FIELD STATION OF THE NATIONAL PARK ACADEMY IN PETRONELL, AUSTRIA: A CASE STUDY OF EVOLVING THERMAL PERFORMANCE EXPECTATIONS

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ABSTRACT

Sustainability in the construction sector is increasing in importance. Due to a number of factors such as energy resource limitations and increasing occupancy expectations, the thermal performance standards concerning buildings are becoming stricter. In this context, it would be useful to document in practice, to which extent such developments in the standardization domain have affected the actual performance of buildings. The present contribution describes a research effort toward documentation of the evolving thermal performance of a specific building's refurbishment in Petronell, Austria. Subsequently, solar-thermal collectors and photovoltaic elements were added to explore the potential for utilizing renewable energy sources. In 2011, a new effort was initiated to capture the actual thermal performance of the building and its various components and systems in a structured and systematic manner. Thereby, a monitoring system was installed to collect data concerning indoor climatic conditions, user behavior and energy consumption. To put the performance of the building in the pertinent microclimatic context, a weather station was installed on the building. The collected results facilitate the treatment of a number of salient questions: Has the thermal retrofit of the building resulted in the expected performance improvement? How do previous standards compare to the currently valid thermal codes and requirements? What would be the potential of further improvement in building's energy efficiency if the implications of occupants' habits and behavior are considered? What is the actual output of the installed renewable energy harnessing systems? What lessons from the present monitoring exercise can be learned and applied to the context of other building projects? The paper concludes with a summary of the existing and necessary answers to these questions.

Key words : thermal performance, monitoring, thermal retrofit

1. INTRODUCTION

Buildings are suggested to be responsible for about 40 % of the world's whole energy demand (IEA 2012). In the last decades many attempts have been made toward energy use reduction. New technologies have been developed to increase the use of renewable energy resources. Numerous buildings have been planned and equipped with such technologies. The present study deals with a building (referred to, hereafter, as NAT) after its refurbishment in 1996. It was planned according to newest energy standards at that time. This building was selected as a case in point in view of comprehensive performance monitoring approaches.

2. MOTIVATION AND BACKGROUND

2.1. Motivation

In 1980, Austrian federal estates agreed to minimize energy demand for building structures. The European Union requires all member states to create an energy certificate for new buildings (EPBD 2011). Additionally, building performance requirements were tightened both for new buildings and building refurbishments. Buildings constructed before 1900 are estimated to have an U-value (building envelope) of 1.6 $W.m^{-2}.K^{-1}$. In the 1960s, constructions were required to have U-values of 1.2 $W.m^{-2}.K^{-1}$ (OIB LF6 2011). The refurbishment of the aforementioned case study building in 1996 targeted with layers of plaster, 25 cm bricks and 14 cm special cork insulation boards, a value of 0.25 $W.m^{-2}.K^{-1}$. These changes of guidelines and requirements prompt several questions: What is the magnitude of saved energy (if there is a saving)? How can we measure this energy saving? Are there any further impacts on buildings, people or the environment?
Figure 1 includes visual material pertaining to NAT before and after the renovation.

Figure 1. From left clockwise, NAT sketch (areal view), facade (before renovation), courtyard (before renovation), courtyard (after renovation), facade (after renovation); pictures: Lötsch, Deubner

2.2. Background

The case study building NAT is located in Petronell, Lower Austria, 50 km east of Vienna. In 1996 it was renovated (see Figures 2 and 3). The goal was to realize a building that performs better than the minimum energy standards of the time. Furthermore, the owner intended to use renewable, eco-sensitive products (to be obtained – to the extent possible – from the near vicinity of the building site). Prior to the refurbishment, the building's function was combined residential and commercial. Since completion of the renovation, the building houses the "Nationalpark - Akademie" of the Vienna Museum of Natural History. NAT serves educational, administrative, and short-term residential functions. The new construction mainly uses natural and regional products, with the exception of the insulation material (a high-performance cork product) for walls, roofs and floors, which was not produced in Austria, but was imported from Spain. Electricity demands are covered in part by roof-mounted photovoltaic panels. When solar radiation is not sufficient, the electricity from grid is used. Solar collectors provide energy for room heating and domestic hot water. The heating system is also supported by a wood-pellet burner. To reduce heat losses through building elements, very low U-values were targeted.

