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Performance analysis of commercial buildings—Results and experiences from the German demonstration program 'Energy Optimized Building (EnOB)'

Andreas Wagner[a,*], Thomas Lützkendorf[b], Karsten Voss[c], Guido Spars[d], Anton Maas[e], Sebastian Herkel[f]

[a] Building Science, Karlsruhe Institute of Technology, Karlsruhe, Germany
[b] Sustainable Management of Housing and Real Estate, Karlsruhe Institute of Technology, Karlsruhe, Germany
[c] Building Science, University of Wuppertal, Wuppertal, Germany
[d] Economy of Planning and Building, University of Wuppertal, Wuppertal, Germany
[e] Building Physics, University of Kassel, Kassel, Germany
[f] Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany

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ABSTRACT

With the objective of monitoring and building performance analysis the German research initiative 'Research for Energy Optimized Building (EnOB)' has funded more than 70 buildings so far. The buildings comprise a large variety of new as well as refurbished examples of building types in the residential and commercial sectors. An important feature of all buildings was the integration of energy efficiency technologies into the architectural concept. The focus of this paper is on performance evaluation of non-residential buildings, mostly office buildings, which are characterized by passive cooling strategies. The monitoring revealed very low total site energy consumptions outperforming the reference values in the German building code by far. First approaches for net zero energy concepts were investigated as well. A thorough analysis showed that the investment costs of energy-efficient buildings were in the same range as the costs of conventional buildings. Surveys in the buildings discovered that high energy efficiency does not necessarily coincide with higher occupant satisfaction. A significant correlation was found between indoor temperature and air quality and the occupants' possibilities to control them individually.

1. Introduction

Within the program 'Research for Energy Optimized Building (EnOB[1])', the German Federal Ministry of Economics and Technology (BMWi) has been supporting the planning, construction and monitoring of demonstration buildings since 1995 as part of Germany's energy research program. Main objectives are an accelerated implementation of innovative, energy-efficient building technologies in practice and their scientific investigation in a real-life context. Different funding areas for demonstration projects range from single buildings (EnOB, EnEff:Schule) to urban districts (EnEff:Stadt) considering new buildings (EnBau) as well as refurbishments (EnSan) through a variety of building types; further lines focus on energy performance optimization (EnBop) and heat infrastructures (EnEff:Wärme). The continuity of the funding program over a period of more than 15 years emphasizes the importance which is associated with the building sector within the national German energy concept and energy research program [1].

To date, 53 individual buildings have been monitored and evaluated in EnOB for at least two years while a further 23 buildings are presently being planned, built or monitored. Three of them received the highest rating of the German certificate for sustainable buildings (golden DGNB certificate). The majority of new buildings investigated are used as offices or administration buildings, whereas renovations can be predominantly found in the residential sector. The spectrum is currently widened in order to encourage the application of new concepts and technologies. Museums, swimming pools, supermarkets and hospitals represent new categories. Detailed information on each project is provided on the project website http://www.enob.info/ together with cross-sectional analyses on various topics. This paper focuses on the performance evaluation of non-residential buildings, mostly office buildings, which are characterized by passive cooling strategies.

* Corresponding author. Tel.: +49 721 60846511; fax: +49 721 60846092.
E-mail address: wagner@kit.edu (A. Wagner).
[1] See glossary at the end for all acronyms used in this paper.

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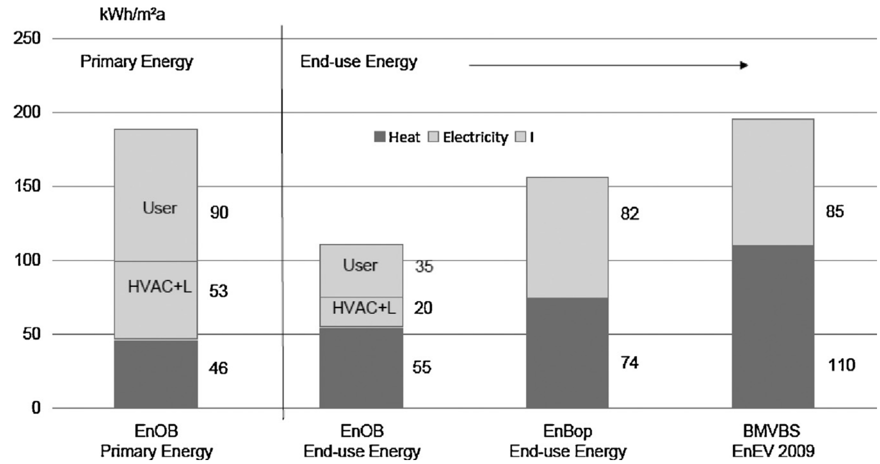

Fig. 1. Energy consumption for 12 selected EnOB office buildings (end-use energy and primary energy) compared to data from consumption-based energy certificates according to the actual German Energy Conservation Regulation EnEV 2009 [4] and from a cross-sectional analysis of 30 recently built modern office buildings according to an evaluation within EnBop. User related electricity consumption includes IT and all other appliances for office work.

