INNOVATIVE LOW ENERGY RENOVATION OF AN OFFICE BUILDING: CONCEPT AND SIMULATION

Friedrich Sick¹ and Alfred Kerschberger²

INTRODUCTION

Energy considerations are often neglected when it comes to refurbishments in office buildings erected in Germany during the first postwar decades. With a primary energy consumption ranging from 200 to 300 kWh/(m²a),* it is worthwhile thinking about lowering the operating costs for these buildings using ambitious design concepts for their capacity to lower building energy consumption. The German Federal Ministry for Economic Affairs tries to encourage model refurbishments in a funding program called ENOB – ENergy Optimized Building. Within this program, an interdisciplinary planning team developed a concept ready for realization for the office building of the DEGEWO company, located in Berlin (see Figure 1) [1].

Seventy-five percent of the existing buildings in Germany were built at times when there was no heat protection legislation in force. They account for about 90% of the heating energy demand in the country. Thus, the challenge is to improve the building stock, and this requires a lot more creativity than designing an energy efficient building from scratch [2].

The funded project of an innovative low energy renovation of an office building is of overriding importance to the planning of similar building types: the single elements of the energy concept and the general principles are transferable and adaptable to almost all office buildings erected in the 1950s, 1960s, and 1970s. The experiences and findings of the planning concept can be utilized independently of the specific project.

This paper first describes the energy concept and its components as a result of an integral planning approach. In its second part, the application of dynamic building simulations as a powerful analysis tool during the conceptual phase of this project is demonstrated. The design team is introduced in section 3.

CONCEPT

Situation

A typical office building built in the post World War II decades in Germany consumes about 125 kWh/(m²a) for heating. Electricity consumption for ventilation, air conditioning, and lighting adds up to about 50 kWh/(m²a) [3]. This is "site" or "delivered" energy. In terms of primary energy, this means a consumption of roughly 300 kWh/(m²a), mostly due to a primary energy factor for electricity of about 3 in Germany.** Single examples may show twice this value, i.e., 600 kWh/(m²a), whereas new and very energy efficient office buildings may reach values below 100 kWh/(m²a) of primary energy consumption. This sets the mark for refurbishment projects as well; new technologies and innovative materials enable run-down office buildings to be transformed into forward-looking real estate properties with the highest possible workplace qualities at operating costs clearly below what they were before.

The seven-story DEGEWO office building is located in the center of Berlin next to the Potsdamer Strasse, a heavy traffic arterial road. It was built in 1967 as a concrete frame structure and offers a total floor space area of 6500 m². Both the structural design and the technical equipment show the energy

1. PhD, Professor for Renewable Energies at FHTW Berlin University of Applied Sciences, Marktstr. 9, D-10317 Berlin, Germany, phone: +49 30 50 19 36 58, fax: +49 30 50 19 21 14, email: f.sick@fhtw-berlin.de; Consultant at Sick's Consulting Engineers Berlin, Kanistr. 53, D-12625 Waldesruh, Germany, phone: +49 30 56 58 85 56, fax: +49 30 56 58 85 57, email: info@ib-sick.de, www.ib-sick.de.

* 1 kWh/(m²a) equals approximately 317 Btu/(ft²a).
** For the production of 1 kWh of electricity, about 3 kWh in the form of oil, gas, or coal are being burned in the power plant.
A user evaluation performed by the Berlin University of Applied Sciences (FHTW Berlin) clearly showed an urgent call for action, especially on the street-facing side of the building, oriented SE. The users on this side are extremely dissatisfied. The solar beam radiation heats up this side early during the day. Noise and exhaust from the street are a second important aspect bothering the employees. Among employee suggestions for refurbishment on submitted evaluation forms, the most frequent request was the installation of air conditioning equipment. Also requested were sound-proof windows and the installation of semi-automatic exterior blinds (the existing blinds are manually operated and partially damaged). On the other hand, there were also requests that explicitly rejected the installation of air conditioning equipment. This can be explained by a widespread attitude for environmental protection in Germany and the knowledge that air conditioning systems consume a lot of energy, which can often be avoided by integrated energy concepts like the one described in this paper. It is also well known that air conditioning systems may lead to health risks, such as “sick building syndrome.” “Both opinions could work well with the mostly passive energy concept developed during this project,” concludes the evaluation report.

