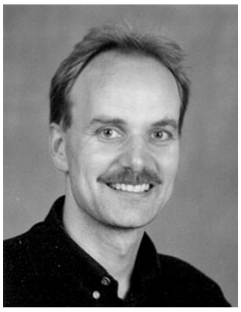
ENERGY EFFICIENCY IN COMMERCIAL BUILDINGS

Experiences Results from the German Funding Program Energy Optimized Building, EnOB



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Summary

In order to gain access to the energy use in office buildings, the German Federal Ministry for Economy launched an intensive research and demonstration program in 1995. In advance of the 2002 EU EBPD (Energy Performance Directive) a limited Primary Energy Coefficient of 100 kWh/m²a has been postulated as a goal for the complete building services technology (HVAC + lighting) for all demonstration buildings to be supported. Another specification was to avoid active cooling measures within main parts of the buildings. Techniques like natural or mechanical night ventilation or heat removal by slab cooling with vertical ground poles were applied as well as earth-to-air heat exchangers in the ventilation system. An accompanying research was established to keep track of the results and lessons learned from 25 demonstration buildings realized and monitored until end of 2006.

In comparison to the building stock the energy consumption of the buildings is significantly less and even lower than many other best practice demonstration buildings monitored in Germany and Europe. In some cases the limit was exceeded because of unexpectedly high consumption for heating or electric lighting caused due to the building concepts while others could have been adjusted by an improved energy management. Calculation results will be discussed with respect to monitoring results for detailed energy services such as lighting or ventilation. Three of the projects enter the range of a zero emission building by the combined approach of drastically reduced demand and more or less equivalent credits by the use of renewable energy.

As one outcome this paper summarizes the energy performance of a selection of characteristic buildings together with an overview on the summer thermal comfort situations achieved. This work will proceed during the next five years. Another result is that a higher quality of energy and comfort building performance will not necessarily cause extra building cost when the project has been planned carefully by an integrated design process. Future results and building data can be downloaded from: www.enbau-monitor.de.

Keywords: Office buildings, energy efficiency, monitoring, passive cooling, thermal comfort, user behaviour, integrated design

1 Introduction and Background

1.1 Energy Use in Office Buildings

Numerous office buildings of the eighties were designed to isolate the internal conditions from the outdoor climate as completely as possible, at the cost of high energy consumption. Thermal and visual comfort as well as the air quality is guaranteed by extensive technical building services for heating, ventilation, air-conditioning and lighting (HVACL). High investment and operating costs are accepted to ensure that it can control even extreme indoor conditions caused by generously or even totally glazed building envelopes. In combination with the space demand of wiring for communications technology – double floors, suspended ceilings – it is quite common to occupy 20 to 30 % of the building volume for technical services solely. The main share of the electricity consumption is due to the HVACL facilities and not to the office equipment.

Despite the heat generation associated with electricity consumption within the building (internal heat gains), the space heating demand in Mid and North European Climates is still dominating the overall energy figure due to the high proportion of glazing and the high air exchange rates. **Fig. 1a** gives a qualitative impression of a typical energy consumption profile as a function of the outdoor temperature, the so called ET- diagram. In addition to a base energy load which is independent of the weather, there is a contribution for heating and humidifying below the balance temperature, and for cooling and dehumidifying above it. The balance temperature is defined by the outdoor temperature at which thermal losses are balanced by the internal and solar gains. The base load is mainly caused by office equipment and the idling consumption of building services technology. The waste heat associated with the base load affects the position of the balance temperature. The higher the base load, the lower is the balance temperature. Due to the decoupling of the room air from the building mass – suspended ceilings, double floors, lightweight walls – and the maintenance of constant indoor conditions throughout the whole year, there are hardly any days when there is neither active heating nor cooling demand.

1.2 Thermal Comfort and Health

The diverse technical approaches to achieve a good indoor climate were often accompanied by complaints from office workers about many types of discomfort and dissatisfaction, which are summarised as the "Sick Building Syndrome". One German investigation of this phenomenon, the so-called "ProClima-Project" (Bischoff, 2003), reaches the conclusion that although buildings with air conditioning maintain an objectively good indoor climate, they are subjectively rated lower than naturally ventilated working conditions by the majority of persons questioned. The rating is significantly affected by

- the magnitude which an individual person can determine the prevailing conditions at his workplace and
- the degree of maintenance of the technical service systems.

Today an increasing fraction of office buildings are being constructed or retrofitted which allow individuals to control their own indoor climate to a large extent, and which replace almost complete isolation from the weather outdoors by a moderate interaction. Daylit workplaces and the option for natural ventilation are typical characteristics. However, a combination of integrated measures to achieve so-called "passive cooling" is a pre-requisite if summer comfort is to be ensured without actively cooling or dehumidifying the inlet air. This type of concept became known as "lean building", due to the smaller volume of the service equipment required. The task is to design buildings such that even when the weather outdoors varies greatly, the indoor conditions remain within a well-defined comfort zone, which meets the expectations of the occupants, **Fig. 1b**. The comfort zone is exceeded only for periods of extreme outdoor temperatures. The maximum acceptable number of working hours with temperatures above the comfort zone has to be discussed on the basis of simulation results in the early design phase of a building and checked against legal standards.

