ENERGY EFFICIENCY IN THE CONTEXT OF THE OVERALL BUILDING PERFORMANCE

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Summary

The building sector has a very important role with regard to protecting resources and the environment under the framework of sustainable development. Energy efficiency in building design, construction and operation is one major issue to proceed in this direction. However, there is a tendency to understand energy efficiency to a large extend as energy saving only. In this paper it is shown that energy efficiency in buildings has to be an integral part of an overall building performance assessment.

Keywords: Energy efficiency, sustainability, occupant satisfaction, building performance

1 Introduction

The planning, construction and operation of buildings has a significant influence on sustainable development due to the interactions with society, environment and economy. For this reason, economic, ecological and social effects must be recorded and assessed for all decisions in the life cycle of real estate, besides questions regarding compliance with functional- and technical requirements. Assessing a single structure's contribution to sustainable development is therefore very complex. Besides resource utilisation and the effects on the global and local environment and also the life cycle costs and value performance among other things, it comprises of creative and urban quality as well as the comfort and safety of users and residents. The performance of the building that is to be planned, realised and subsequently maintained and continuously improved, presupposes high-quality planning, implementation and management

With regard to energy transition, people in politics, science, industry and society are presently discussing the requirements for the further improvement of energy efficiency intensively. They are focused on a significant partial aspect of it, which initially contributes to resource conservation and climate protection. But energy efficiency is more than just energy conservation. While in the past energy efficiency was often viewed within the confines of energy expenditure, the aspects of stipulated and achievable use in the form of health and comfort must be taken into consideration more intensely in the future. In the sense of achieving an ideal ratio between effort and utilisation, this initially concerns the formulation of appropriate user requirements, which will ultimately be realised with a minimum of primary energy and resulting environmental pollution. This addresses a multitude of aspects, for example the resource utilisation and environmental pollution with regard to the manufacture and maintenance of components and technical systems, the construction- and usage costs, the health and satisfaction of the users as well as the design quality. It becomes clear that on one hand sustainability cannot be reduced to aiming for energy efficiency, and on the other hand that energy efficiency has a direct connection to all partial aspects and dimensions of sustainability issues. This is where building physics can make a significant contribution – the pathway to influence and assessment of buildings energy efficiency to the participation on planning design and sustainability assessment of real estate is wide open.

1.1 Energy efficiency subject to change of perception

In connection with topics such as energy efficiency and sustainability, the disciplines of building physics play an important and indispensable role. By examination of topics like energy conservation and thermal insulation, noise insulation and room acoustics, indoor air quality and hygiene, building climatology, humidity protection and visual comfort, the results of building-physical considerations and concepts, among other things the influence on material selection, take on the design and usage of buildings. Construction defects and building damage can be avoided and the durability and reliability of constructions can be strengthened. Finally, it also closely relates to economic issues – from the influence of construction – and usage costs to depreciation and the building's value trend.

The contribution of building physics to thermal insulation should thereby, besides traditional functions of building protection, hygiene and the thermal comfort in the winter and summer, increasingly serve energy conservation as a means to resource conservation and climate- and environmental protection. This is often associated with the objective of energy efficiency. Thereby, energy efficiency is quickly equated to simple energy conservation. In the past this has often led to optimising buildings unilaterally with regard to their energy quality (often focused on heating needs), and only integrate questions regarding user acceptance, user satisfaction, design quality, material expenditure and profitability after the fact. This has and is partially leading to reservations regarding energy-efficient buildings.

The authors propose a different approach and reference, among other things, efficiency in the sense of expenditure/use ratio and also the state of European standards for sustainable construction. Initially, the primary goal is the formulation and realisation of justified requirements, derived on one hand from laws, standards and recognized rules of engineering (*required* characteristics and properties) and on the other hand from user requirements requested by the building owner or other principals (*agreed upon* characteristics and properties). DIN EN 15643-1:2010 expressly allows for additional requirements on the ecological, social and/or economical quality to be formulated – see Fig. 1.