At the beginning of the project, FHTW Berlin took infrared thermographies in order to document the thermotechnical situation. One representative of a large number of images is given in Figure 4, which shows a partial view of the building’s rear side (to-
wards the courtyard). One can observe the effects of tilted windows, the joints between and the fixing points of the facade concrete slabs (secondary rooms, right-hand side of the image), and the position of the radiators in the offices (left-hand side).

Design Principles
The design team pursued several principles for the building renovation, which served as a guideline during the conceptual phase aiming at a cost optimized and functional low energy refurbishment. These principles are:

• Lowering the winter heat losses and the summer cooling loads with an improved building shell.
• Energy efficient HVAC equipment in order to obtain a minimized specific energy demand for the energy services of heating, cooling, ventilation, and lighting.
• Linkage of the energy services by complex intelligent controls leading to a demand side oriented system that is adapted to the respective usage.
• Creation of synergy effects by the combination of many complementary components.

Dynamic thermal building simulation was used as a tool for the analysis and evaluation of single measures discussed during the design process. This will be covered in more detail.

The components of the conceptual design described below consist of mostly well-tried and reliable designs and products. For two of the products, however, no long-term experiences are available: the Vacuum Isolation Panels (VIP) and the Phase Change Materials (PCM). Nevertheless, their functionality is well tested and products are available on the market.

Design Components
Insulation with Vacuum Isolation Panels (VIP).
While conventional insulating materials like mineral wool or polystyrene foams exhibit conductivities from approximately 0.035 to 0.045 W(m•K), evacuated isolation materials can reach values within the range of roughly 0.002 to 0.008 W(m•K). Particularly fine-arranged materials (nano structures) may show conductivities below the value for dry, resting (i.e., non-convective) air of approximately 0.026 W(m•K). Compared to these non-evacuated insulating materials, vacuum insulation exhibits an improvement potential of a factor 5 to 10. While in other evacuated insulating systems, such as evacuated tubular collectors, cylindrical housings are able to withstand the outside atmospheric pressure of 1 bar, in flat-plate VIPs pressure-stable low conductivity
filling materials must take up the forces. Different fiber, powder, or foam products are applicable. They must be open-pored, in order to be able to become evacuated. A VIP consists in principle of the filling material and a covering. Thus it is less an insulating material, which can be worked on and shape-cut as required, and more a prefabricated high-efficient insulating unit, in some respect comparable to a window.

There are different types of Vacuum Isolation Panels (VIP) available. Foil-coated VIP is economical, but sensitive. High-grade steel sheet metal covered VIP has its origin in the building of refrigerating chambers and is suitable for facades in a modified version (Figure 5).

In the DEGEWO project, the street-facing exposed aggregate concrete facade experiences a clearly visible change through the replacement of an area of 600 m² with high-grade steel sheet metal covered Vacuum Isolation Panels. The VIPs are only 40 mm thick; however, their insulation value corresponds to 35 cm of polystyrene. Such a slim VIP isolation panel permits a smooth transition to the neighboring building facade plane. The panels are neither screwed nor stuck, but adjusted only into the sub-construction and fixed with clamping rails. This ensures that no means of mounting the panels penetrate the insulating layer and cold bridges are reduced to a minimum.

**Phase Change Material (PCM).** In order to noticeably increase the thermal storage mass in the interiors, ceiling panels with integrated latent heat storage material (PCM) are installed in the southeast oriented offices. PCM takes up an enormous amount of heat with the phase change from solid to liquid. For example, a 1-centimeter-thick PCM plate with a melting point of 25°C stores as much heat as 10 centimeters of concrete with a temperature rise of 6 K. During night hours the ventilation exhausts the heat stored in the ceiling panels to the ambient and the PCM solidifies. A radial fan improves the critical nocturnal heat emission, if necessary (Figure 6).

There are different types of PCM material on the market. As mentioned above, there are no long-term experiences available for review. In order to increase reliability and confidence in the planning and dimensioning of the PCM for increased thermal storage capacity in the offices, the thermal behavior of samples from three manufacturers was examined in a climate chamber at the Braunschweig Technical University (IGS institute).

One typical result is shown in Figure 7. The sample was placed in the climate chamber at about 20°C. Then the temperature in the chamber was raised by roughly 3 K resulting in a heat flux into the PCM material until the sample showed the same temperature as the surrounding air (steady state). This process was repeated twice. The top heavy line shows the air temperature, and the top fine line the sample’s surface temperature. The bottom fine line indicates the heat flux into the sample and the heavy one the integrated heat flux over time. The differences between the steady state integrals are a measure of the PCM thermal capacity within the respective temperature ranges. It can be well observed that this capacity is a lot higher in the range between 23°C and
27°C due to the latent heat storage in the melting region of the sample. These data were used to establish a calculation model of the material for the dynamic building simulation.

