional building. Ideally, the building owner initially formulates a matrix of requirements and issues for the future building. Certain weights should be assigned to the matrix elements which reflect personal preferences, the available economical resources, the anticipated working conditions for the users and the sustainability of the resulting building. The composition of the design team should reflect the earlier chosen preferences so that an *integrated design process* can be initiated in which the interrelations between the usually independently and sequentially treated design aspects can be addressed and exploited. In the latter case, the extra costs created in the planning phase can be counterbalanced by reduced initial investment or lower operating costs (see Fig. 3). It is crucial to note, that a lean building concept might not guarantee the required temperature and humidity levels specified in building codes comparable to the German VDI 1946, e.g. $T_{operative} < 26^{\circ}C$ for a mechanically ventilated office (VDI 1946). The operative temperatures might well lie above this threshold for a number of hours per year. To avoid future legal actions between the design team and the building owner, it is advisable to formulate a written agreement, e.g. of the number of hours per year at which indoor temperatures above 26°C are tolerated.

Lean buildings follow an holistic approach - they feature energy efficiency measures, an advanced control of the incoming solar gains as well as solar assisted energy supply systems (Hestnes 2000). Alternative measures are assigned different priorities according to their energy avoiding or saving potential and costs. Fig. 2 hints that while the overall design of a building should certainly not be purely cost oriented, alternatives among energy saving measures should follow a *least cost planning* (LCP) approach: Energy efficiency measures like low energy electrical appliances and improved envelope insulation tend to have the lowest pay back costs followed by passive solar systems like smart windows and an increased use of daylight. Solar energy supply systems like collectors and photovoltaics are gaining importance as their prices keep falling and their contribution to the total energy demand of the building rises.

SolarBau

The German Ministry of Economy and Technology has launched an evaluation program to foster the construction of lean buildings and test the above described concepts in a *real-world* environment. As a lean building by definition features a cost effective and sustainable energy concept, funding has only been provided for extra planning efforts, e.g. to carry out simulations of variants which investigate the suitability of passive cooling approaches for the building. This funding of the integrated design process has been provided, because the use of simulation tools to predict the interaction of the various energy flows in a building is presently not a standard. The necessary costs are subject to fall once the available knowledge has spread and the necessary simulation tools are available.

The formal requirements for admittance of a building to the program are an anticipated total primary energy use (heating, cooling and lighting) below 100 $kWh/(m^2a)$ [31,700 $Btu/(ft^2a)$] and excellent visual and thermal comfort conditions for the inhabitants. Fig.1 shows how ambitious this objective is compared to conventional building practices[1]. The actual energy demands of the

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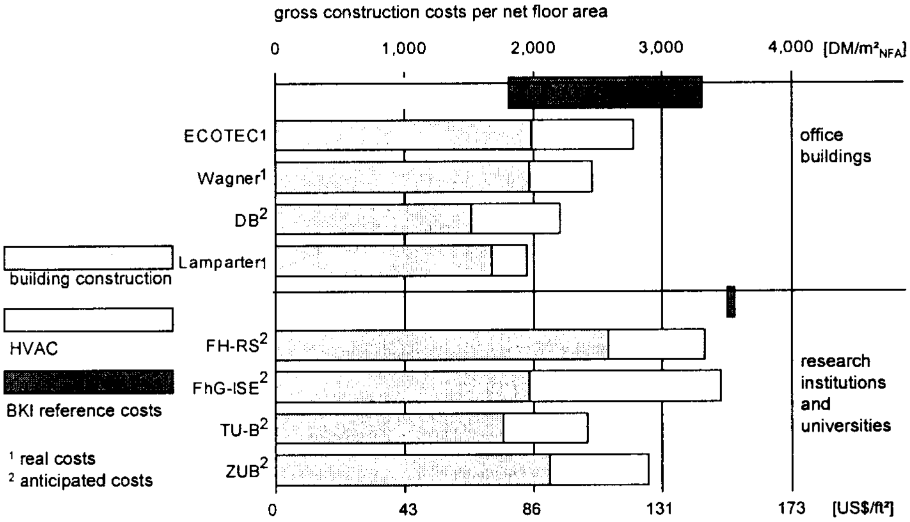
[1] The business related electrical energy use of the buildings is estimated to be 20 $kWh/(m^2a)$.