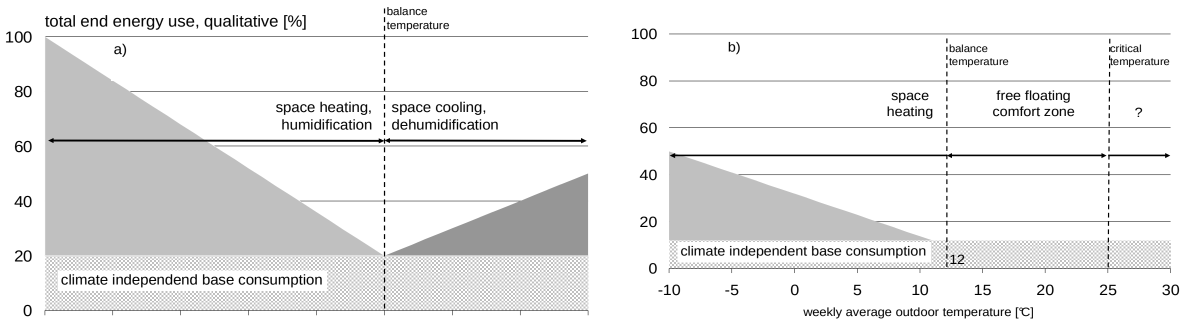


Fig. 1 Qualitative profile of the energy consumption of a “conventional building” (a) compared to a "lean building" (b), the so-called ET-diagram.

2 Results and Experiences

2.1 Energy Monitoring

Tab. 1 gives an overview of the monitored projects and the applied passive cooling concepts. Detailed information together with a comprehensive overview on results and experiences are presented in (Voss et al., 2005). Additional information is available via internet (www.enbau-monitor.de).

Data are presented for end and primary energy use respectively, taking into account the energy conversion factors for the specific conditions of Germany as given with a national standard (DIN 4701-10, 2001). Using the primary energy factor concept allows the comparison of the building’s energy consumption and to rate the energy supply in terms CO_2 emissions.

Fig. 2 summarises the monitoring results from buildings for which data from at least one year were available. We have chosen to present the information as a graph rather than numerically, as the boundary from HVACL to user-specific electricity consumption (PC, printers etc.) was difficult to define in some cases. This could cause quantitative but not qualitative changes to the results. Particularly for separating the electricity use for the type of energy service (e.g. electricity for lighting and for computer operation) requires a very detailed and expensive metering concept. It is not common to allocate the electric circuits within a building according to the equipment connected to them. In many cases, detailed analysis of the electricity consumption helped to identify weaknesses in system operation and aid their correction.

In order to separate the effects of reduced energy use and energy efficient energy supply, in case of CHP and photovoltaic to the primary energy balance were shown separately.