Given this context, it would be interesting to find out how the building has performed since 1996 and is performing today. Thereby, changes in standards and guidelines are to be examined. Can NAT still be considered an energy efficient and ecologically sustainable building?

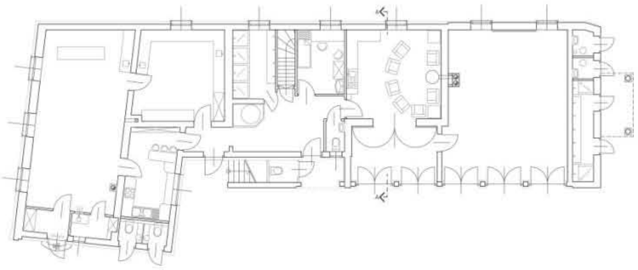

Figure 2. Ground floor (NAT), plan: Deubner

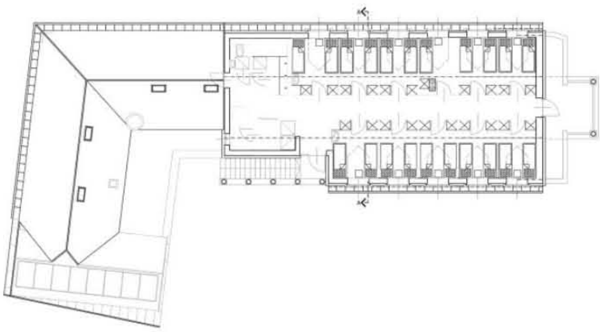

Figure 3. First floor (NAT), plan: Deubner

3. METHODOLOGY

3.1. Historical data acquisition

To evaluate the energy performance of the building in the time before the installation of a monitoring system, we need "historical" data. In this case study, information from various sources were obtained. Documented quantities of deployed pellets were considered as well. Table 1 provides an overview of the different data sources.

Table 1. Historical data acquisition

Information	Period	Remarks
Pellet consumption	2006 - 2012	Handwritten list, partly incomplete, approximate values
Weather data	1982 - 2012	Data from weather station in Seibersdorf (30 km west of Petronell), gaps in data
Occupancy	1996 - 2012	General information based on NAT's administration

3.2. Monitored data

For detailed analysis of energy use, occupancy, and energy gains of the renewable energy-systems, a monitoring system was installed in NAT in March 2012. Several sensors regularly collect data and send it to a database. Data is stored and provided via MOST-system, a toolkit for building monitoring, data processing, and visualization (Zach et al. 2012). Table 2 illustrates the measurements and devices applied in the building.

Table 2. Installed sensor types in the case study project

Sensor type	Unit	Information
CO_2	ppm	Carbon dioxide concentration
Contact	boolean	Opening/closing of windows/doors
Electricity meter	Wh	Electricity use
Illuminance	lx	Light levels
Occupancy	boolean	Presence of people
Compact heat meter	Wh	Heating energy
Relative humidity	%	Relative humidity in a specific location
Compact heat meter	MWh	Solar energy
Temperature	°C	Indoor air temperature of a certain area
Flow meter	l/h	Water usage

The building can be functionally divided into nine different zones with individual characteristics concerning temperature, occupancy, and user behavior. In Table 3 the zones and their size are summarized.

Table 3. Zones in NAT

Zones	Office	Kitchen	Bed-room	Cellar	Corridor
Areas [m²]	36.7	12.5	89.4	114.9	40.8
Zones	Bath-room	Ancillary	Stair-case	Storage	
Areas [m²]	17.3	19.2	2.9	22.4	

Energy certificate

In Austria, one of the main energy performance indicators for buildings is the heating demand per year and m² gross area. This is mainly dependent on geometry, construction, and the local climate. The calculation for the energy certificate was conducted with the software tool ArchiPhysik 10 (A-Null 2012), which incorporates applicable standards. The calculation was executed for seven scenarios (see Table 4). Each scenario corresponds to different qualities of the thermal envelope (U-Values). These are: "Prior to refurbishment", "Minimum requirements of 1988" (OIB LF6 2011), "Refurbishment (1994-96)" (OIB LF6 2011), "Minimum requirements of 1996" (OIB LF6 2011), "Minimum requirements of 2012" (OIB RL6 2011), "Passivhaus building components" (without and with controlled ventilation) (Energiesparen 2012).