Figure 3. Investment Costs for the Building Construction and the HVAC System; Planning and Site Costs are not included. The Areas are evaluated according to the German Standard DIN 276 (DIN 1997). The Acronyms refer to the individual Projects (refer to www.solarbau.de).



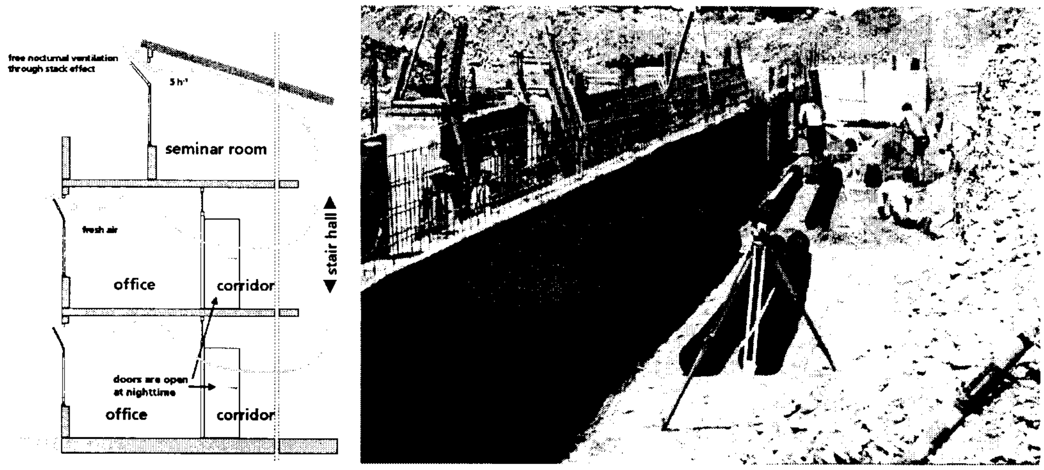
projects are not yet available, as the buildings have only been constructed very recently or are still under construction. Presently, 12 non-residential buildings are participating in the project and funding will be provided for up to 25 buildings.

Further funding is provided after construction for a thorough monitoring of the actual energy demand in the finished buildings. The absence of investment subsidies ensured that all design solutions were realized under representative economic conditions although usually at least one of the involved parties - architects, planers and building owner - tended to be committed towards a sustainable development. Figure 3 shows that the investment costs of the buildings lie within the range of the German references costs for office buildings of medium to high standard (BKI 1999). The BKI reference costs are annually published by the German "center for construction costs" and are based on mean German construction costs for a given building type. Care should be taken when transferring the costs listed in Table 1 into other countries as the costs for energy efficient measures are highly interwoven with regular construction costs. So far, the available results from the SolarBau projects hint, that the building standard, the size and type of a building and the economic situation in the construction industry tend to have a greater influence on the final costs than peculiarities of the energy concept.

Exemplary Buildings

The following section presents the energy concept of three buildings, two of which are participating in the SolarBau program. The buildings have been chosen according to both how rigorously their energy concepts follow an integrated design approach and on the degree of involvement of the Solar Building Design Group at the Fraunhofer ISE into the design process. As space is limited, not all energy concepts of the SolarBau buildings can be presented here. The interested reader is encouraged to visit the official SolarBau website (http://www.solarbau.de) which lists all participating buildings and provides details and pictures of the single buildings. The website is written in German.

Figure 4. (a) Free nocturnal Ventilation Concept (Lamparter) (b) *Air-to-Earth* Heat Exchanger from the Fraunhofer ISE; plastic Tubes with a total Length of 700 m and a Diameter of 25 cm are installed 6 m below Ground.

