Interdisciplinary development of a modular façade system with decentralised building services

H. G. Schuster, H. F.O. Mueller
University of Dortmund, Germany

ABSTRACT

The current discussion about energy saving measures in the built environment and the forthcoming new European guidelines “Energy efficiency in Buildings” motivated an aluminium façade company (Hydro Buildings Systems) to set up an interdisciplinary team for the development of a new façade. Therefore around ten partners from different backgrounds joined to create innovative and energy efficient solutions.

The University of Dortmund was asked to do the architectural design and the project management as well as the basic environmental strategies. Multiple firms provided the technical components and expert consultants were included to work on thermal and air flow simulations, the balancing of energy production and consumption and to set up innovative control strategies. The basic idea was to design a high quality modular façade with enough freedom for individual expression of buildings. It had to include all building services to run an office building and which should produce the energy needed for running the systems itself.

Within only nine month a first prototype called TEmotion has been presented at the fair “Bau 2005” in Munich, Germany.

1. INTRODUCTION

Nowadays the development of a facade system especially for office buildings is a complex task. Not only the energy consumption of a building has to be included with concern to design, climate and technical facilities needed, but also the time for erection, the spatial needs both in terms of function and space, the maintenance costs for the building as well as for technical components and last but not least the user requirements need to be fulfilled. The interior as well as the function and layout of a facade have an impact on the productivity of employees [1] and therefore on costs. Especially the lighting issues apart from noise levels, air quality and indoor temperatures have an essential impact on the well-being of the user (Figure 1).

Figure 1: Source of regular disturbance after CAKIR 1998 [2]

Fully automatic controlled buildings often create dissatisfaction [3]; therefore manual interference must be possible to allow individual preferences with concern to the indoor climate. An optimised control system therefore allows as much interference as possible and controls as much as necessary. Visual feedback takes care for the transparency of information about the building systems behaviour. When carefully planned the interior environment will not even be noticed, but when disturbing it can result in a high rate of dissatisfaction and even manual manipulation of systems.

The current questions around the value of real estates as well as the potential for lease need high flexibility in new buildings. The use of an interior space must be easy to change without interfering in the built environment. Furthermore the greatest part of buildings in industrial countries has been already built. The concern nowadays therefore should include the reuse and reconstruction of existing buildings. Usually the technical components need to be replaced, therefore other than the existing space is needed for the incorporation of advanced building technologies. A decentralisation of mechanical services therefore offers a great potential of savings for construction (installations and space savings), not only for new but also for existing buildings.

2. DESIGN PROCESS – AN INTEGRATED APPROACH

Within the here described development the integrated planning process was one of the conditions necessary
to fulfil the requirements of the task to create new innovative solutions. In contrast to the conventional linear planning process, where each team member sets the framework for the following member and therefore the possibilities for innovations get the narrower the more progressed the project is, in this project all members of the planning team have been working together from the first outline on. The framework for the project this way has been set up together and innovations could be much more easily integrated (Figure 2).

Figure 2: Example for a conventional linear and an integrated planning process

Running from March to December 2004 the development of a first prototype needed to be set up within a time span of only nine month. The interdisciplinary team included architects, lighting engineers, consultants and a number of firms with different backgrounds (Table 1 left).

Table 1: Team setting

<table>
<thead>
<tr>
<th>On behalf of:</th>
<th>Initiator, aluminium profile manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro Building Systems, Ulm</td>
<td></td>
</tr>
<tr>
<td>Companies Involved</td>
<td></td>
</tr>
<tr>
<td>W+W+Z+K</td>
<td>Shading devices</td>
</tr>
<tr>
<td>D+H Mechtronik AG, Hamburg</td>
<td>Control systems</td>
</tr>
<tr>
<td>Saint-Gobain, Achten</td>
<td>Glazing, photovoltaics</td>
</tr>
<tr>
<td>TRIO/FL, Neukirchen-Hayn</td>
<td>Desenralised modules</td>
</tr>
<tr>
<td>ROTL, Landshut-Erding</td>
<td>Drive units</td>
</tr>
<tr>
<td>Consultants</td>
<td></td>
</tr>
<tr>
<td>Dr. For Environmental Architecture, Univ of Dortmund</td>
<td>Architecture and environmental concepts</td>
</tr>
<tr>
<td>GLB-Gesellschaft für Licht u. Bautechnik, Dortmund</td>
<td>Artificial lighting concepts</td>
</tr>
<tr>
<td>Schmidt-Ruten Integrated Planning Consulting GmbH, Köln</td>
<td>Thermal and air flow simulations, costs</td>
</tr>
<tr>
<td>Energy Office, D-Ing, Schwab, Munich</td>
<td>Energy balancing, energetic strategies</td>
</tr>
<tr>
<td>Engineers Office Prof. Dr. Becker, Blaenbach</td>
<td>Control strategies</td>
</tr>
</tbody>
</table>

An open system, which should fulfil the different requirements of new and existing buildings, needs planning rules which integrate modularity, (partly) prefabricated elements and erection issues. The process of the state of the art building industry therefore needs to be analysed and interpreted in a new way. Within the development of TEmotion we looked at the automotive industry which has a very special and effective logistical and prefabrication system (Figure 3).

Figure 3: Overview of the systems strategy with respect to the automotive industry

3. THE DEVELOPMENT OF A MODULAR CONCEPT - FREEDOM OF DESIGN AND FEATURES

A basic system, modular and extendable, allows many different facade typologies with individual designs and technical standards according to the needs. Single building components are meant to be prefabricated to deliver complete elements on site. This results in a reduction of construction time, less mistakes on site and a high potential of economic saving; all that with a high potential of freedom concerning the design. Media components furthermore can be integrated to present the building during the night to the outside and to serve the need for a 24-hour representation.