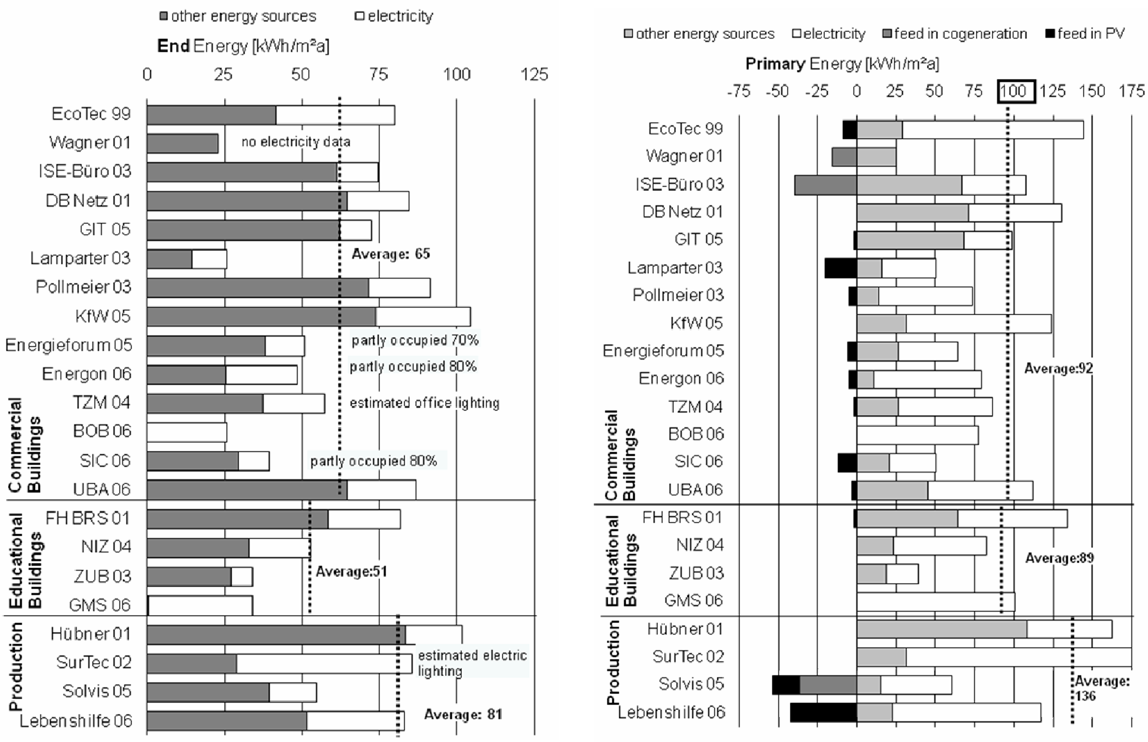


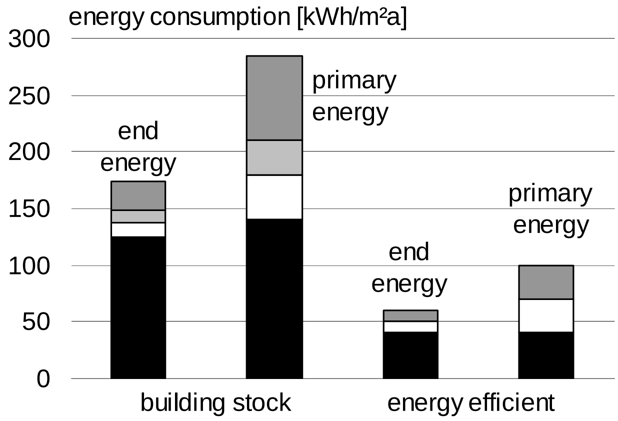
Fig. 2 Measured end energy (left diagram) and primary energy coefficients derived from them (right diagram).

All data refer to the heated net floor area. Data are collected from the monitoring institutions according to **Tab. 1**. The primary energy factors and electricity credits are based on German DIN 4701 (DIN 4710, 2001): Electricity 3, fossil fuels 1.1, biomass 0.2. To simplify the balancing procedure, photovoltaic electricity (PV) was evaluated with the same electricity credit as for combined heat and power plants (CHP). The consumption values refer to HVACL. The numbers following the project titles indicate the year for the measurements. The data source in each case was the university which was responsible for the measurement programme. In the case of the "ISE-Büro" building, a zone of 525 m² consisting purely of offices plus the adjoining access areas was selected from the Institute building with a total area of 14,000 m². Aside from the Hübner building the so called production buildings have a mixed use of office and workshop or pharmaceutical production.

Nine out of the 14 office and educational buildings show primary energy consumption below or close to the required limit of 100 kWh/m^{2}a, five buildings range above this limit. As the end energy use for HVACL in production buildings (workshops, factories) strongly depends on the requirements regarding indoor air quality and internal loads strongly depend on the production process, a fixed primary energy target of 100 was achieved by two of the four evaluated production buildings. It is satisfying to see that the consumption of each building is much lower than the comparative values for the building stock according to Chyba! Nenalezen zdroj odkazů..

Individual design and target values are only available for some of the buildings, as no common methodology for calculation of the energy demand for cooling, ventilation and lighting was used. Heating energy demand was calculated based on the national standard (DIN 4108-6, 1994). Additionally building simulations were performed for most of the buildings. Therefore comparisons with target values are valid only for the same building.

The limit for primary energy use was exceeded in some cases because of unexpectedly high heating demands (DB, GIT), high electricity consumption for lighting (FH BRS, Hübner), etc. Some of the causes are due to the building concepts; others could have been avoided by an improved energy management. The Pollmeier building avoided high consumption values for primary energy, despite unexpectedly high heating energy consumption by burning wood off-cuts from its own sawmill, representing a largely CO_2-neutral source. Combined heat and power plants result in a primary energy credit (Wagner, ISE, Solvis), as the measured gas consumption also contributes to electricity generation and thus to substitution of grid electricity. Drawing heat from a district heating network with CHP also proved to be favourable (ECOTEC, ZUB).



	building stock		energy efficient	
lighting	25	75	10	30
cooling	11	30	0	0
ventilation	13	40	10	30
heating	125	140	40	40

Fig. 3 Target values for energy efficient office buildings according to the programme compared to end energy use values for office buildings from the existing stock in Mid European climate according to (Weber 2002). The net heated floor area is used as the reference area. End energy was transferred to primary energy by a factor of 3 in the case of electricity and about 1 for all other forms of end energy in order to compare it with typical German situation.