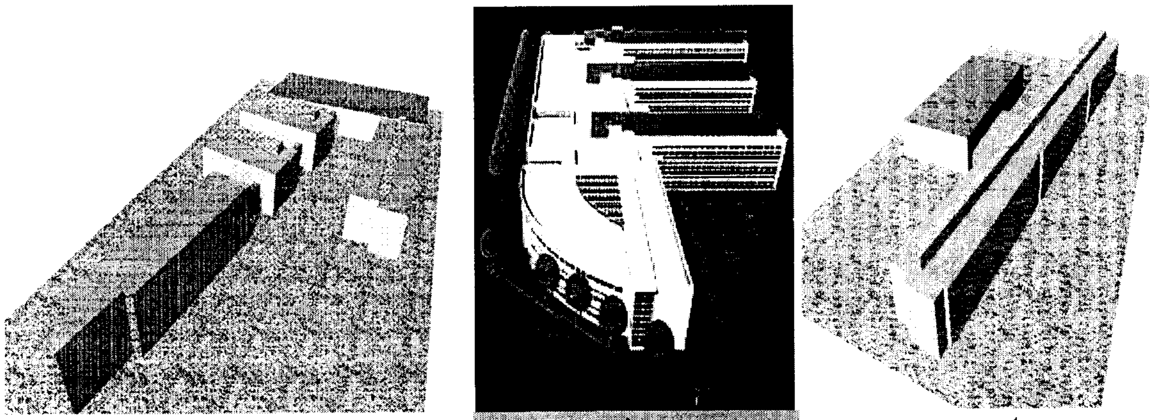


(a) (b)

The *leanness* of an energy concept can be expressed in terms of several aspects:

- Overall heat losses: The thermal insulation standard of a building is an important factor. A compact building design further reduces energy losses through the building's outer surface but is usually accompanied by higher room depths which reduce the available daylight and increase internal loads due to artificial lighting. So far, 5 SolarBau projects feature atria or large sky lights which admit daylight deep into the building. The atria usually serve as circulation areas. Apart from the type and quantity of the insulation materials, a high construction quality is essential to avoid heat bridges and create a thermal envelop with a low overall U-value. In the projects the mean U-value ranges from 0.22 to 0.55 $W/(m^2K)$.
- Energy conscious lighting: The ultimately available quantity and quality of daylight in a building is decisively influenced at several design stages: crucial is the early design phase in which the distribution of the building masses on the site, the orientation of the building, the room depths and ceiling heights as well as the horizontal transparency of the building are defined. Later in the design process, the suitability of a facade for daylighting is determined by the position and size of apertures, the width of the window frames and the utilized types of glazing. Further important parameters are the photometrical properties of the surfaces of the ceilings and walls, the utilized shading devices and finally the artificial lighting system. The latter should have the character of a backup system for the available daylight.
- A passive cooling concept is necessary to avoid electrical cooling in most parts of a building and meet the low electrical energy benchmarks required for a lean building. This implies that internal loads, solar gains and fresh air from the outside are controlled at all times to avoid indoor temperatures above 26°C and maintain a high thermal comfort for the inhabitants. Similar to the daylighting concept, a suitable "solar gain management" is supported by suitable facade orientations. The shading devices need to be versatile and able to reduce the incoming solar gains to the minimum indoor illuminance requirement. Atria often enhance the attractiveness of a building's interior but care should be taken to avoid excessive solar gains in the summer. Internal loads can be reduced by purchasing energy-efficient devices and avoiding wasteful standby periods. Controlled ventilation is an efficient way to limit the air exchange to the hygienically reasonable (approximately 30 $m^3/per{\cdot}h$). A popular concept in the SolarBau

Figure 5. **RADIANCE Visualization and Evaluation Results of the Energy Concepts for three Building Variants of the Fraunhofer ISE (architects: Dissing & Weitling, Kopenhagen)**



