Construction of the building started on February 16, 1987. It is planned to carry out detailed monitoring of the completed building.

9. References

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INFLUENCE OF THE BUILDING ENVELOPE ON THE INTERNAL THERMAL CONDITIONS DEMONSTRATED AT THE NEW AIRPORT BUILDING IN STUTTGART

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1. Introduction

The present-day economic planning of buildings for administration and infrastructure requires the quantification of the interactions between

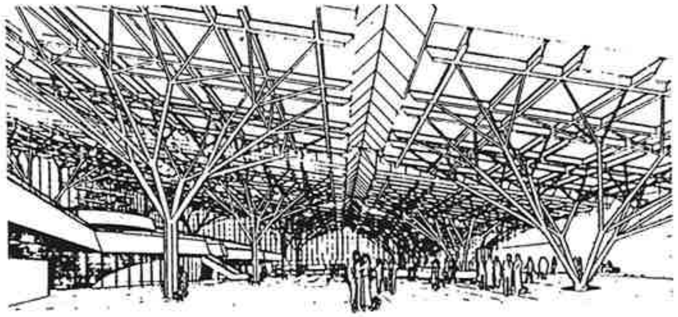
- building envelope
- heating, ventilating and air-conditioning (HVAC)
- climatic loading
- usage requirements

to miminize investments and future operating energy costs.

This report follows the execution of such an interaction analysis with a practical example where a decision-making basis was required at an early stage: The departure hall of the new airport in Stuttgart.

On the basis of a competition the overall detailed design was awarded to a German Architect. The architectural scheme for the competition concept is shown in figure 1. The 8 000 m² extensively glazed sloping roof is supported by slender tree-like columns. The visitor to the departure hall is intended to receive the impression of open space.

Fig. 1: Architect's impression of the departure hall



It was apparent to everybody engaged in the design that such an extensively glazed structure would become very hot in summer. A considerable cooling system would obviously be required and excessive costs for HVAC-investments and operating energy would accumulate. Consequently, to assess the feasibility of the planned construction the investor required an energy and cost analysis. This paper adresses itself to the keypoints of the energy analysis.

2. Thermal Model of The Building

2.1 Requirements for the Model

Due to the unusual structural form, the effect of solar radiation had to be modelled more accurately than is usual. Techniques with empirically based utilisation factors were inadequate.

On one hand the problem was concerned with cooling power requirements and, on the other hand, with varying thermal loads (solar radiation, passenger-flow at peak departure times). Since all these parameters exhibit extreme daily variations, dynamic calculations were necessary. For the dynamic simulation of the building thermal-balance the computer programme IGLOU-G was used. At the present time there exist relatively few such dynamic programmes. Capabilities tend to be very variable, and the programmes can usually only be used by the current owner or author. This impedes further distribution of the programmes whilst also bringing into question the verification of results.

A short description of IGLOU-G is contained in the Appendix (see also Ref. 1). IGLOU-G was verified using an instrumented building at the EMPA (= Eidgenössische Materialprüfungsanstalt) in Maugwil. The results will be briefly described:

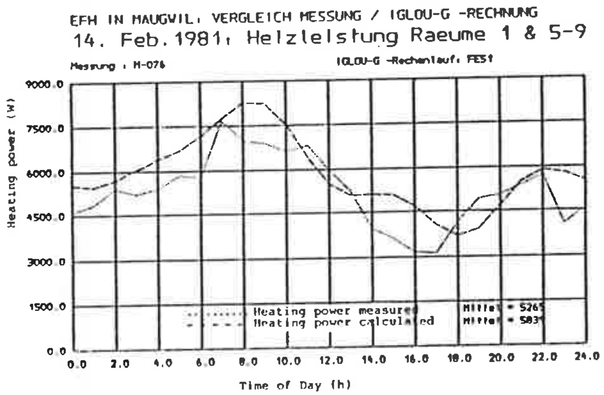
2.2 Verification of IGLOU-G

The main thermally-relevant data for the detached house in Maugwil was measured on a half-hourly cycle by the EMPA for 2 years. This data, together with a description of the building, are available at the EMPA for the purpose of verifying computer programmes.

For the testing of IGLOU-G, test days with large temperature and sunshine variations where chosen. The results are as follows:

For a winter day (14.02.81) Fig. 2 shows the calculated heating time-history and the measured heating time-history.

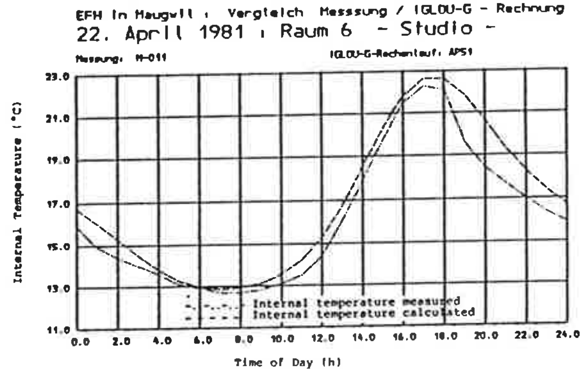
Fig. 2: Comparison of heating power time-history



The agreement of dynamic caracteristics (phase differences and amplitudes) is good. The calculation determines the ideal necessary heating requirement. The steps in the observed curves, as well as their deviations around the calculated curve, are due to the sluggishness of the actual heating systems controls. The difference in the mean values (daily heating energy) of the calculated and observed curves is approximately 10 %.