It is therefore a crucial prerequisite for energy efficiency evaluation to first be informed about the expected use that must be guaranteed long-term. It can – following the approach of a performance based building – be expressed or verbally described in a stipulated user satisfaction level (PMV or PPD) either generally and aggregated, or be expressed explicitly via select parameters (e.g. interior air temperature, range of permissible air speed, requirements on indoor air quality etc.). The specification of detailed parameters for the formulation of user requirements usually already presents a first "translation" and must be supported by experts. Subsequently, solutions that are appropriate to meet these requirements must be developed. So energy efficiency is initially about implementing the requirements to guarantee a certain user satisfaction level and implementing additional secondary conditions with as little energy as possible in the building's use phase.

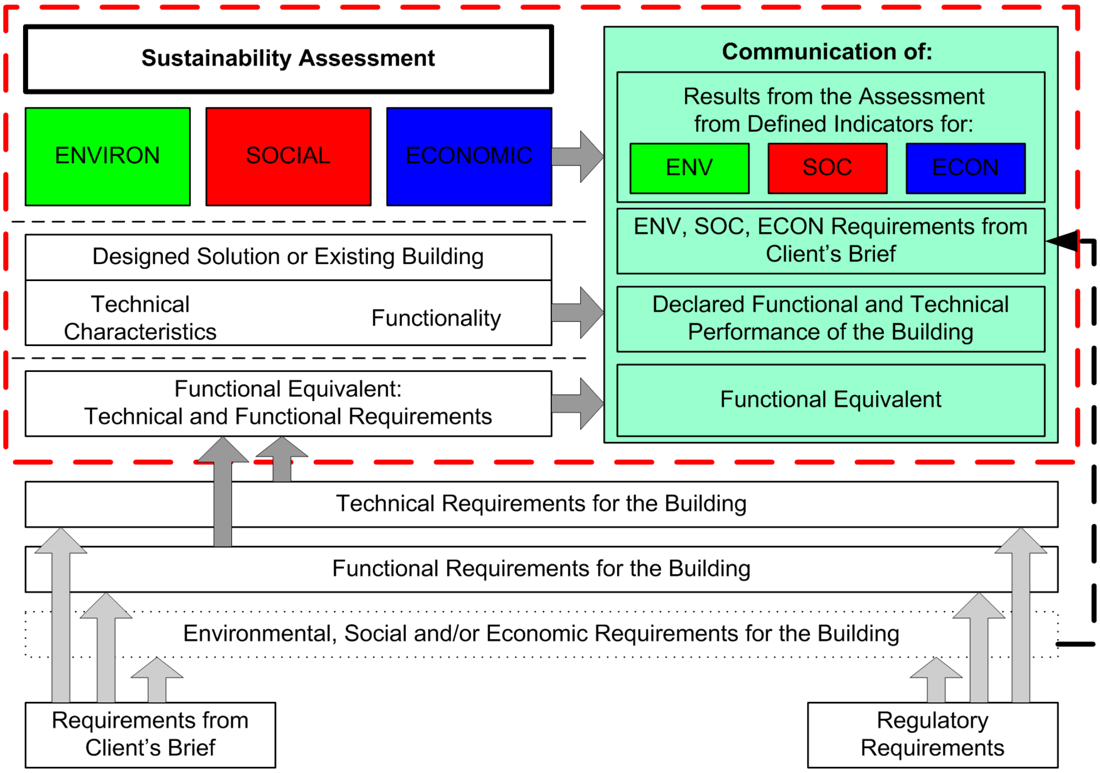

Fig. 1 *Basic sequence of a sustainability assessment according to EN 15643-1.2010*

Building physics contributes to the development of suitable energy concepts and especially also to the development of safe and economical materially-constructive solutions, in close cooperation with materials science, building services as well as energy technology. But the same way the description and evaluation of use of purely constructional dimensions by inclusion of additional economic and ecological aspects has developed, the recording and evaluation of the effort is becoming more complex as well. Construction and usage costs must be included in resource utilisation – also for the production and maintenance of the construction – as well as the resulting effects on the global and local environment. A slow transition from evaluation of energy efficiency to a sustainability assessment is taking place.