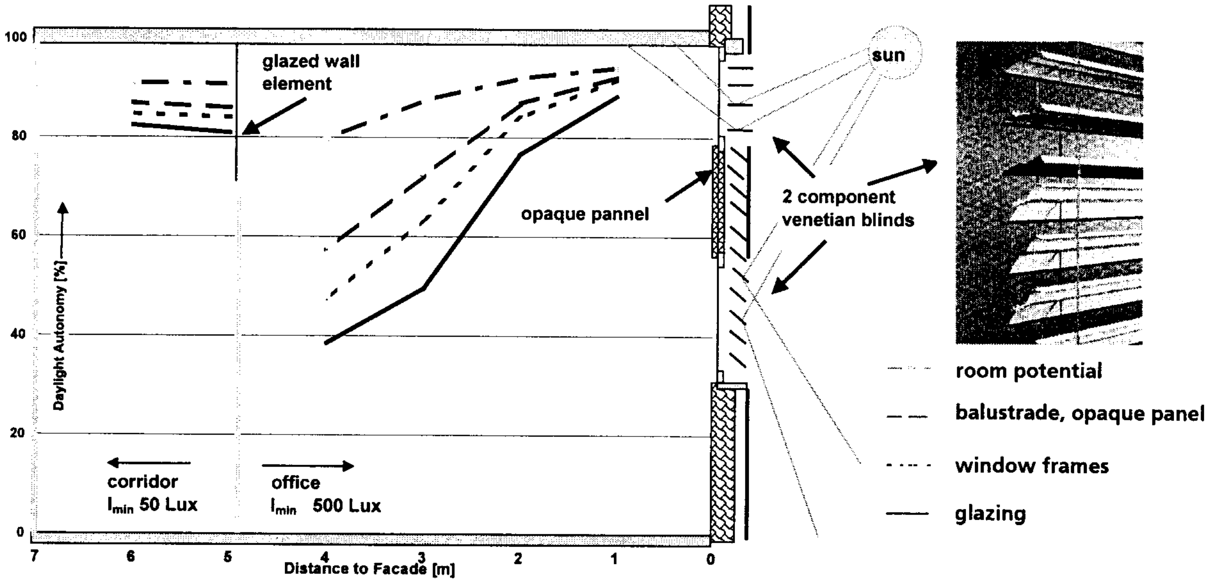
	campus	**wings**	**compact**
daylighting potential	o	+	-
heat losses	-	o	+
passive cooling potential	o	+	-

projects is an automated ventilation system combined with a high efficiency heat exchanger ($\eta>75\%$) to transfer heat or cold from the outgoing to the incoming air and /or an earth-to-air heat exchanger to exploit the earth as an energy sink or source (Fig. 4). The hygienic aspects of ground-coupled air systems have been investigated in 12 exemplary system in Switzerland by Flückiger *et al.*. They found that the concentrations of fungal spores and bacteria tended to be lower at the end of the underground pipes than in the outdoor air. Another popular architectural practice is to expose the concrete ceilings and walls to the indoor air in order to use the high thermal capacity of the building masses to dampen the amplitude of daily temperature variations. Conflicts with the acoustic situation require carefully balanced solutions.

Research Institute *Fraunhofer ISE*

The Research Institute Fraunhofer ISE is the future work place for the 300 employees of the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany, with a net floor area of 14,000 m^2. The main objectives for the building are to realize a high-quality working environment with an energy conscious design and high architectural quality. In this uncommon situation for an integrated design process the building owner could rely on in-house energy consulting services. The site for the building is challenging as it exhibits a North-South elongation as opposed to the generally favorable East-West elongation. Fig. 5 shows three variants for the overall building layout which have been proposed at an early design stage. The spectator is facing North. The *compact* variant is energetically favorable but features rooms with high room depths and predominant East or West facade orientations which are susceptible to the appearance of glare and unwanted solar gains throughout the year. The *campus* solution -although architecturally pleasing- exhibits similar climate and glare problems and substantial thermal losses due to a large building surface to volume ratio. Accordingly, the *wings* variant has been chosen.

Figure 6. Daylight Autonomy in a typical Wing Office of the Fraunhofer ISE; the 2 Component Blind System (see Inlet) allows for a versatile Management of the incoming Daylight as it allows glare free Work Spaces while the Daylight is redirected to the Ceiling via the above-head Window Aperture.