Table 4. Heat transfer (U-values) of building elements of NAT in [$W.m^{-2}.K^{-1}$]

Building element	Prior to refurbishment	Min. req. of 1988	Refurbishment (1994-1996)	Min. req. of 1996	Min. req of 2012	Passivhaus
Outside wall	1.50	0.50	0.25	0.40	0.35	0.15
Window	2.50	2.50	1.30	1.80	1.40	0.80
Floor adjacent ground	1.20	0.70	0.28	0.50	0.40	0.12
Roof	0.60	0.25	0.40	0.22	0.20	0.10

4. RESULTS AND DISCUSSION

4.1. Energy certificate

The development of U-values and calculated heating demand is summarized in Table 5 for all seven scenarios. The results of the energy certificates' calculations (heating demand) are also depicted in Figure 4. Note that the mean U-value of NAT as targeted in the refurbishment of 1994-1996 was lower than the applicable requirement of the time.

Table 5. Heating demand and mean U-values for the scenarios

Scenarios	Year	Heating demand [$kWh.m^{-2}.a^{-1}$]	mean U-value [$W.m^{-2}.K^{-1}$]
A	Prior to refurbishment	136.00	1.58
B	Min. req. of 1988	88.02	0.51
C	**Refurbishment (1994-1996)**	66.93	0.41
D	Min. req. of 1996	66.22	0.41
E	Min. req of 2012	54.46	0.35
F	Passive house without ventilation	21.47	0.19
G	Passive house with ventilation	9.19	0.19

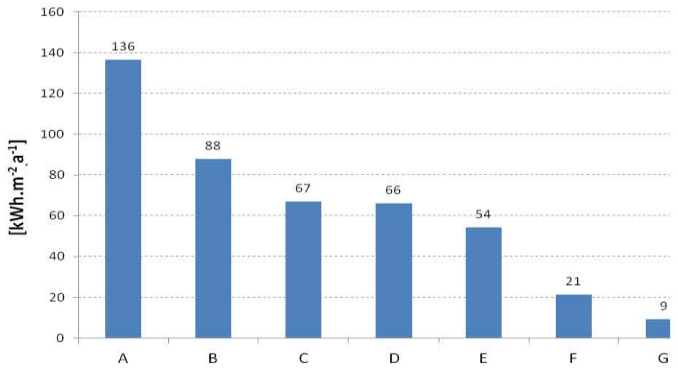

Figure 4. Comparison of seven different energy certificates for NAT according to the applicable requirements at the respective time period

In comparison to the state prior to the refurbishment (136 $kWh.m^{-2}.a^{-1}$), the calculated heating demand was 51% after completion (67 $kWh.m^{-2}.a^{-1}$). Virtually implementing today's minimum requirements would reduce the heating demand to 54 $kWh.m^{-2}.a^{-1}$ (39% of the value "prior to refurbishment"). The planning of the refurbishment (starting in 1994) exceeded the demands of 1988 and fulfilled the demands of 1996. The Passivhaus scenario would reduce the heating demand down to 21 respectively 9 $kWh.m^{-2}.a^{-1}$ (depending on the use of a controlled ventilation system with heat recovery).

These results demonstrate that the refurbishment intention (generating an energy efficient construction) was on target for its time. However, considering today's expectations towards low energy buildings, the heating demand is not low enough. It has to be mentioned that heating demand does not take into account the ecological performance of used building materials. Given the use of cork as insulating material, such an indicator would possibly yield a favorable evaluation. Hence, NAT could be seen as a progressive instance of low energy buildings of the 1990s. Its development could still provide lessons for today's building planning.

4.2. Energy use records

4.2.1. Pellets

In the period of 2007 to 2011, NAT's annual heating energy use is between 15225 and 23428 kWh per year (Table 6). For this period, the highest heating demand was recorded in 2010, the year with the highest heating degree days. Concentrating on monthly values, January and February show higher energy use. In August the burner is switched off. The usual summer period without any heating is assumed to be from April to November. The heating is switched on only on demand (Figure 5, Table 6).