Questions regarding influence and evaluation of energy efficiency of buildings have therefore an immediate connection to all dimensions and sub-themes of sustainability.

The formulation and realisation of requirements on comfort relevant to energy efficiency, the health and safety of users exhibits a substantive proximity to the social dimensions of sustainability. User satisfaction can be recorded during operation, among other things. In addition, effects on design quality can be derived if applicable. Affordability is at the junction of social and economic aspects, which is influenced by, for example, energy costs, but also modernisation-related adjustments of rents. Questions related to energy performance of the building have an immediate effect on construction- and usage costs and therefore on the life cycle costs. Besides cost of energy, repair- and maintenance costs for the building shell and building services are part of the usage costs. The selected energy standard, depending on the actual market situation, can have an effect on the rentability and marketability, the rent amount and finally on the economic value and its development.

The energy quality of buildings not only influences the resource demand in the use phase as well as having effects on the environment, whereby in which the emissions of local pollutants depending on the corresponding energy source must be observed which influence on the location quality. The construction and maintenance of the building shell and building services use resources and produce waste as well.

Sufficient heat and humidity protection is a prerequisite to fulfil technical requirements and can be assigned to the aspects of building protection and ensuring durability. Questions arise in this regard relating to service, maintenance, demolition and recycling friendliness of components and building service's components. I.e., a connection to all partial aspects of sustainability becomes evident. This is illustrated in summation in Fig. 2.

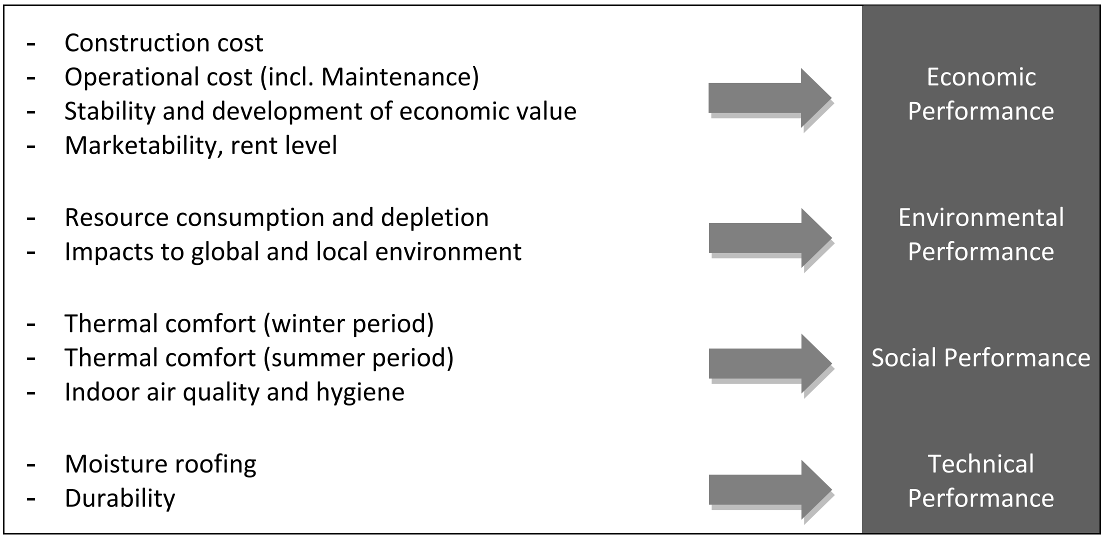

Fig. 2 *Energy efficiency related issues and their impact on dimensions of sustainability*

1.2 Energy evaluation of buildings

The evaluation of building's energy performance has undergone significant changes in the last 20 years. For a long time – through requirements on a building's usage-heat demand (Insulation regulation 1977, 1984, 1995) – only the constructional thermal insulation in the winter was addressed, which was fully justified considering the energy consumption due to the German climate and covering the need primarily with oil and coal (requirements on the heating system were formulated separately through the heating system regulation). Since then, increasing insulation requirements on the building shell have triggered diverse developments in the materials sector, which has led and is leading to completely new solutions in components, as is the case for example with vacuum insulation. Especially this insulating material, or shall we say insulation system, clearly shows the above indicated correlation between energy performance and cost: The reduction of construction surface by using more efficient insulation materials leads to an increase in marketable usable space (with equal gross floor area), which can considerable affect the overall economic evaluation.