Aside from energy saving and thermal use of renewable energy, some of the buildings apply measures such as combined heat and power plants (co-generation) or photovoltaics to produce electricity to feed into the public grid. This energy subsidies grid electricity to be generated on national average conditions with a mixture of power plants. In case of so called "zero energy buildings" primary energy credits for the subsidies grid electricity balance the buildings primary energy consumption on a yearly cycle. Three projects (Wagner, Lamparter and Solvis) enter the range of a "zero energy building" by the combined approach of minimized consumption and more or less equivalent credits (**Fig. 5**).

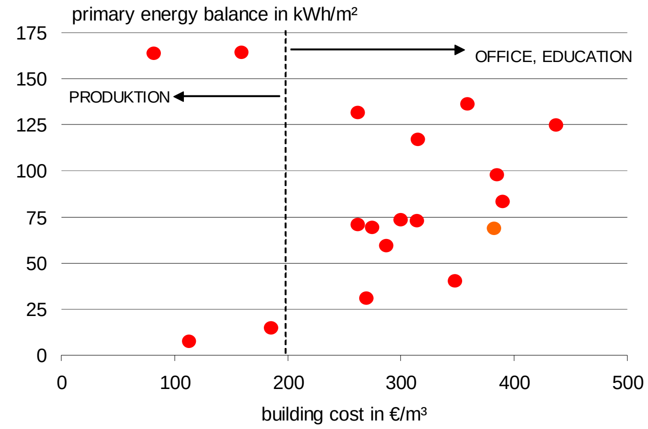


Fig. 4 Primary energy use versus building cost. The primary energy use is more or less independent from the cost for construction and HVAC equipment.

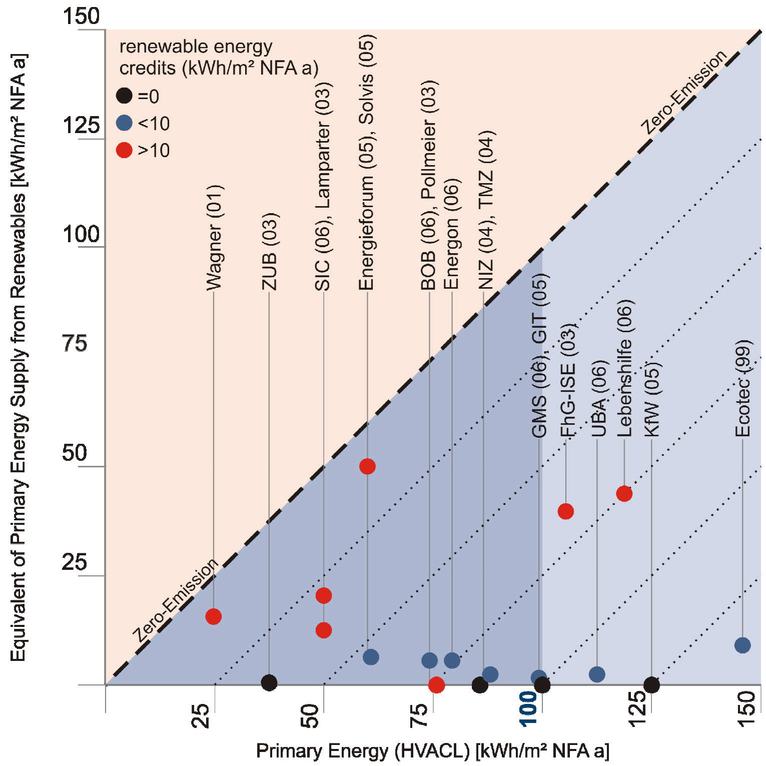


Fig. 5 Primary energy benefit versus primary energy consumption. Dotted lines show buildings of the same primary energy balance. Note: The primary energy consumption of Wagner building does not include electricity for HVACL.

2.2 Technologies Used by the Demonstration Buildings

The (combinations of) technologies to achieve energy efficiency depend on individual energy goals and specifications of local conditions on building type, use and location. The four tops used in the projects include Daylighting, Passive Cooling, Heat Recovery and Building Automation according to the scope of technologies as illustrated in **Fig. 6**.

