Analysis and evaluation of large glass-roofed spaces in office buildings

Goal of the Research Project

Tendencies to integrate large glass-roofed spaces into architectural concepts of office- and administration buildings spread increasingly over the past few decades. Apart from architectural aspects such as generating a representative appearance or providing weatherproof space for recreation and circulation, atriums are considered to give visual evidence of high energy efficiency of a building. Planners expect energy savings in the field of heating and ventilation similar to the effect of winter gardens and due to accumulation of solar heat gains and the possibility to use natural ventilation for the adjoining office rooms.

A commonly approved method to consider thermal performance of an atrium and adequate guidelines for construction and operation already during planning process has so far not been established. Planning is realized according to individual standards with varying planning tools. The present state of standardization as listed in DIN V 18599 provides with no planning support for optimization of energy consumption and comfort of large glazed air spaces. Often savings of effective energy have in practice not met estimated values, whereas aestival overheating and temperature stratification in the atrium considerably exceed projections. Significant solar heat gains during summer are permanently underestimated and cause unwanted overheatings. This leads to a higher consumption of cooling energy as well as a decrease of thermal comfort and also precludes the possibility to ventilate via the atrium.

These experiences and the access to a number of atrium buildings brought about the idea at Institute of Building Services and Energy Design, Technical University Braunschweig, Univ.-Prof. Dr.-Ing. Fisch, to analyse atrium buildings in full operation in regard to energy efficiency and operation mode. Possible causes of an atriums malfunction in the context of the buildings energy concept and the ventilation strategy are being detected and analysed. Projection qualities of general planning tools are being evaluated based on gained data and by means of a CFD-program, dynamic building simulation and further analytical methods. In conclusion, guidelines will be drawn that summarize all relevant knowledge of atriums for the planning process.

Procedure of the Research Project

The research project is carried out in two parts, a general analysis and a detailed analysis.

General Analysis

Part of the general analysis is an outline comparing 15 atrium buildings and their parameters in regard to specific energy values, characteristics of structural physics and atrium concepts. To evaluate energy efficiency of atrium buildings, their energy specific values are being compared to the values of buildings without integrated atrium. Further reinvestigations are made to discover correlations between energy efficiency of atrium buildings and the characteristics of their structural physics. Series of temperature measurements are available for part of the atriums, gained from previous research projects. Those measurements serve as reference data to compare thermal performance among atriums as well as in regard to outdoor climate. Result is the derivation of general interrelationships between constructional edge conditions and thermal performance of an atrium. In addition, the vertical thermal gradients of the atrium air are being compared at similar edge conditions. These considerations can not evaluate influences of operation such as settings of building automation and survey of accurate implementation in practice.

Detailed Analysis

Three atriums of the general analysis are being selected for closer examination in course of the detailed analysis. The selected atriums are firstly the headquarters of LBS Nord in Hanover Kronsberg, secondly Energieforum Berlin in Berlin Friedrichshain and thirdly the new building of the Computer Science Centre on campus of Technical University Braunschweig.

Basic idea of the atrium of LBS Nord is a house-in-house concept where the core buildings are almost completely enclosed by a glazed shell. The likewise enclosed courtyards between parts of the building are planted in medieval manner and are not heated. The atrium of Energieforum Berlin is confined by the building itself on three sides and opens southwards to the riverside with its vertical paned glass face. It is heated as it serves as main circulation area and occasionally hosts special events. The atrium of Computer Science Centre of TU Braunschweig is enclosed on four sides, is heated and mainly used for public circulation. Both, the Energieforum Berlin and Computer Science Centre were initially designed as low-energy-buildings and meet the required energy standards.

The metrological testing programme of the detailed analysis is divided in long-time monitoring and additional short-time tests. Parameters of the indoor climate of the atrium as well as data on outdoor climate are being collected during long-time monitoring. At the same time operating data on the building control system is being recorded. This data gives information about functionality of the control diagram responsible to activate ventilation openings. Reference variables essential for the control such as outside and indoor temperatures are also among the collected data. Short time tests mainly refer to measuring air change rates and smoke tests to analyze exchange of air mass and air flows. Main factors responsible for the inside temperature of the atrium are the air exchange rate as well as quality, ratio and orientation of glazed faces. Due to the fact that changes concerning the transparent building shell and the type of glazing are very restricted during planning process at time of sectoral planning, position and size of ventilation openings as adaptable values are of great significance.

Results of different methods to calculated air change rates such as analytical methods and CFD–simulation-tools are being compared to measured ventilation numbers. This reconciliation of calculated values and measured results defines the projection quality of the individual planning tools.