Two main elements have been created: The “glass element” with all visual functions such as daylighting, artificial lighting, shading and glare protection, and the “functional element” with all non-visual functions such as heating, cooling, mechanical and natural ventilation and the control module (Figure 4).

Figure 4: The elements of the facade development, here the example of the prototype
The following concepts have been developed within that project:
- Unitized facade concept
- Double skin facade with integrated shading, daylighting and artificial lighting devices
- Natural ventilation via window openings
- Decentralized, mechanical ventilation systems to heat, cool and ventilate
- Energy gaining through photovoltaic panels
- Control system integrated in the facade
- Plug-In concept with a link to the facility management of the building
- Media components to the outside
- Artificial coloured light to enhance activity

To fulfil the criteria of flexibility and freedom of design a number of different layouts and designs have been developed as examples (Figure 5 left). The one on top left has been further developed to the prototype (Figure 5 right) which will be explained now in more detail.

4. THE CONSTRUCTION OF A TYPICAL EXAMPLE

The construction of the prototype was done with aluminium profiles (Hydro Building Systems). The glass elements consist of a double facade system with an outer single glass layer and an inner insulating glass layer. Figure 6 upper shows the aluminium supporting frame with the integrated visual functions (shading device, protected by the outer glass layer against wind and rain, light direction and artificial lighting components). Figure 6 lower shows the functional element with all non-visual functions (such as control, media components, energy gaining components). It has been constructed with an integrated thermally insulated box containing a combined heating, ventilation and cooling element. The inner border is constructed as wooden door with lamellas for fresh and exhaust air.

5. THE ENVIRONMENTAL STRATEGIES OF THE PROTOTYPE

The prototype includes special natural and artificial lighting concepts, natural and mechanical ventilation concepts as well as energy gaining measures and a highly user friendly automatic control system.

The lighting concept was based on the best user accept- ance possible (Figure 7 upper). It integrates the shading device with concave louvers and a highly reflective surface to direct sunlight in the upper part of the glazed area onto the ceiling and through reflection in the depth of the room. The lower part can be closed completely to provide shading. Glare protection will be provided by the system as well. Furthermore the artificial lighting concept consists of spotlights in the facade space to reduce additional heat transfer into the interior. The artificial light will be directed through white light holograms onto the ceiling according to the natural light supply and therefore creates a similar lighting environment as during the day. In addition LED have been integrated in the inner aluminium profiles to add blue
light when activation is required, as recent research has found that the biological rhythm of human beings is mostly activated by blue light [4]. For the 24-hour representation of a building LED have also be integrated in the outer vertical profiles of the functional element.

Figure 7: Upper: Artificial and natural lighting concept; lower: natural and mechanical ventilation concept

Figure 7 lower shows the natural and mechanical ventilation concept in the functional element of the prototype. Task was to allow as much natural sources as possible without neglecting the comfort of the user neither the energy efficiency of the facade. Fresh air supply in both variables will be supplied by openings above the ground whereas the exhaust air will be extracted on ceiling level to allow the best ventilation rates possible. When outside temperatures ask for mechanical ventilation, a combined heating, cooling and ventilation system [5] was installed to cool or heat up the incoming fresh air from the outside following the same principle as the natural strategy. Conventional double facade principles often suffer from overheating in the space and therefore in the interior. The fresh air supply in this case therefore will be always independently and directly from the outside without creating the problem of high wind speeds in high rise buildings as the openings are protected by the photovoltaic panels. The photovoltaic panels will partly cover the energy needed for the facades operation. The overall task of the facade development was to reduce the overall energy consumption of a building in two more ways: to reduce the energy needed for operation and to reduce grey energy for the building itself through reduction of construction space for technical services. The control system was developed to create as much user comfort as possible without neglecting the physical requirements of the building. Therefore a visual feedback screen has been created to inform the user about the energy efficiency of his preferred settings. The system chooses the least energy consuming method to achieve the users preference, e.g. when a higher lighting levels is chosen, the systems responds either with more artificial light or, if thermally possible, with opening the shading device. Lower temperatures can be achieved by either more natural ventilation or by running the cooling system.

6. EXEMPLARY ENERGY DEMAND AND COSTS

Up to now only the prototype has been built and there are no test results available. Different calculations and simulations (thermal, air flow and daylight as well as artificial lighting simulations [7]) have been carried out. The total energy consumption for the prototype so far has been calculated on the base of an exemplary office building (with 7000 sqm and five floors) with a state-of-the-art facade according the German building regulations [8]. According to these calculations CO² emission is assumed to be reduced by up to 34% and the overall energy consumption by up to 36% depending on the technologies used in the facade. Furthermore there will be a severe reduction of costs for technical services within the building as most of it has been integrated in the facade. The changed construction methods also can help to reduce construction time on site as well as maintenance costs. The plug-and-play function of the single elements will also help to reduce mistakes when assembling the facade on site. Detailed calculations are in process.

7. CONCLUSION

The development of TEmotion has been an efficient and successful example of an integrated building process with an interdisciplinary team. It showed a number of innovative environmental strategies which help to reduce energy consumption in buildings and which can be applied for new and existing buildings. The modular design showed an overall flexibility both in functional as well as in esthetical ways. The overall performance has not been monitored yet but calculation showed a marking energy reduction for the prototype.
REFERENCES

1. BOM 2001 2002, MAR, FIG 2002, Boy 2003a, KÜL Arbeitsplätze
4. Rea, Mark S. Licht – Mehr als nur Sehen. Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY, USA
5. FSL GmbH & Co KG, Neukirchen-Vluyn, Germany
7. Daylight simulations with radiance and siview by University of Dortmund
8. Calculations done by: Schmidt Reuter Integrale Planung und Beratung GmbH, Cologne