For a spring day without heating (22.04.81), the air temperatures in every room were calculated and compared with the corresponding measured values (Fig. 3 for Room 6). The agreement is very good, the other rooms are similar.

Fig. 3: Comparison of temperature time-history, Room 6



The results presented, together with successful practical applications since 1980, confirm the performance of the IGLOU-G simulation model for dynamic thermal analyses of buildings.

3. Analysis of the Departure Hall

3.1 Basic Assumptions

The following specifications were assumed:

a) Building

In the course of the study numerous variants and sub-variants for the layout of the building envelope were examined. The four main variants that bound the initial architectural layout were as follows:

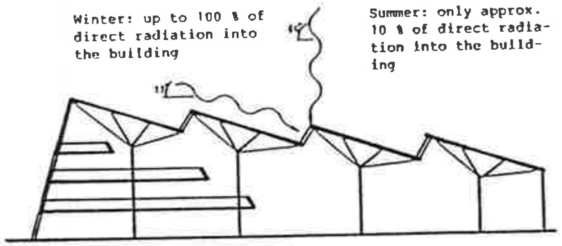
- Variant 1 "Translucent": This variant was the closest to the Architect's competition submission. The roof and side-walls have a glazed fraction of 70 %. In view of the high expected transmission losses in winter, a translucent glazing with a K-value of approximately 1.0 was chosen.

- Variant 2 "Intermediate": The glazed fraction of the roof is reduced to 30 %. The glazing is transparent. This variant formed the lower bound of what the Architect was prepared to concede in terms of structural layout.

- Variant 3 "Container": The building envelope consists entirely of opaque components.

- Variant 4 "Sun-Trap": The glazed fraction is, as in Variant 2, 30 %. However, the form of the roof is so conceived that passive solar heating is possible in winter. In summer on the other hand, the glazing is deprived of direct solar radiation without the use of mechanical means (Fig. 4).

Fig. 4: Variant 4, "Sun-Trap"



b) Climatic Loading

The analysis was carried out for representative days in summer, winter and spring and for an entire year. The solar radiation data for the given location and date was calculated by the IGLOU-G programme itself. The data was checked using locally observed measurements.

c) Use of Building

The internal heat generation due to personnel-flow is high and extremely variable. A representative profile for the flow was determined with the help of the future flight-timetable.

For the determination of the heat generated by artificial illumination a lighting study was carried out for each variant.

3.2 Results

a) Summer case

Figure 5 shows the daily inside temperature variations without air-conditioning for the four variants. Fig. 6. shows the cooling energy requirement necessary to limit the temperature to 27 °C.

Fig. 5: Inside temperature, summer

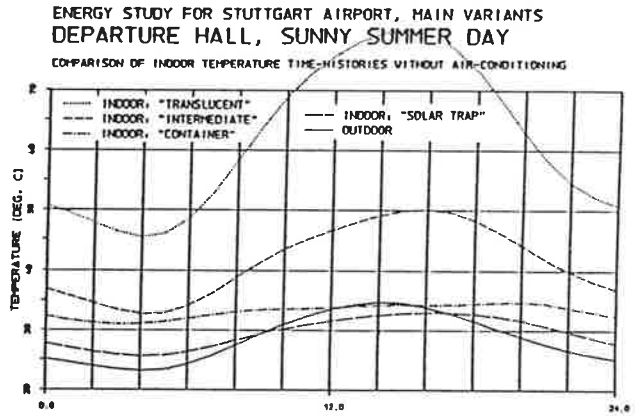
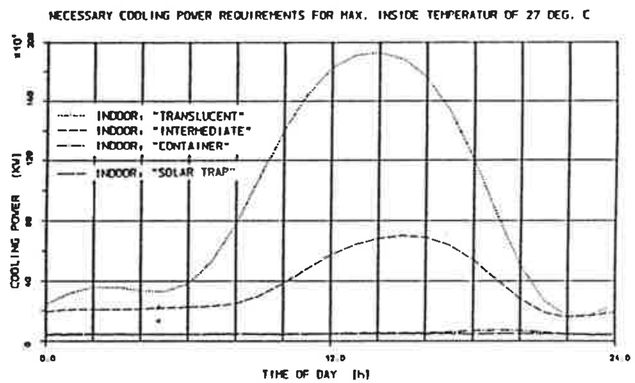


Fig. 6: Cooling power time-histories, summer



As expected, the "Translucent" variant results in extremely high inside temperatures (peak at 80 °C) and correspondingly high cooling requirements. The insulating effect of the translucent glazing is a negative contributory factor in that it counteracts transmission cooling. The solar radiation alone is responsible for the extreme behaviour for on overcast day the temperature would climb little above 30 °C. The variant "Translucent" is a veritable solar collector whose air-conditioning is economically impossible.