Conventional Heat Protection Measures. A conventional thermal insulation composite system of 20 cm thickness is installed on the courtyard-facing façade. Thus the exterior wall u-value improves to 0.15 W/m²K. Triple-pane windows with a window u-value (including edge effects and frame) of 0.9 W/m²K and good sound insulation replace the old simple double-pane windows. With 20 cm of roof insulation and 12 cm for the basement ceiling there is a good heat protection upward and downward.

Optimization of Daylighting and Artificial Lighting. Exterior venetian blinds with a separately controllable upper part provide optimal use of daylight. They distribute the daylight deep into the room and reduce the electricity consumption for artificial lighting while at the same time providing sun and glare protection to the work places (see Figure 8). If the incident daylight is not sufficient, occupant controlled supplementary lighting is added in critical zones improving the lighting quality. An optimized lighting fixture arrangement as well as electricity efficient lamps further add to the electricity savings.

Optimal Sun Protection of the Building. Highly selective glazings with high daylight transmission and low g-value (total energy transmittance) reduce the summer solar loads and at the same time optimize the daylight supply (light transmission 60%, g-value 30%). A shading control depending on temperature and solar irradiance advances the building’s sun protection to today’s usual standard for new buildings.*

Energy Saving Ventilation and Air Conditioning. A slim-dimensioned supply and exhaust air system

* Exterior shading with automatic controls dependent on temperature and irradiation are state-of-the-art—often though not always used in new office buildings. It is not a standard like an ASHRAE standard or comparable.
with intelligent controls, low air change rates, low air velocities in the duct system, high-efficiency heat recovery, and occupancy control for each room provides the highest ventilation qualities at the smallest power requirements. The cooling loads resulting from internal gains are considerably reduced by the exchange of all CRT monitors with flat screens as well as the above-mentioned energy-efficient lighting. In addition, during the summer months the supply air is adiabatically cooled. The principle: the exhaust air is humidified and the resulting evaporative heat loss is used via heat exchanger to chill the supply air. A bus controlled night ventilation system cools down the office spaces in the summer nights. Ventilation wings open automatically allowing the interiors to be cooled by natural convection. During extremely hot summer periods the mechanical ventilation system supports this effect with forced ventilation.

**Photovoltaics.** The concept is topped off by a grid-connected photovoltaic system integrated into the roof of the building according to the project’s requirement, i.e., high use with small expenditure. Due to the feed-in tariff fixed in Germany’s Renewable Energy Law (EEG), the plant writes off within 10 to 15 years, even without any initial investment funding.

**Results**
The renovation is conceived in such a way that it can be implemented in the fully occupied building without substantial operational disturbances. The resulting primary energy demand for heating, cooling, and lighting is reduced from 300 to 100 kWh/m²a. The ventilation system permits the closing of still operable windows facing the road even in summer. A gentle adiabatic cooling with minimum energy consumption chills the supply air up to 10 K below ambient temperature. The lighting quality ensures good visual conditions for work at VDT workstations. Although the concept does not provide for conventional air conditioning systems with high electricity consumption, the thermal comfort increases to a lasting extent, both during summer and winter. The improved interior quality, however, is not limited to the thermo-hygric aspect, but also includes indoor air quality, noise control, and natural and artificial lighting.

**Costs**
The energy related costs of the project amount to 565 €/m². A refurbishment according to the German heat protection legislation (EnEV) would cost approximately 270 €/m², in both cases including value added tax (VAT) but not including building additional expenses, which account for another 12 to 15 percent. Not included are other renovation costs, e.g., the remodeling of the restrooms and the entrance hall. Annual operating cost savings amount to approximately 65,000 € per year. Considering the pilot promotion in the context of the ENOB funding program by the German Federal Ministry for Economic Affairs, an amortization period of approximately 13 years is reached. As a positive side effect the increase in value of the building is added, which is a function of the high-quality building shell in connection with most modern building equipment. Additional building value is due to the lower operating and maintenance costs.