2. Energy performance

Detailed analysis of energy monitoring and indoor climate data is a fundamental component of all demonstration projects. Fig. 1 exemplary shows the average energy consumption for selected office and administration buildings and its distribution among energy for heating and electricity.[2] Electricity comprises energy for ventilation, cooling/air-conditioning and lighting. Primary energy consumption for this representation was calculated by multiplying the metered quantities of each energy carrier (electricity, gas, wood chips etc.) with a primary energy factor which is given in the German standard DIN V 18599, Part 1 [3]. E.g. the actual primary energy factor for electricity in Germany is 2.6 due to the current mix from different utilities and renewable sources. Credits from building-integrated PV systems are not considered in the shown data.

The heating energy consumption amounted to 56.3 kWh/(m^2 a), the electricity consumption for lighting was 6.8 kWh/(m^2 a). Including the electricity consumption directly related to the buildings' occupants (computers, office equipment and other appliances), the average end-use energy consumption with a value of 110 kWh/(m^2 a) outperformed the reference value for consumption-based energy certificates according to the actual German building code by 45% [4]. The large effect of the usage-specific electricity consumption which counteracts energy savings on the building design and technical building services side, has to be considered more seriously in future building energy consumption assessment. More than 30% of the end-use energy and almost half of the primary energy consumed in the EnOB buildings are allocated to this consumption category. The emission of greenhouse gases (CO_2 equivalents) is about 37 kg/(m^2 a) and is dominated by the share of 76% related to electricity consumption. For this reason, not only improved efficiency but also CO_2-neutral generation of electricity is very important to achieve climatically neutral buildings.

3. Economic evaluation

Apart from solutions to technical problems and tasks relating to planning, construction and technical operation, an essential prerequisite for wider dissemination of energy-efficient buildings is proof of their economic viability. Therefore, real building project costs of ten EnOB buildings from which consistent data were available have been analyzed and compared to the average costs for conventional buildings of the same type and usage by conversion to a common price level. The result for newly built office and administration buildings was that high-quality energy concepts corresponding to the current EnOB goals can be achieved either for the same costs as conventional buildings or with additional investment costs of less than 5%.

Additionally, operational costs have been analyzed for another 15 buildings with available data (10 new and 5 renovated buildings) in order to assess total life-cycle costs [5,6]. Initial results indicate that lower building-specific energy costs can be identified. They are significantly below the coefficients which are widely used in the real-estate sector to estimate the anticipated energy costs during early planning phases (see Fig. 2, left). If no measured data are available, estimated or calculated building-specific end-use energy consumption (differentiated according to type of end-use energy) will provide a more reliable basis for life-cycle cost analysis.

Initial evaluation of maintenance costs in energy-efficient buildings shows that these do not have to be higher than those for comparable conventional buildings, although the technical building services are more complex (Fig. 2, right). As there is a lack of suitable data or reliable approaches to estimate repair and maintenance costs for a specific building in an early stage of planning, maintenance and repair contracts for its technical services will be analyzed more thoroughly in future.

4. Occupant satisfaction

Apart from energy-related and economic coefficients, occupant satisfaction is a decisive factor in assessing the building performance. A cross-sectional investigation addressed questions concerning the acceptability of buildings and indoor climate concepts to the occupants in real-life operation and the influences which were significant for occupant satisfaction. A total of almost 3800 data sets from 38 buildings in which an allowance for surveys could be acquired were available for analysis. They divide up into 15 office buildings built in the conventional way (construction dates 1900–2004) and 23 new and refurbished buildings complying with the "EnOB standard" (built in 1999 or later).

With regard to indoor climate parameters, the "EnOB standard" does not necessarily perform better. In particular, the indoor temperature and air quality in summer are judged to be poorer in some

[2] In contrast to the German Energy Regulation for Buildings [2] all values presented in this paper refer to the net heated floor area and exclude non-heated spaces.