A dynamic building simulation of the office space is carried out based on results of temperature measurements in the atriums and with the purpose to quantify the influence of atrium temperature and ventilation strategy on the energy consumption of the office space. Consequently a function can be derived from the correlation of air temperature in the atrium and the outdoor temperature. Reference temperature sequences of the ambient air in the atrium can be calculated with this function based on a test reference year.

Finally the demand of effective energy needed for heating and cooling one of the adjacent office rooms is calculated considering the synthetic atrium climate as surrounding climate of the office room. Conclusively, representative guidelines for the planning of energy efficient and comfort oriented atriums are being established.

Summary of Results

Influence of Type of Glazing on Energy Consumption

Comparing energy characteristic values of 15 atrium buildings to other administration buildings without atrium and in regard to their atrium concept and structural edge conditions showed, that atrium buildings can cover the whole range of energy efficiency just as non-atrium buildings. The fact attracting attention is, that buildings with heated thermal atriums (15° - 25°C) show lesser heat consumption than buildings with unheated cold atriums (5°C - 15°C). The circumstance that heated atriums according to HIO (Heat Insulation Ordinance) have to be fitted with heat absorbing glazing seems to be cause of lesser heat losses of the core building. Using heat absorbing glass and thereby shifting the heat insulating layer to the atrium shell leads to an effective reduction of the ratio A/V. Above all, solar heat gains inside the atrium are not lost via the building shell.

Thermal Performance of Atriums

High energy consumptions of the observed atrium buildings have all been traced back to faulty operation modes (control diagram and its operation). Rate of the temperature level and the increase of temperature in regard to the height of the air space for compatible outdoor conditions (summer 25°C, winter 0°C) is shown in figure 1.

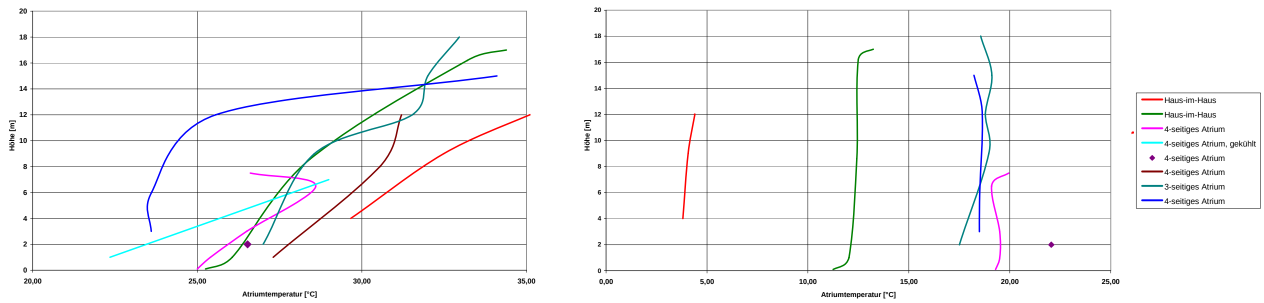

figure 1 vertical temperature gradient of the airspace of different atriums at compatible outdoor conditions, respectively summer (approx. 25°C) and winter (approx. 0°C).

In summer the spread of the atrium temperature reaches from 22°C to 35°C at a vertical temperature gradient of up to 10 K. These values are not interdependent on the ratio of ventilation openings, the height difference between the openings or the solar heat gain coefficient of the glazing.

An almost constant temperature level over the height of the atrium is reached in winter and is conditioned by operational demands. Heat absorbing glazing is requested according to Heat Insulation Ordinance (1995, relevant for all analysed buildings) as long as heaters are installed in the atrium (radiators, floor heating). Usually the requested temperature values can thus be achieved. Cold atriums reach the desired temperature level in winter via opening and closing ventilation flaps.

As shown in figure 2, all temperatures measured over the entire height of the atrium lie above outdoor temperatures all-season. This accounts for all analysed atriums.