Table 6. Heating demand, heating degree days, and solar gains for 2007 – 2011

Year	Heating energy use (pellets) [kWh]	Heating degree days [Kd]	solar heat gains [kWh]
2007	17 491	2887	6 309
2008	15 225	2933	n. a.
2009	17 346	2946	n. a.
2010	23 428	3437	n. a.
2011	21 004	3083	11 323

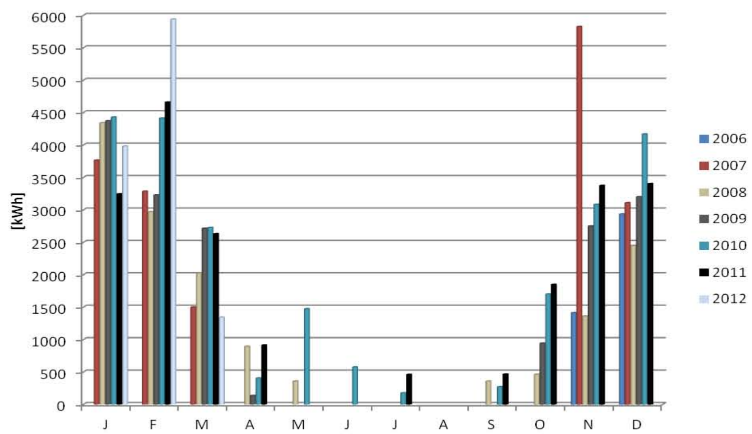

Figure 5. Mean heating demand (2006-2012) per month (pellets) in [kWh]

4.2.2. Solar gains

Given the few data available, the period from April to September is the most productive in terms of solar gains, while the gains during the winter months December and January are very low (see Table 6). In Figure 6, mean monthly heating energy use is compared with solar gains

Table 7. Mean monthly heating energy use (2006 – 2011) and solar gains (2007, 2011); mean monthly outdoor temperature

	Mean monthly energy use [kWh]	**Mean solar gains** [kWh]	**Mean outdoor temperature (Seibersdorf)** [°C]		
			2007	**2010**	**2011**
Jan	4024	50	5.42	-2.22	0.41
Feb	4084	307	5.32	0.72	0.18
Mar	2157	948	7.56	5.99	6.11
Apr	587	1633	12.58	10.43	12.88
May	916	1380	17.54	14.33	15.68
Jun	576	1292	20.70	18.70	19.60
Jul	319	1200	21.49	22.40	19.51
Aug	n. a.	1359	20.16	19.34	21.06
Sep	365	1655	13.87	14.44	17.92
Oct	1239	782	8.88	7.78	9.86
Nov	2968	274	4.02	7.06	3.19
Dec	3211	48	0.31	-3.18	3.09

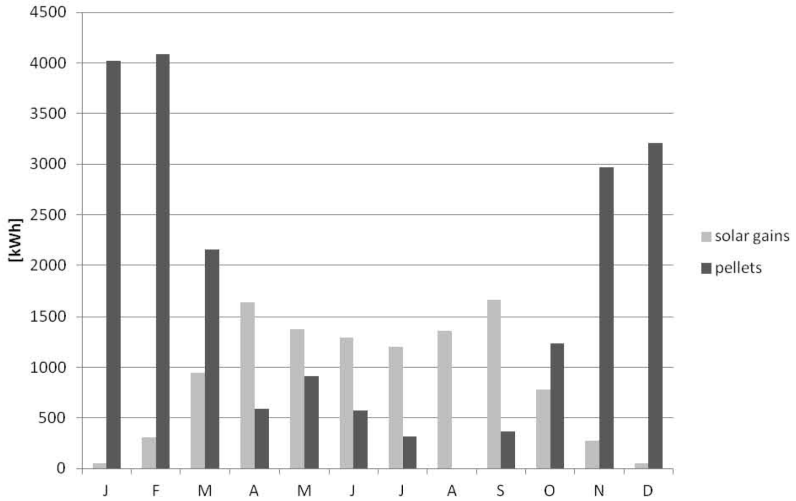

Figure 6. Comparison of mean monthly heating demand and solar gains (2006, 2007, 2011, 2012)

4.2.3. Climate

Figures 7 to 9 provide data on solar radiation and outdoor temperature for the NAT location (Seibersdorf weather station). Despite multiple gaps and inconsistencies in the available microclimatic data, certain tendencies can be extracted from the data. For instance, both heating energy use and solar energy gains can be shown to be consistent with microclimatic information.