	Ecotec	Wagner	Hübner	FhG-ISE	DB-Netz	FH-BRS	GIT	Lamparter	NIZ	SurTec	ZUB	Pollmeier	Solvis	KfW	Energieforum	Energon	TMZ	BOB	GMS	Lebenshilfe	UBA	SIC	Ritter	DVZ Barnim	Regionshaus
Passive house concept	○	●	○	○	○	○	○	●	○	●	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
Passive Cooling	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○
Optimization of daylight	○	●	○	●	●	●	●	●	●	○	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●
Automation of artificial light	●	○	○	●	●	●	○	○	●	○	○	○	○	○	○	○	○	○	●	○	●	○	●	●	○
Atrium	○	○	○	●	●	●	○	○	●	●	●	●	○	●	●	●	○	○	●	●	●	○	○	●	○
Solar thermal	●	●	●	●	○	○	○	●	○	○	○	○	●	●	○	○	●	○	○	○	●	●	●	○	○
Solar power	●	○	○	●	○	●	●	●	○	○	○	●	●	○	●	●	●	○	○	●	●	●	●	●	○
Heat recovery	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Activation of thermal mass	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	●	○	●	●	●	○	○	●	●	●
Ground coupled heat exchanger	○	●	●	●	●	●	●	●	○	●	●	○	○	○	○	○	○	○	○	○	●	○	○	○	○
Geothermal piles	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	●	●	●	○
Geothermal probes	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	○	●	○	○	○	○	○	○	●
Combined heat and power (CHP)	○	●	○	●	○	●	○	○	○	○	○	○	●	○	○	○	○	○	○	○	●	○	○	○	○
Trigeneration system	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Heat Pump	●	○	○	○	○	○	●	○	○	○	○	●	●	○	●	○	●	●	●	●	○	○	●	●	○
Building Automation	●	●	○	●	●	●	●	●	●	○	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●
Use of Biomass	○	○	○	○	○	○	○	○	○	○	○	●	●	●	○	○	○	○	●	●	○	○	○	○	○
Rainwater concept	○	●	●	○	○	●	○	●	○	○	○	○	○	○	○	●	●	●	●	●	●	●	●	○	○
Ecologic Building materials	○	○	●	○	○	●	○	○	○	○	●	○	●	○	○	●	○	○	○	●	●	○	○	●	○

Fig. 6 Overview of 19 strategies and technologies used in the demonstration buildings of EnOB.

2.3 Passive Cooling and Summer Comfort

In order to improve indoor conditions in summer, so-called "passive cooling" concepts were an integrated part of each building design in different ways and to a varying extent. Passive cooling means the interaction of all measures which act to reduce the heat gains on the one hand, and on the other, which make natural heat sinks such as night air and ground accessible. So in this paper “passive cooling” includes techniques, which are not using a thermodynamic cycle process. The remaining heat loads are transferred to the surroundings with a certain time delay. Heat storage in the building construction, both during the course of a day and over longer hot periods, is substantial, Chyba! Nenalezen zdroj odkazů. (Pfafferott, 2004).

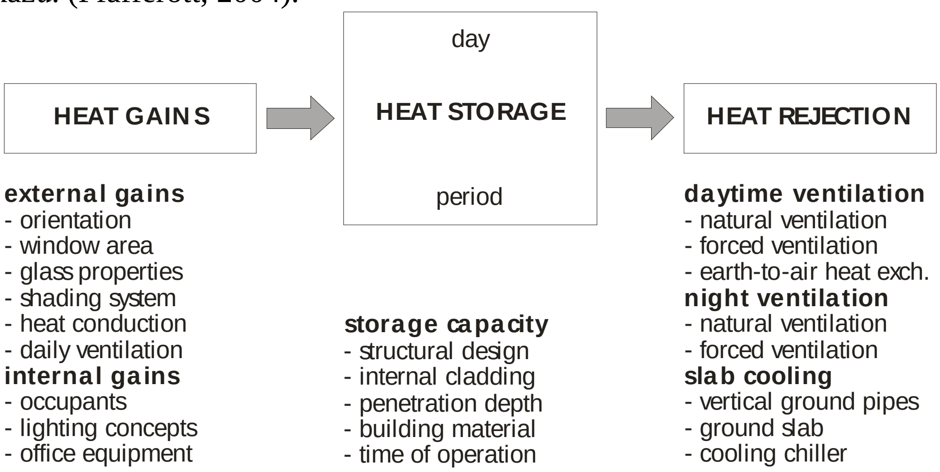
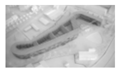


Fig. 7 Passive cooling principle and main issues influencing the building energy balance on a daily or more extended period.

In view of the limited cooling capacity and the long time constants, the main design priority is to restrict the amplitude and dynamics of **external heat gains**. Thus, none of the buildings provides an entirely glazed façade. The average ratio of glazing to opaque area was 43 % or 27 % related to floor area. Almost all of the buildings use external adjustable solar shading except buildings with slab cooling systems (enhanced cooling capacity). Experiences show that the total solar energy transmittance (g_{tot}-value) for glazing and sun-shading should not exceed 10-15 % (Zimmermann 1999). This can be achieved for internal blinds or blinds in the gap between the glass panes only in combination with solar control glazing ($g_{glass} < 40$ %), or by external blinds and standard heat protection glazing. A detailed analysis regarding manual blind use in two buildings (ISE, Lamparter) shows a strong correlation between solar penetration depth and blind occlusion (Reinhart 2002, Herkel 2005). External loads in these cases range in the order of internal loads (Pfafferott 2005).
Average daily total **internal heat gains** observed range between 100 and 200 Wh/m². The range refers to the density of occupation, the operation mode of the computer systems and the lighting concepts, **Tab. 2**.