**SIMULATION**

**Building Energy Concepts: An Optimization Task**

In order to determine or analyze the thermal behavior and the energy requirements of a building, energy balances are to be set up and solved. If this takes place on the basis of average values during longer periods, brief fluctuations are leveled and dynamic effects are eliminated. This can for example result in the indication of justifiable summer average room air temperatures, although the actual temperatures are occasionally intolerably high within their fluctuations. Therefore, reliable statements about the thermal behavior of a building are possible only with dynamic time step simulations, which solve the energy balances for each time interval (typically max. one hour) of a typical yearly climatic data set with corresponding data intervals. The contributions to the energy balance of a building are possible only with dynamic time step simulations, which solve the energy balances for each time interval (typically max. one hour) of a typical yearly climatic data set with corresponding data intervals. The contributions to the energy balance of a building and their dependencies are various, partially moving in opposite directions and dependent on climatic region and building usage. Therefore, the building material glass plays a substantial role. Functionally, the glass’s task in the facade is to let daylight inside while maintaining weather protection and visible connection between inside and outside. There is no other need for glass in building facades.
Transmission heat losses of glazings are relatively high. Two-pane insulating glazings (u-value approx. 3 W/m²K) were standard in Germany until 1994 (!); u-values of less than 1.5 W/m²K have been required by law for only a decade. According to this law, called EnEV [6], opaque external walls must exhibit u-values of 0.35 W/m²K or lower when being remodeled. The comparison between windows and walls shows that the heat protection of glazings is still bad compared to the surrounding opaque wall. Glazings thus lead to benefits in the balance (solar radiation) on the one hand, but on the other hand to increased transmission losses of the wall. The effect of these characteristics can be positive or negative according to season and sky condition:

• What is gladly accepted in the wintertime as a heating contribution, can lead to overheating in the summer and a cooling load very unfavorable to the total energy balance.
• A large area of glazing, which is regarded as a welcome source of daylight on overcast days, can become an intolerable glare source during sunny periods.

Independent of season and the local weather situation the effects can also be characterized with the term of utilizability. The question is, “Can the thermal or photometric gains be used or not?” If they are not usable, the following question must be added: “Are they even harmful, i.e., must be compensated for by an energy expenditure?” Often, in particular during the transition periods spring and autumn, the utilizability of thermal gains changes within hours.

The described variety and potential opposite effects on the building’s energy consumption permit two fundamental conclusions: first, controllable components for sun and glare protection, if necessary also for heat protection and for artificial lighting, are required in order to permit gains when they are usable, but switch them off as soon as they are counterproductive; second, extreme solutions, which dedicate themselves to one energy aspect, definitely do not represent the optimum variants. The glass facade is such an extreme solution. In order to avoid such, and also less striking, erroneous trends, an early close cooperation is necessary between architect and specialized planners. An independent energy planner in the team avoids possibly counterproductive conces-
sions, which have their cause in remuneration questions or in a lack of interest in sustainable concepts. The optimization task can be expressed generally as follows:

Achievement of greatest possible thermal and visual comfort for the desired building usage with minimum primary and end energy expenditure and thus minimum operating costs.

Buildings that achieve this goal usually get along also with very small technical expenditure and therefore also with decreased capital costs. Small additional expenditure for the preceding integral planning amortizes quickly.

Dynamic Building Simulation in the Example of the DEGEWO Building Project

During the conceptual phase of the DEGEWO energy concept reliable forecasts of the thermal building behavior were necessary in order to evaluate different variants. Therefore, for the analysis of the influence of individual measures in the total package and for the comparison of the thermal behavior of individual areas within the building, the dynamic thermal simulation was applied. The simulation package TRNSYS 16 [7] was used. TRNSYS is a modular simulation library for the dynamic simulation of building energy systems with a world-wide recognized, numerously validated, multi-zone building model.

For the simulation model, not the whole building, but repeated sections were looked at, each consisting of a standard office on the street side, an opposite office on the courtyard side, and the corridor section between them. Thus a model consists of three thermal zones (see Figure 9).

This model can be used in a flexible way with small adjustments and thus virtually be shifted within the building. In this way, the different thermal behavior of the areas can be modelled as a function of the adjacent sections and the shading by obstructions can be considered. The thermal behavior of such a model is being reproduced quasi-dynamically in hourly time steps. Among other things the following were determined:

• the average zone air temperatures;
• the so-called operational zone temperatures;
• the heating energy demand for a heating set point of 20°C during the heating season;
• a fictitious cooling energy requirement for a simulated cooling set point of 27°C in the summer; this represents a criterion for summer overheating; in parallel, a simulation is being run without cooling (according to reality) with free floating zone temperatures;
• frequency distribution of summer zone temperatures;
• comfort criteria according to the German Industry Standard ("Deutsche Industrie Norm") DIN 7730 [8], among others, with a statistical forecast of the number of possibly (with thermal conditions) dissatisfied persons.