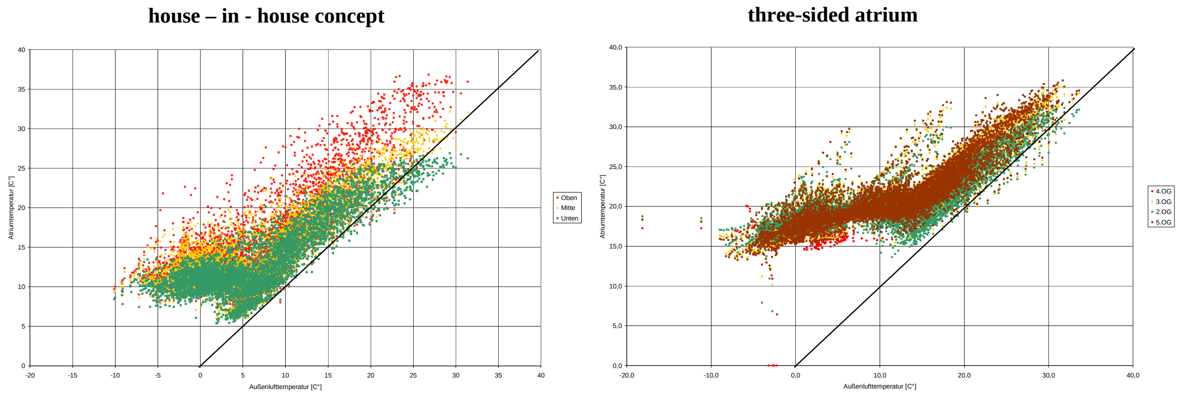

figure 2 interdependence of atrium temperature on outdoor temperature in case of an unheated (l.) and a heated (r.) atrium. heights of the measuring points are indicated by colour. (bottom to top: green, yellow, red, brown)

Influence of the Atrium Temperature and the Ventilation Strategy of the adjacent Rooms on the Energy Consumption of the Building

The fact that atrium temperatures exceed outdoor temperatures all year round is an important conclusion in regard to energy consumption of the building. In case of heating, the excess temperature of the atrium leads to energy savings and in case of cooling to additional demands of cooling energy. The ratio of saved heating energy versus additional consumption of cooling energy turns the annual balance of over-consumption and under-consumption caused by an atrium. This ratio is being influenced by the temperature level of the atrium that is preferably small in summer and respectively high in winter. Further influence of the atrium temperature on the conditioning of the core building is depending on the level of convection (ventilation strategy, air exchange between atrium and core building) and transmission towards the core building.

Tests with a dynamic simulation based on measured values showed in case of the cold atrium, that the consumption of effective energy is increased by 50% once air exchange exists between atrium and core building in case of cooling. Under these conditions, thermal heat gains of the atrium are transferred to the core building via transmission and convection.

However, solar preheated air should be used for ventilation of the core building during heating period. A well adapted ventilation concept can lead to a 50% decrease of effective energy consumption of a room adjacent to the atrium in comparison to a room adjacent to external air.

The air exchange rates measured at aestival weather conditions showed values between 2.0 and 3.2 for the analysed atriums, see table 1. Comparing the results of analytical formulas of the British Standard Method with the so called Schachtformel and Dachaufsatzformel showed that the British Standard is the most reliable method to calculate air exchange interdependent on excess temperature of the atrium and wind rates. See figure 3.

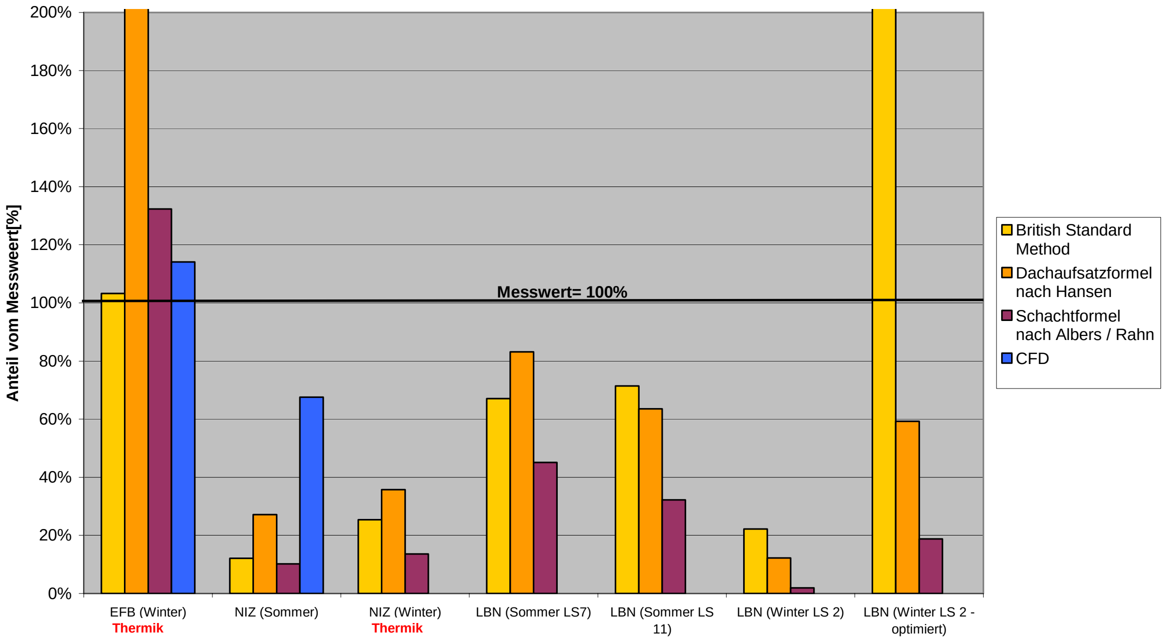

figure 2 calculated air exchange rates related to measured values. The measurand is set to 100%.