Tab. 1 Demonstration Buildings with a comparison of the applied passive cooling concepts

Building	Monitoring Team	Net heated area [m²]	Umean [W/m²K]	Aperture area / net heated area [m²/m²]	Night ventilation	Earth-to-air heat exch.	Slab cooling	Ground pillars	
ECOTEC	University of Bremen	2,941	0.54	0.13	**X**				
Wagner	University of Marburg	1,948	0.21	0.25	**X**	**X**			
Hübner	University of Hannover	2,122	0.32	0.18	**X**	**X**			
FhG-ISE	Applied University of Biberach, FhG-	13,150	0.43	0.21	**X**	**X**			
DB Netz	Technical University of Karlsruhe	5,974	0.57	0.24	**X**	**X**			
FH BRS	University of Dortmund	26,987	0.42	0.34	**X**	**X**			
GIT	University of Siegen	3,243	0.36	0.27	**X**	**X**			
Lamparter	Applied University of Stuttgart	1,000	0.30	0.28	**X**	**X**			
NIZ	Technical University of Braunschweig	8,570	0.63	0.20	**X**				
Surtec	University of Darm-stadt, Passive House	4,423	0.27	0.34	**X**	**X**			
ZUB	University of Kassel	1,732	0.32	0.21		**X**	**X**		
Pollmeier	ZUB, Kassel	3,510	0.29	0.33	**X**				

Solvis	Applied University of Braunschweig	8,215	0.61	0.17	**X**				
KfW	Technical University of Karlsruhe	8,585	0.54	0.15	**X**				
Energieforu m	Technical University of Braunschweig	20,693	0.69	0.17	**X**			**X**	
Energon	Applied University of Ulm	6,911	-	0.23			**X**	**X**	
TMZ	Applied University of Erfurt	8,976	-	0.42			**X**		
BOB	Applied University of Cologne	2,072	0.48	0.25			**X**	**X**	
GMS	Applied University of Biberach	10,650	0.43	0.24			**X**		
Lebenshilfe	Technical University of Munich	4,623	0.38	0.24	**X**		**X**		
UBA	Technical University of Cottbus	32,384	-		**X**	**X**			
SIC	Applied University of Offenburg	13,833	0.74	0.23	**X**			**X**	
Ritter	Technical University of Karlsruhe	3,232	0.49	0.54				**X**	
DVZ Barnim	Technical University of Cottbus	19,399	0.43	0.3	**X**			**X**	
Regionshaus	Institut für Gebäude- und Solartechnik, TU	7,222	-	0.30				**X**	

Tab. 2 Internal heat gains detected in selected projects. Numbers refer to Wh per m² office floor area and day. Data source: Monitoring teams

	Total	persons	equipment	lighting
Wagner	100	24	66	10
DB Netz	141	30	79	32
Lamparter	100	40	-	-
FhG ISE	188	53	125	10
Pollmeier	92	21	50	21

Most of the projects realized in an early starting period of the funding programme applied night ventilation in combination with earth-to-air heat exchangers to **remove excess heat** in summer; several of the more recent projects have applied slab cooling in concert with vertical ground ducts or ground pillars due to the increased cooling capacity. For mechanical and hybrid night ventilation COPs between 4.5 and 14 have been monitored which are higher than those of conventional cooling but also show the need for quality assurance during the design phase and in building commissioning. The evaluated earth-to-air heat exchangers achieved COPs between 20 and 280.

Within the framework of EnBau:MONITOR the passive cooling concepts were evaluated regarding to the achieved thermal comfort. Thus, standardized graphs had been provided as part of the accompanying research in order to allow the comparison of results on summer indoor conditions between different projects.

Fig. 7 illustrates the results using annual cumulative frequency distributions for the indoor air temperature. If the upper limit of 25 °C according to DIN 1946-2, old edition, is taken as a reference, the buildings demonstrate that the frequency of higher temperatures can be kept below 10 % of the usual working hours with suitable passive cooling measures of building design strategies.

Nevertheless this consideration does not indicate whether an acceptable thermal comfort was achieved in the buildings or not. The main disadvantage of a cumulative frequency distribution analysis for thermal comfort is the information loss on the correlation between indoor temperature and real time outdoor temperatures monitored. Four different comfort criteria, ISO 7730 according to Fanger, the proposal for the European standard prEN15251, the former DIN 1946 and the new Dutch NPR-CR 1752 have been used to analyze comparative building comfort performances. For detailed discussion on these criteria see (Pfafferott 2006).