The variants "Intermediate" and "Container" illustrate the decreasing cooling requirement with decreasing glazed area. Even with a small glazed area a pronounced peak in the cooling power requirement is apparent. However, air-conditioning is only required on sunny days.

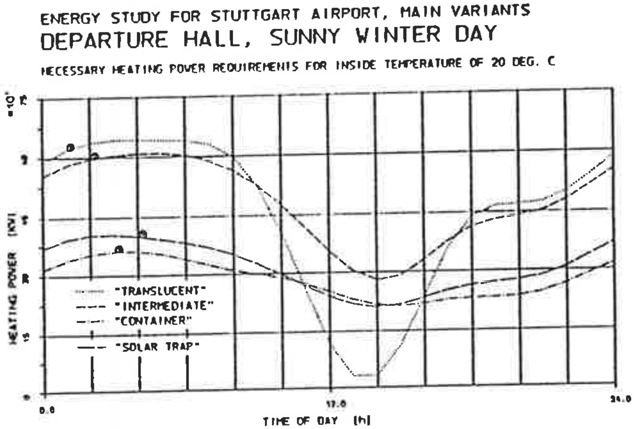
The "Sun-trap" case gives interesting results: although the 30 % glazed fraction provides the desireable roof transparency, the cooling energy requirement is as low as the totally enclosed "Container" variant.

Conclusions for the "Summer" case:
If the 30 % glazed area is to be adopted, then the "Sun-trap" variant is the only possible economical solution. Otherwise for an economical solution the glazed fraction of the roof has to be below 10 %.

b) Winter case

In order to make a comprehensive assessment, the winter case also had to be considered (Fig. 7).

Fig. 7: Heating time-histories, winter



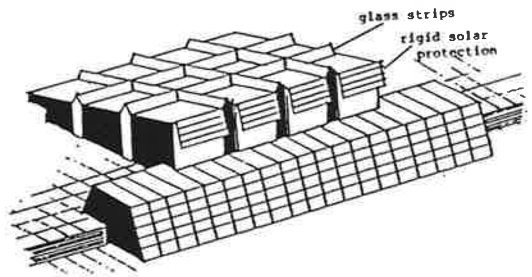
The variants "Transclucent" and "Intermediate" also show up poorly here. Variant "Sun-trap", with the same glazed area as variant "Intermediate", results in a 30 % lower energy requirement due to passive solar heating.

3.3 Execution Solution

The calculated variants served as a decision-making basis for the investor and the planning specialists. The energy consultant favoured a design tending towards the "Sun-trap" variant. However, this was perceived by the Architect as an unacceptable departure from his original concept. The solution finally adopted was one with a considerably reduced glazed area consisting of glass strips (glazing fraction 7 %).

Further economical analysis based on a more developed IGLOU-G model clarified important construction details (Rigid solar protection, Solar protection glazing etc.) and lead to the finally executed project (Fig. 8). It is presently under construction.

Fig. 8: The executed solution



4. Conclusions

The following conclusions can be drawn:

a) For the economical optimisation of building envelopes with unconventional structural forms and usages, dynamic thermal computer simulation offers considerable advantages. These are:

. accurate determination of cost-governing, time-dependent quantities (cooling power etc.)

. rigorous inclusion of physical parameters (solar radiation, storage capacity)

. considerable flexibility for studying variants

c) There exist such programmes which are well proven and have been widely used in practise for years.

b) In practise the energy consultant is one of several specialists that make up the design team, and his requirements often contradict other criteria. Since compromises must therefore be reached, spectacular energy-saving buildings are seldom. The energy consultant can however prevent costly (design) errors, and make a considerable contribution to more economic and environmental-conscious buildings.

5. References

(1) Lanz J., Schopfer A., Energetically-optimized retrofitting of existing building envelopes. IEA Conference on new energy conservation technologies and their commercialisation. Berlin 6 - 10, April 1981

6. Appendix

Short description of the computer model IGLOU-G

7.1 Purpose

Dynamic simulation of the thermal performance of an entire building with all interactions between the particular rooms.

7.2 Application

. Calculation of time-histories for cooling and heating power
. Generation of energy-flow diagrams
. Solar protection, passive solar gains
. Description of comfort criteria (inside air temperatures, surface temperatures)

7.3 Method

Fourier-Analysis of the periodic parameters of the thermal building performance (Method Haferland/Heindl/Fuchs).

7.4 Input Data

. Building structure:
  - envelope (area, orientation, material)
  - internal rooms
. Usage of the building:
  - personnel-flow
  - internal heat gains
  - comfort criteria
. HVAC parameters
. Climatic loading

7.5 Computer Code

Fortran for Prime 9950