An expanded point of view regarding building's energy performance evaluation has become more prevalent with the Energy Conservation Ordinance of 2002: at first limited to the heating sector and subsequently (EnEV 2007) including all energy services in the building (with exception of user-specific energy consumption), the expenditure of making the corresponding form of energy available in the building as well as the pre-stored energy performance to the transfer to the building in form of a primary energy index is recorded.

This also takes auxiliary energy into account. At the same time the term "heating protection" is replaced by the term "energy efficiency" with the Energy Conservation Ordinance of 2005. Not only was the path forged for integral building- and energy concepts with this expanded viewpoint, but it also emphasised the relationship between energy services and the needed energy source and its relevance regarding resource availability and environmental pollution. This was done via the primary energy factor until now, but other values (e.g. global warming potential GWP in kg CO_2 equivalent) are possible.

To what extent obtaining primary energy really permits a sensible evaluation of buildings energy performance in the future must be carefully examined. The system boundary plays an important role in this, which must especially be solved with regard to the evaluation of zero energy houses, as well as developments in different energy sources with regard to the reconstruction of the total energy system to a primarily regenerative supply (compare [1]). The wrong signals can be sent with the primary energy factors that lead to non-sensible use or favouritism of certain energy sources with respective negative consequences for society (e.g. energy – versus food supply).

From the planners or building owner’s perspective, an evaluation of the buildings energy efficiency based on energy consumption would be much more concrete with regard to the planning task, because the end energy directly reflects the amount of energy required by the building. The undoubtedly important resource- and environment-related classification of energy sources would then have to be done on a different level and could be reflected by energy policy control variables and the planning result through energy prices, for example. The timely availability of individual (regenerative) energy sources should be reflected in a suitable manner in a new evaluation system, because the question of energy storage will be instrumental in determining the design of future energy systems.

In principle, a step in the right direction was taken with the Energy Conservation Ordinance by offering discretion for energy efficiency for the planning of buildings through a total energy key value for the building services related energy services. In this respect, maybe the name should also be adjusted in the sense of the European guideline "Energy Performance of Buildings Directive (EPBD)" in the direction of "Energy Efficiency Ordinance". What seems important however is that in connection with the sustainability of buildings addressed in the previous section, the relation between the total energy efficiency of a building to the individual user requirements, which at times significantly influence the energy performance, is becoming more evident.

Corresponding standards – e.g. EN 15251 (input parameter for indoor climate for the interpretation and evaluation of energy efficiency of buildings – indoor air quality, temperature, light and sound) – and according guidelines are available and could be easily integrated into the provision. Thereby, planning objectives in the areas of functional and socio-cultural sustainability would be clearly named in relation to this and would be in context with the building energy concept and therefore energy efficiency. In addition, the method of calculation for the documentation of the energy index (DIN V 18599) should be modified to this effect, so that measures for a user- and climate-friendly building design are immediately apparent in the result, i.e. in the produced energy demand, so an optimisation can be achieved on this level before technical systems are improved. At the moment, the spatial disposition, the size and arrangement of window surfaces etc. are "frozen" via the reference building, i.e. the design potential with regard to indoor climate (including daylight) and energy efficiency goes largely unused. The calculation method and -program EnerCalc [2], which permits such optimisations based on DIN V 18599, presents a very good example for possible developments.