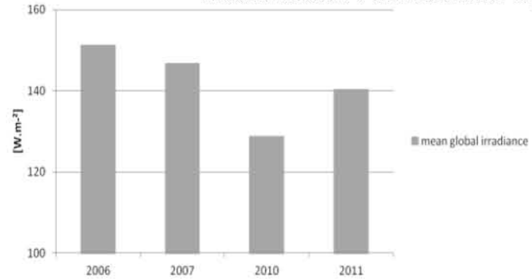

Figure 7. Mean global irradiance for 2006, 2007, 2010, and 2011 in W.m^{-2}

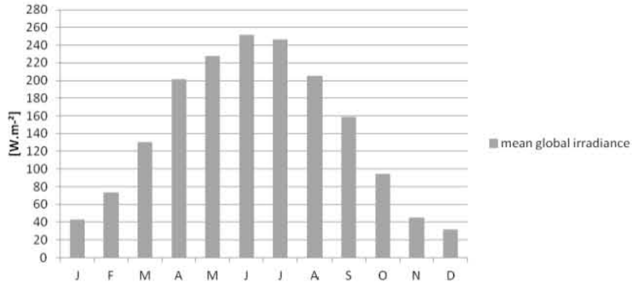

Figure 8. Mean monthly global irradiance and outdoor air temperature (2007, 2010)

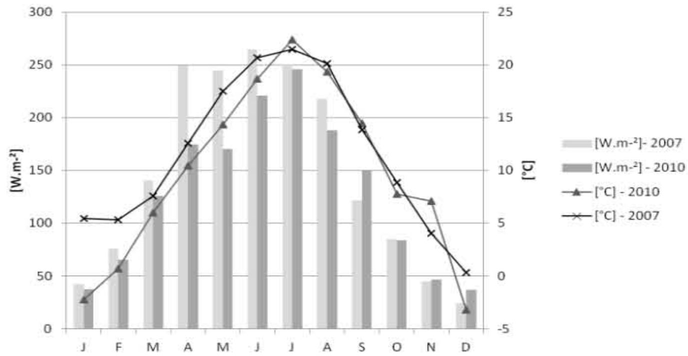

Figure 9. Mean monthly global irradiance (over the years 2006, 2007, 2010, 2011)

4.3. Ongoing monitoring

4.3.1. Heating

From April 2012 onwards, the energy use of the heating system is monitored on a continuous basis. April was the last month of the heating period, before the burner was switched off. In this month, the heating energy use was measured as 321 kWh for the whole building. The monitoring system gives the option of determining the exact working hours of the pellet burner. With the newly installed monitoring system, it is possible to estimate the energy delivered via the floor heating systems not only as a whole, but also in terms of individual zones. Hence, it becomes possible to state which zone or part of the building requires which amount of energy at which time.

4.3.2. Solar gains

Metering the solar gains started in June 2012. The total gain measured in June and July was 1568 and 1468 MWh respectively. On an average day in June, the solar collectors produced 52.3 MWh, in July 56.5 MWh. The maximum gain was measured end of June with a daily value of 102 MWh. Regarding solar gain, the most productive hours during the day were found to be between 9 am and 1 pm.

4.3.3. Thermal comfort

Beside internal CO_2 concentration and relative humidity, the temperature was analyzed in comparison to outdoor conditions. Figure 10 and 11 show internal and external temperatures for one month in winter and in summer (February and July) in 2012. In February the mean indoor air temperature was around 20°C while the outside air varied between -10 °C and +10 °C. Regarding the summer period, there is not much difference between inside and outside temperature (in average 25 °C). During the winter period, an indoor temperature of 20 °C is maintained using the pellets burner.