As an example for this evaluation, in **Fig. 8** the indoor temperature data of the Pollmeier building are sorted by the outdoor temperature (Herkel, 2005). Hourly room temperature data are plotted against a floating mean outdoor temperature of the last three days. Using different comfort criteria leads to different ratings regarding the achieved comfort. If a 90 % satisfaction of the user is requested, the range of violation of the comfort criteria during working hours is between 4-10 % (ISO 7730) down to 0-2 % (NPR-CR 1752)(**Fig. 9**). It is noted here is that if extreme meteorological conditions are given like in summer 2003 these buildings are upon their capacity limits of thermal comfort. The results show strongly the need for common design criteria regarding indoor comfort in the European framework.

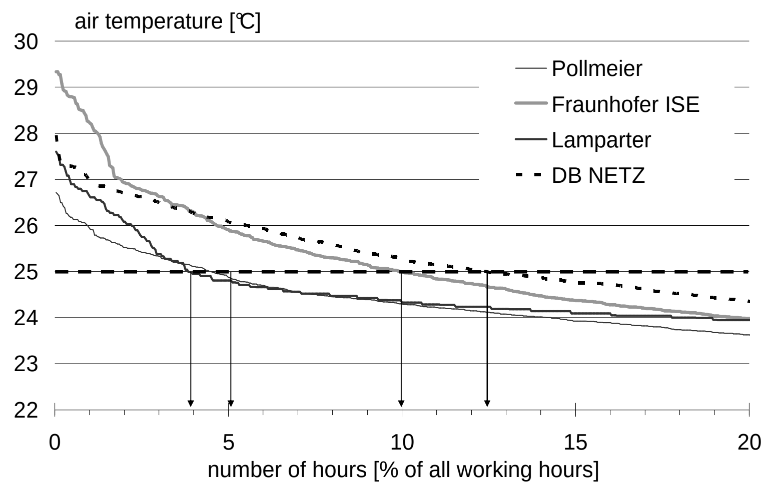


Fig. 8 Cumulative frequency distributions for the hourly average temperatures in the offices of four selected buildings.

The temperature limit of 25 °C according to DIN 4108 is exceeded for 4 % (Lamparter), 4.5 % (Pollmeier), 9.5 % (FhG-ISE) and 12.5 % (DB) and of the working hours 8:00 to 17:00 during the course of one year, 2400 h/a. Due to the type and position of the temperature sensors, the values quoted for the Lamparter building represent indoor air temperatures, whereas the values for the other projects provide corresponding operative temperatures. The meteorological boundary conditions differ between the buildings due to their different locations (e.g. maximum outdoor temperature FhG-ISE: 37 °C, Lamparter: 36 °C, DB: 34 °C, Pollmeier: 35 °C).

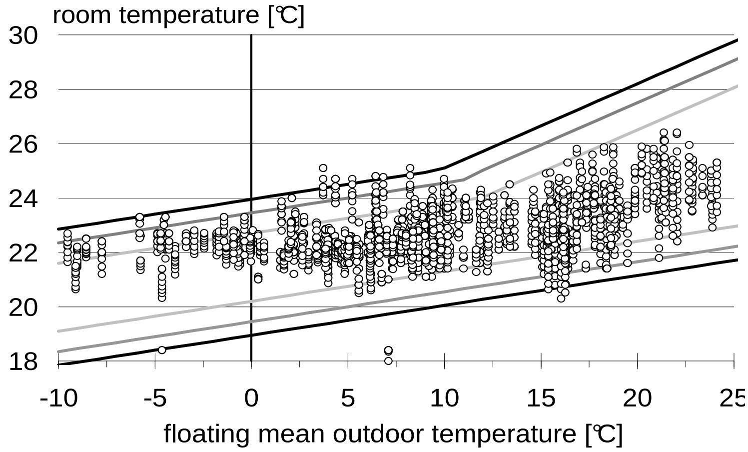


Fig. 9 Analysis of hourly data on temperature monitored in the Pollmeier open space office building in 2002

The lines mark the boundaries of the so-called class A, B, C buildings according to the Dutch guideline NPR-CR 1752 (Raue, 2004) considering the thermal adaptation. The Pollmeier building (passive cooling using night ventilation) mainly meets the strict class-A-criteria for high ambient air temperatures (above 20°C) according to the guideline.

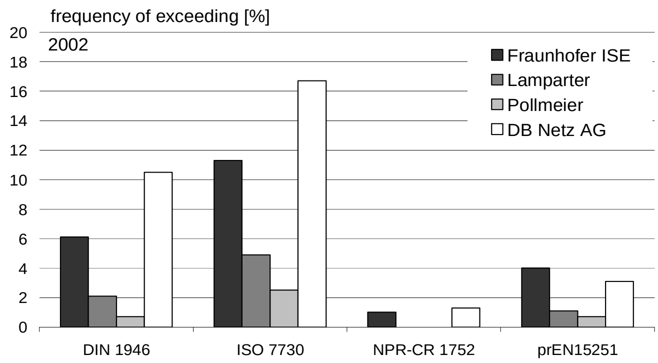


Fig. 10 Comfort analysis of four buildings in 2002

Each building is not only performing differently for the four used comfort criteria: It is a basic assumption, that the criteria should qualitatively yield the same conclusion: If a building is better than another in criterion A, it is also better in criteria B, C and D. Nevertheless, the comfort criteria can give different quantitative numbers for comfort, since the criteria are based on different studies, databases and assumptions: Criterion A can be exceeded by 5 % while criterion B is only exceeded by 2 % of all working hours.