Good examples of buildings with a high degree of energy efficiency and pioneers for new building concepts with innovative technologies, which are the demonstration buildings from the BMWi research program "Energy Optimised Building" (EnOB), can be found at www.enob.info. The above mentioned, broader understanding of energy efficiency might be best exemplified by the office buildings with passive cooling (see Fig. 3 and 4), where on one hand the user comfort was a decisive factor during planning (can thermal comfort even be achieved in the summer without a technical system?), and on the other hand only a stringent overall building concept – control of solar entry with consideration of simultaneous daylight availability, a storage mass in the building that can be activated, release of heat by using natural heat sinks – would ensure success [3]. An examination of selected buildings based on measured indoor climate data shows that the specified comfort temperatures according to the adaptive comfort model of EN 15251 can be achieved (see Fig. 5, [2]).

Monitoring the office buildings evaluated in the scope of the EnOC research program also shows that the level of the total energy index is far below today's EnEV implemented buildings, but that the user-caused power consumption with more than 30 % of the total final energy consumption is of significance at the same time [5]. This must be kept in mind with regard to further energy optimisation in buildings and also for the definition of a term for building energy efficiency in the broader sense.

Fig. 3 *View of the administration building of the company Pollmeier in Creuzburg which is a demonstration building in the EnOB project. Passive cooling is achieved by a night ventilation strategy.*

Fig. 4 *View of the Energon office building in Ulm which is a demonstration building in the EnOB project. Passive cooling is achieved by a thermally activated building system (TABS) where earth piles connect to the ground as a heat sink.*

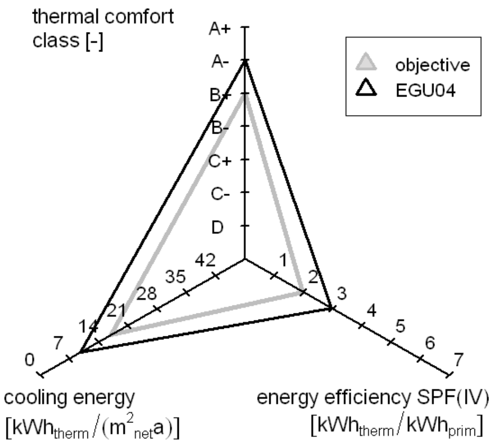

Fig. 5 *Exemplary building signature in the summer (passive cooling) for the Energon office building in Ulm. It can be seen that a high degree of comfort was achieved in the year 2004 (thermal comfort class A-), with simultaneous high energy utilization (cooling energy) and a high degree of energy efficiency with regard to primary energy use. For additional explanation of the diagram see [2].*

1.3 User comfort and satisfaction in energy efficient buildings

To what extent consumer issues were actually considered and implemented within the scope of the planning will be explained with a cross-sectional survey. For this purpose, buildings from the above mentioned research program were compared to common buildings [5]. In principle, it can be determined that no general statements of satisfaction for different energy standards could be made based on the survey. The "EnOB standard" does not perform as well in the summer for example regarding the room temperature and air quality. In turn, these parameters are lower for both building groups in the summer compared to winter time, which basically illustrates the potential for improvement for thermal insulation in the summer. Furthermore a high degree of correlation between the room temperature and the air quality assessment and the user influence on both values is evident, which underlines the need for user interaction options (compare to Fig. 6).