The existent situation and a conventional refurbishment fulfilling the conditions of the German building energy saving regulation (EnEV) are used as comparisons. The simulation is accomplished gradually in variants in order to evaluate the individual effects of planned remodeling components. Each variation results from the preceding component with the addition of one further element. Seven such steps are briefly introduced here.

- Variant 1: This differs from the EnEV variant (the standard according to German building code) by a further increased thermal optimization of the building shell (thicker conventional insulation, VIPs, and better windows), as described above.
- Variant 2: The supply ambient air quantities for the ventilation system are limited to 20 and 40 m³/h per person (winters/summers),
- Variant 3: A ventilation heat recovery system is supplemented,
- Variant 4: An additional temperature-dependent free convection ventilation by automatically operated facade openings is added during summer nights between the hours of 21:00 and 7:00, provided the climate conditions permit the heat removal from the interior.
- Variant 5: If the ambient temperature is above 23°C in the summer and provided the outside air conditions are favorable, adiabatically cooled ambient air is supplied to the zones.
- Variant 6: The internal loads by equipment are reduced from 230 to 140 W per workplace. The lighting system has a specific installed power of 13 W/m² in its optimized version as compared to 19 W/m² before.
- Variant 7: 6 m² of phase change material (PCM) with a latent storage capacity of 195 Wh/m² are added as additional thermal storage mass on the street-side offices.

The simulation results of the single steps to refurbishment are represented in summary in Figure 10 on the basis of the yearly energy balance for the street-side offices. The effectiveness of the measures in relation to the existing building, but also in relation to the EnEV reference is obvious:

- The new facade and the ventilation with heat recovery reduce the heating energy demand (black columns).
- The fictitious cooling need, i.e., the summer overheating, increases slightly by these measures at first.
- Night ventilation and adiabatic cooling (the next steps), however, compensate for this effect. The resulting computational cooling demand disappears almost completely.
- Reduced internal loads eliminate the cooling demand completely. The heating demand rises...
somewhat, since fewer electrical consumers contribute to the heating. The summer effects become clearly visible in the temperature statistics (Figure 11):

- The night ventilation reduces the frequency of operational temperatures above 28°C in the street-side offices by almost two thirds, in the courtyard offices even by three quarters,
- Combined with adiabatic cooling, a reduction of 86% on the street side and 96% on the courtyard side can be observed;
- The latent storage phase change material implemented only in the street-side offices adjusts the conditions between the thermally more strongly charged street side and the courtyard side very well. The frequencies of operational temperatures above 26°C are almost identical in the end.

An exemplary summer temperature development (Figure 12) demonstrates the improvement of the situation from the existent to the remodeled status. While the temperatures before remodeling stay on a high level around and over 30°C, they are reduced to levels around 25°C by the presented measures, even though there are ambient air temperatures of over 32°C. Lastly, the predicted satisfaction with thermal conditions rises strikingly. From Figure 13 it becomes clear that the predicted percentage of dissatisfied (PPD=Predicted Percentage of Dissatisfied) hardly reaches values above 15%, which is generally regarded as a lower justifiable border.

**Summary**

Dynamic thermal building simulation serves as a tool that can be used for the thermal analysis of a building during the conceptual phase and gradually ac-
Integral planning is difficult. The project partners must be prepared for new and unconventional ways. In many cases, standard solutions “off the shelf” are not the ones that change a conventional into an energy efficient building. The final solution is often not found immediately but rather as a result of an iterative process. The design team of the DEGEWO project realized a true integral planning approach. The partners were:

**DEGEWO company:** building owner, planner, project leader

**RK-Stuttgart:** energy concept, project management, accompanying research

**Ridder und Meyn Berlin:** HVAC

**Dr. Riedel AT GmbH Berlin:** heating and ventilation controls

**FIGURE 12.** Typical summer course of the operational zone temperature before and after refurbishment, course of the ambient temperature as comparison.

**FIGURE 13.** Predicted thermal comfort before and after refurbishment.
FHTW Berlin: monitoring, user evaluations
Sick’s Consulting Engineers Berlin: thermal building simulations
IBUS Berlin: lighting
ebök Consulting Engineers: ventilation consulting
Happold Consulting Engineers: structural engineers
Braunschweig Technical University: PCM analysis

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