3 Discussion and Conclusions

The results of the monitored buildings show, that the energy consumption of new office buildings can be reduced by 50 % compared to the building stock without enhancing building construction costs compared to the average. The limitation of a primary energy consumption of 100 kWh/m²a and even lower is possible.

Future building concepts will focus on the goal of achieving zero energy demand on an annual base, first buildings within the program EnOB already showed the possibility of such concepts combining a low energy demand with a renewable energy supply.

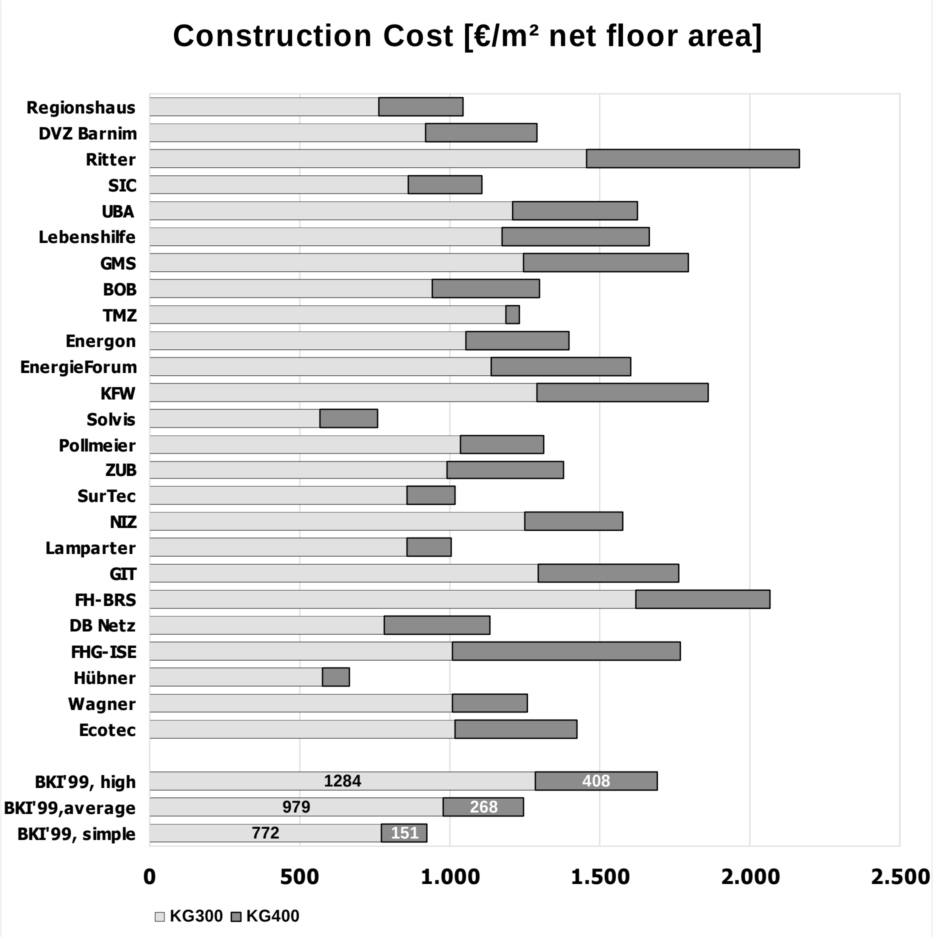


Fig. 11 Consideration of Construction Cost.

The results of the passively cooled low-energy office buildings provide a high thermal comfort even without mechanical cooling or air-conditioning, when the heat dissipation in summer is enhanced by e.g. thermally activated building components or night ventilation. The evaluation of passively cooled office buildings demonstrates that during a commonly hot summer such as 2003 prevalent criteria for thermal comfort in naturally ventilated buildings (i.e. prEN 15251) are exceeded for less than 5 % of the building operation time – considering realistic user behaviour.

The demonstration projects have lined up with the purpose to achieve long term energy-savings and cost-effectiveness during building operation. They also show that high performance buildings can be realized to normal market conditions are. Finally it is important that there is a balance between architectural quality and the comfort, the "right" cost-consciousness of builder-owners and a certain flexibility in dealing with the costs during building design phase and construction (cost shifting).

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