Cases dominated by thermal influences are being indicated. CFD-methods are likewise capable to calculate air exchange rates with similar preciseness. All analysed cases show that an influence of wind is relevant for the air exchange during summer. Nevertheless, a sufficient vertical height between fresh air openings and exhaust air openings has to be considered in order to be prepared for worst case scenarios of windless summer days.

table 1 absolute values of air exchange

Measurement Results / Calculation Results	Measurement Volume Flow Rate [m³/h]	Measurement Air Change Rate [1/h]	British Standard Method [m³/h]	Dachaufsatzformel nach Hansen [m³/h]	Schachtformel nach Albers / Rahn [m³/h]	CFD-Results [m³/h]
EFB (Winter)	202.655	5,4	209.285	723.284	268.187	231.336
NIZ (Summer)	26.054	3,2	3.147	7.077	2.658	17.600
NIZ (Winter)	18.750	2,3	4.767	6.692	2.550	
LBN (Summer LS7)	62.294	2,0	41.781	51.824	28.071	
LBN (Summer LS 11)	86.742	2,8	61.961	55.128	27.907	
LBN (Winter LS 2)	50.022	1,6	11.120	6.120	935	
LBN (Winter LS 2 - optimized)	13.080	0,4	27.277	7.756	2.452	

Relevance of Standardization as Planning Aid

Within the calculations of energy consumption of a building according to DIN V 18599, atriums are being referred to as either heated or unheated glaze porches. For a detailed monthly balance the atrium is being classified as one-zone-model with fixed ventilation numbers regardless of operational requirements. This method provides with no planning support in regard to dimensioning of ventilation openings and estimating thermal characteristics of the atrium. Also the simplified method comes up with calculated atrium temperatures in summer that lie below outside temperatures. At contrary, the research data have shown that excess temperatures are measured year-round inside all atriums.

Conclusions relevant for the planning of atriums are summarized in the following guidelines:

Type of use of an atrium should be defined at early stage as further planning is mainly determined by this factor.

The vegetation of an atrium can interfere with a system control based on energy efficiency and optimized comfort conditions. This applies especially for medieval plantings that require temperature levels of 5-15°C during heating period. Solar heat gains can thus not be taken full advantage of.

Consideration of Realistic Air Temperatures Inside Atriums

All atriums show exceed temperatures year-round and regardless of careful planning. Especially during summer high temperatures are measured at top level of the atriums. These exceed temperatures cause an additional consumption of cooling energy required to cool the adjoining building parts but also reduce the demand on heating energy. Depending on dimensioning of the building, savings due to less consumption of heating energy could outbalance additional expenditures caused by an increased cooling energy demand.

Free ventilation via the atrium increases the effect of atrium temperatures on the adjoining rooms. Therefore all rooms adjoining the atrium should be mechanically ventilated as alternative and in order to reduce cooling energy demands. An over dimensioning of the atrium provides crush room for ascending warm air and thus minimizes negative effects of aestival overheating and temperature stratification.

During heating period, ventilation via an atrium can be reasonable in order to use solar heat gains directly to precondition supply air.

Selection of Glazing

The solar heat gain coefficient of the atrium glazing should be less than 0.4 whereas the light transmission factor should correspond to the technical means and be equivalent to about twice the sum of the solar heat gain coefficient.

Placement of Ventilation Openings

Ventilation openings should be placed at different altitudes with intervals as large as possible. The position of openings meant for fresh air inlet should be placed in a northward direction or alternatively eastwards. Overheating is rarely an issue in the morning and openings with no direct exposure to solar radiation only fractionally contribute to heating up the atrium.

Opposing openings are needed on top level of the atrium in order to reduce temperature stratification. Cross-ventilation is more effective and preferable to one-way ventilation where opening flaps are depending on wind direction.

The British Standard Method [BS 5925] is an important tool to calculate the required amount of effective openings. In case of dimensioning, lift-induced ventilation rates serve as variable and should at least amount to n=3 h-1. CFD-studies are a proper tool for further analysis taking into account influence of wind and drafts of ambient air. The effects of top-hung sashes and gills fixed to ventilation openings have to be considered as they reduce the size of effective opening.

Control of Ventilation System

The control of the atrium ventilation should react quickly to changing conditions and be dimensioned according to reliable reference variables. This applies especially to the location and accuracy of indoor and outdoor temperature sensors (radiation shield). In favour of planners, constructors and operators, the control concept should be designed as simple as possible in order to maintain high traceability and verifiability. A monitoring period of at least one year should be initiated at first operation in order to discover variations between planning and operation and thus be able to adjust operation to actual use of the building and thermal characteristics of the atrium.

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