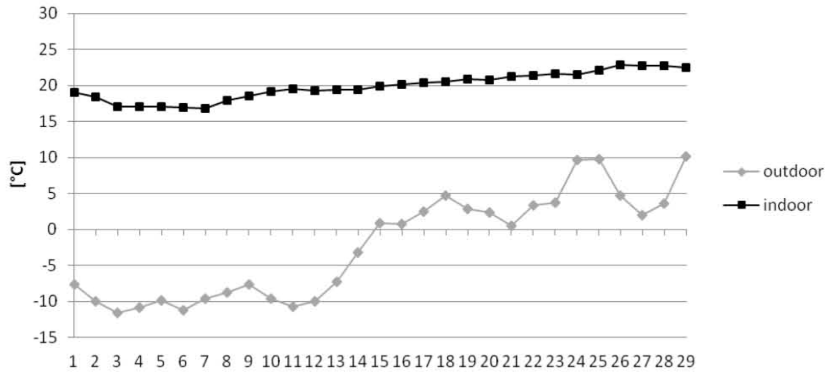

Figure 10. Daily mean outdoor and indoor temperature in February 2

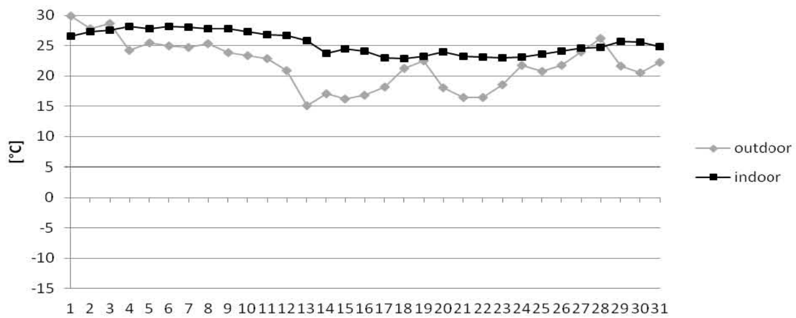

Figure 11. Daily mean outdoor and indoor temperature in July 2012

5. CONCLUSION AND FUTURE RESEARCH

The NAT case study illustrates the possibility to construct, following the guidelines, an energy efficient building that deploys regional – ecologically advantageous – products and incorporates systems to harness renewable energy. With regard to today's energy standards, NAT could be placed in medium level performance category. Given the newly installed comprehensive monitoring system, further potential for energy efficiency and indoor climate improvement can be detected and exploited. The monitoring system in NAT offers various analyses opportunities. Not all capabilities of this system have been exploited so far. The ongoing research shall further capture this building's performance in detail. Moreover, we shall use the monitored data for calibrating simulation models in order to further analyze and interpret the building's actual energy and indoor environmental performance, demonstrated in the context of microclimatic dynamics and user behavior. Moreover, the solar gains and electrical energy generation shall be analyzed to obtain data that would not only benefit system performance in NAT, but also installation and operation methods for future projects.

ACKNOWLEDGEMENT

The authors would like to acknowledge the support of Professor Bernd Lötsch and Dr. Claudia Roson toward conducting the project presented in this paper. We would also like to thank Architecture Atelier Deubner (Vienna, Austria) for providing us with plan documentation on the case study building.

REFERENCE

A-Null 2012, A-Null Bauphysik GmbH, Product Archiphysik V10.

IEA 2012, International Energy Agency, http://www.iea.org/aboutus/faqs/energyefficiency/ (last call: 4. Oct. 2012)

EPBD, Energy Performance of Buildings, http://www.epbd-ca.eu/ (last call: 2 Sept. 2012)

OIB LF 6, Österreichisches Institut für Bautechnik, 2011, http://www.oib.or.at/LF6_301211%20Revision.pdf (last call: 2 Sept. 2012)

OIB RL 6, Österreichisches Institut für Bautechnik, 2011, http://www.oib.or.at/RL6_061011.pdf (last call: 2 Sept. 2012)

Energiesparenimhaushalt.de, 2012, http://www.energiesparen-im-haushalt.de/energie/bauen-und-modernisieren/hausbau-regenerative-energie/energiebewusst-bauen-wohnen/waermedaemmung-hausbau/waermedaemmung-k-wert.html

(last call: 2 Sept. 2012)

Zach, R., Glawischnig, S., Hönisch, M., Appel, R. and Mahdavi, A. 2012. MOST: An open-source, vendor and technology independent toolkit for building monitoring, data preprocessing, and visualization. eWork and eBusiness in Architecture, Engineering and Construction - Gudnason & Scherer (Eds) © 2012 Taylor & Francis Group, London, ISBN 978-0-415-62128-1

Lötsch, B., Deubner, H.1999. Nationalparkakademie des Naturhistorischen Museums, Das Ökohaus - Nationalparkhaus der Jugend, Petronell

Deubner, H., Atelier für naturnahes Bauen Deubner