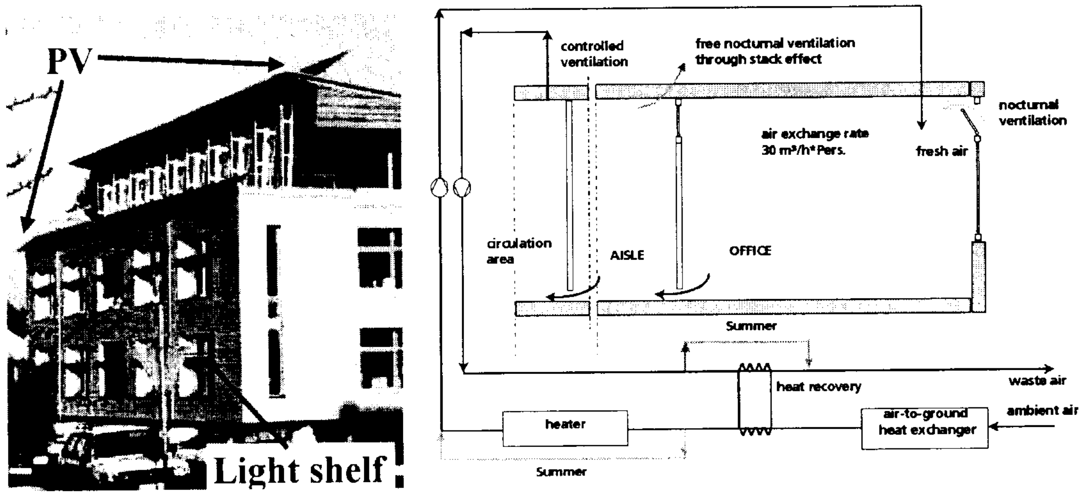
All offices are oriented towards the South while all laboratories (together 4300 m^2) are facing North to avoid unwanted solar gains. The offices feature an uncommonly high room height (3.3 m) since the laboratories and offices border the same aisle to exploit infrastructural benefits. Several facade variants have been investigated in detail based on thermal simulations with esp-r (Clarke 1997) and dynamical daylight simulations with a RADIANCE based daylight coefficient method (Ward 1994, Reinhart, Herkel 2000). Fig. 6 shows a simulation of the daylight autonomy of the chosen facade for a typical *wing*-office. The daylight autonomy is the percentage of the annual working time (8 a.m.–6 p.m.) at which a minimum illuminance level (500 lx in the offices and 50 lx on the corridors) can be maintained by daylight alone, i.e. it is a measure of the annual daylight availability at a work place. The maximum daylight availability at a point outside the building corresponds to 95% for the investigated building site and chosen working hours. Fig. 6 visualizes the influence of the building design on the indoor daylight availability in 4 steps: The room potential (highest, dotted-dashed line) shows the daylight autonomy in the room due to walls and the ceiling and the floor without a facade. The dashed line quantifies the impact of the balustrade and the opaque panel. Note the *nick* in the daylight autonomy introduced by the opaque panel at 2 m distance from the facade. The window frames further reduce the available daylight (dotted line). The solid line describes the actual daylight autonomy for the office including the window glazings. The opaque panel takes away some daylight at the rear of the room, but given that the users will primarily work at a 1-2 m distance from the facade, the opaque panel does not severely impact the annual daylight availability. On the other hand, the thermal simulations with TRNSYS (Beckmann 1999) have shown that the opaque panel considerably improves the thermal comfort conditions in the summer as the offices will not be air-conditioned. Passive cooling is provided through an electrically driven fan which creates a low pressure level in the corridors at nighttime and intakes cool air from the outside through slats in the facades to cool down the offices and the exposed concrete ceiling. In the seminar rooms an earth-to-air heat exchanger (Fig.4(b)) cools down the incoming air to counterbalance increased internal loads from attending listeners.

Office Building *Lamparter*

The office building Lamparter hosts the land surveying company *Lamparter GbR* and has a net heated floor area of 1000 m^2. The West-East elongation of the building site allows for a compact design with all offices facing either North or South (Fig.7). A distinct feature of the building is the high quality thermal envelope (mean U-value 0.3 W/(m^{2}K)) which is realized through a 24 - 35cm thermal insulation layer and triple window glazings with wooden frames. In the summer, the incoming air is pre-cooled through an earth-to-air heat exchanger 2.8 m below ground before entering the offices. In the winter, the incoming air is heated by a heat recovery (η=80%) from the outgoing air (Fig. 4(a)). The anticipated thermal energy demand is an excellent 12 kWh/(m^{2}a) [3,804 Btu/(ft^{2}a)] (annual mean outdoor temperature 8 C^o). This little remaining thermal energy is provided through a gas burning system that directly heats the incoming air. The total power of the heater is 20 W/m^2 and the incoming air is directly heated. No circulation air is needed. The individual offices feature no radiators.

The circulation area between the Northern and the Southern office rows is daylit by a large skylight above the inner stairs and all walls bordering this circulation area are glazed above head. This horizontal and vertical transparency allows daylight to penetrate deeply into the building and is a necessary condition for the free nocturnal ventilation concept which is driven by the "stack effect": air is forced through slats in the office facades into the circulation area and leaves the building through automatically opened slats in the roof.- No electrical fan supports the air movement. The drawback of the free nocturnal ventilation concept is that after the final design extra, cost-intensive fire prevention measures had to be installed to compensate for the dangers of

Figure 7. (a) Low Energy Office Building *Lamparter* (looking West); note the Light Shelves in Front of the Southern offices (40cm wide) which serve as a low cost Glare Protection and Daylight Element. The Climatisation concept of the Building is a Combination of an Earth-to Air Heat Exchanger, a Heat Recovery System and free nocturnal Ventilation for Cooling in the Summer



(a) (b)

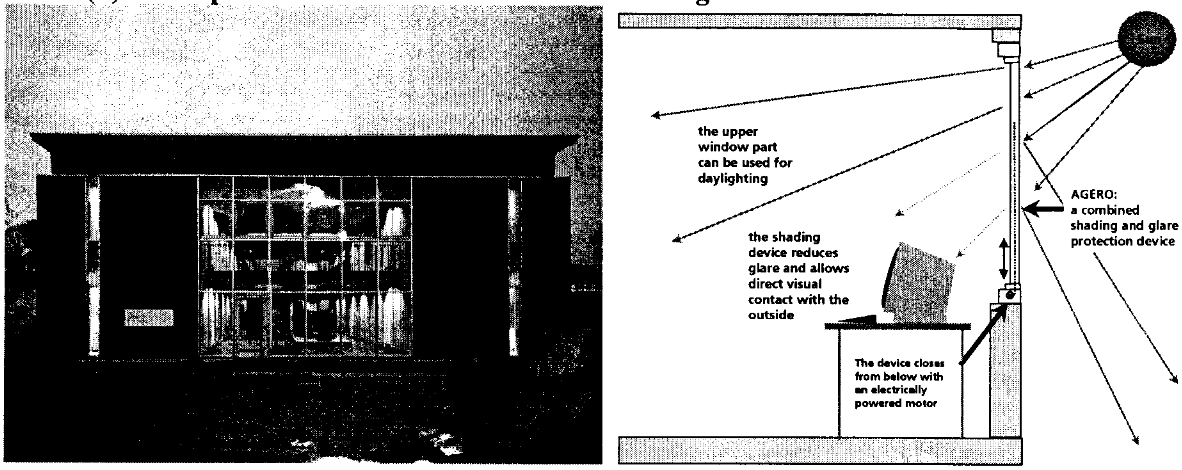
this open building design.

A mere 70 m^2 PV installed on the edge of the Southern balcony and the roof (Fig. 7) complete the lean energy concept by providing 30 % of the electrical energy demand for the HVAC and lighting system. With construction and HVAC system costs below 2000 DM/m^2, [90 US\$/ft^2] the building proves that a lean building can be constructed under economic conditions.

Office building *Athmer*

The office building Athmer is a two-story administration building with a floor area of 900 m^2 situated in Arnsberg, Germany. The building is U-shaped and features a large central atrium with a partly glazed roof and South-Eastern facade (Fig.8(a)). Laboratories are situated in the North-Western part while two-person offices border the atrium at the remaining two sides. A central objective for the building owner was to create mostly daylit, glare-free PC work places for the users and to avoid an electrically powered air conditioning system. Based on daylight and thermal simulations the facade has been designed so that sufficient daylight can enter the building without allowing excessive unwanted solar gains. A special feature is an innovative combined shading and glare protection device (Fig.8(b)) which is installed between the double glazing of the office windows (AGERO 1992). The system consists of a transparent polymer plastic film with a metallic coating. The total solar energy transmittance (g-value) of the foils is about 10% and the shading device is closed from the lower part of the window. The advantage of the system is that visual and thermal comfort for a PC work place near the facade can be maintained without impairing the visual contact with the outside. The upper part of the window is available for daylighting of deeper room depths.

Figure 8. (a) View of the Office Building *Athmer* (looking South-West); an Architectural Key Element of the Building is an Atrium which creates a bright and friendly Entrance Area. (b) Principle of the innovative AGERO Shading Device.



(a) © K. Ortmeyer

(b)

The cooling system consists of a controlled ventilation system: similar to the Fraunhofer ISE: A lower pressure is created by fans in the atrium and the incoming air is sucked in through slats in the office facades and leaves the building through the atrium roof. In the cooling period at nighttime additional fans are turned on in the roof to further foster nocturnal ventilation through the offices.

Conclusion

The experiences gained form the SolarBau projects thus far show that lean buildings with an anticipated total primary energy demands below 100 kWh/(m^2a) [31,700 Btu/(ft^2a)] can be constructed without significant additional costs. The extra design efforts which are presently funded in the SolarBau projects will fall once an integrated design process has become more common. But this will also require that present design practices need to be adjusted to allow an early dialogue on the overall building layout between architect and HVAC engineers. This change will be sociologically demanding as the design parties need to partly redefine their original job prescriptions. Other remaining barriers for a wider market penetration of the above presented concepts are related to a widespread neglect of the significance of the electrical energy demand of a building by architects, engineers and building owners. Falling electricity prices in the European market further foster these tendencies. On the other hand, the development of the past decades in the European building stock has shown, that legal building codes have succeeded in initiating a positive trend towards thermal energy efficiency. The same policy measure could be employed if electrical energy consumption benchmarks would join thermal consumption regulations in extended building codes. This way the design process could be enriched without impairing the creative freedom of the architect. The final goal and not the means would be regulated.

It would also be helpful if simple monitoring practices were developed that would allow the building owner to check whether real energy demands reflect predictions made during the design phase.

References

AGERO, 1992, *"AGREO, first rol, the multifunctional energy-breathing insulation glazing"* (in German), press release, AGERO Corp., Schlattingen TG, Switzerland

N. Baker, 1999, *"Environmental Comfort- Optimization or Opportunity."*, Conf. Proceed. of Low Energy Building Conference '99, September 17th to 18th in Hamburg, Germany

Beckmann W.A. *"TRNSYS – A Transient System Simulation Program"*, Solar Energy Laboratory, University of Wisconsin-Madison, USA

BKI, 1999, *"Baukostenindex Teil 1"*, Baukosteninformationszentrum Stuttgart

J. Clarke et al., 1997, *"The ESP-r System for Building Simulation, User Guide Version 9 Series"*, report number U97/1, University of Strathclyde, Glasgow, Scotland

DIN 277, 1997, *"Grundflächen und Rauminhalte von Bauwerken im Hochbau"*, (legal German Regulation for the calculation of floor areas in buildings)

SIA, 1995, *„Energie im Hochbau SIA 380/1-4“*, guideline for energy use in commercial buildings, Association of Swiss Engineers and Architects (SIA) Zurich, Switzerland

Esbensen Consulting Engineers, 1998, *"Energy Consumption and cost effectiveness of EC2000 buildings"*, report for the European Commission

M. Hestnes, 2000, *"Building Integration of Solar Energy Systems"*, to be published in 2000 in Solar Energy

ESAP sa, 1998, *„Energy in Europe: 1998- Annual Energy Review"*, report for the European Communities, ISBN 92-828-4880-9

B. Flückiger, C. Monn, H.-U. Wanner, 1998, *"Hygienic Aspects of Ground-coupled Air Systems"*, Indoor Air Vol. 8 pp. 197-202

Lohr, 1998, *"Das Kölner Low Energy Office - ein Bürogebäude im Niedrigenergie-Standard"*, annual report Implusprogramm Hessen, Germany

Nilson, Uppström, Hjalmarsson, 1997, „*Energy Efficiency in Office Buildings lessons from Swedish Projects*", Swedish Council for Building Research, ISBN 91-540-5787-6

C.A. Redlich, J. S. Sparer, M. R. Cullen, 1997, „*Sick-building syndrome*", THE LANCET, Vol. 349, pp. 1013-16

C. F. Reinhart, S. Herkel, 2000, „*The Simulation of Annual Daylight Illuminance Distributions- A state of the art comparison of six RADIANCE based methods*", accepted for publication in Energy and Buildings, 21 pages

Schweizer Energiefachbuch, 1997, 1999, ", published by Künzler –Bachmann AG, St. Gallen, Switzerland,

TEMIS. 1999 „Total Emission Model of Integrated Systems, Version 3.x, Ökoinstitut, Darmstadt, Germany

VDI 1946, "Raumlufttechnik", German norm, October 1988, published by Beuth Verlag GmbH, Berlin

L. Weber, U.-P. Menti, I. Keller. 1999. *"Stromverbrauch in Bürogebäuden"*, report of the federal office of energy, Switzerland (in German)

G. Ward, 1994, *"The RADIANCE 2.4 Synthetic Imaging System"*, University of California at Berkeley, USA