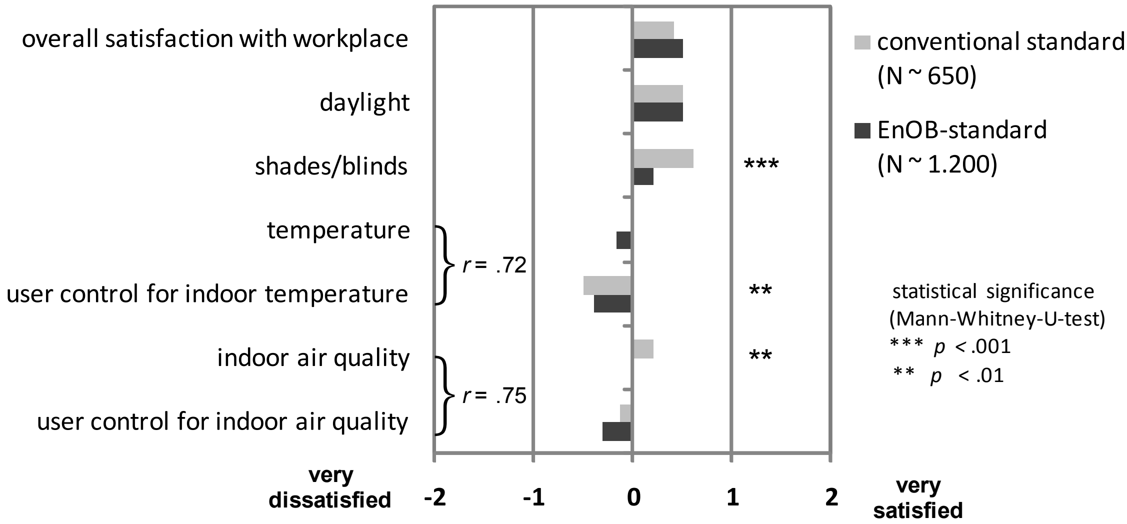

Fig. 6 Results of surveys in office buildings on work space conditions and comfort aspects related to energy consumption in the buildings (r = correlation coefficient). For further explanation of the diagram see [5].

The following factors were identified for the overall evaluation of a building by users: The spatial conditions are of primary importance – with privacy and sound level at the workplace playing an important role related to offices, but the design and furnishing of the rooms as well as the location in the building are also of significance in the user evaluation. Followed by air quality, related to which air humidity is addressed, daylight availability and the usability of sun-/glare protection.

It become quite clear that a high degree of user satisfaction is not automatically related to a good energy index, but that user concerns must be addressed and implemented explicitly as an additional planning objective.

1.4 Economic evaluation

Determinations regarding energy performance of buildings have a significant impact on the economic dimension of sustainability. Cash flow in the building's life cycle as well as the valuation and value trend is affected.

With regard to questions about cost effectiveness, the effects of energy standards on construction costs are discussed. It is often insinuated that additional improvements in energy performance compared to an original option implies significant additional costs. This can be the case if the energy performance of the original version is improved exclusively with additive measures, for example by increasing the insulating material thickness or by using additional building service components.

Alternative approaches and interpretations are possible as well however. This is not a question of additional costs versus the base version (which is worse from an energy point of view). Instead an analysis is made as to if and to what extent a higher quality standard can be realised within the specified financial boundaries (cost boundaries according to DIN 276). All options of integral planning are available in this case.

Possible are, for example, the optimization of the buildings cubature or the prioritised allocation of financial means for "strategic" components that are of importance for energy performance, among other things. Analyses by the authors within the scope of EnOB have shown that high-quality energy standards are possible within the typical cost boundary for according building and usage types. The additional costs that were determined range from 0 to 5 % of the construction costs. EU studies regarding green public procurement assume average additional costs of approximately 2 %. It is a prerequisite to consider the objectives regarding the energy standard strived for early on in conceptualisation, economic competition and in the early planning stages. For this reason, principals should be encouraged in the early planning stages to define the targeted energy standard and to be comprehensively consulted regarding this topic.

This is especially important when, for example, subsidies are planned or if a sustainability level or sustainability certificate is the objective. The energy standard that is to be agreed upon partially requires active participation of future users or the definition of future terms of use. In this context, we refer to "green" rental contracts with the possibility for such definitions.

Energy standards have effects on the use- and life cycle costs. Besides the cost of energy, especially the cost of maintenance, repair and investing in spare components and technical systems within the service life of the building are affected in the usage costs. From defining the type and size of windows down to the cleaning costs has an effect. First it must be verified if and to what extent saving energy with improved energy standards results in an equal amount of energy cost reduction. In particular, this is not always the case for conducted energy. It is recommended to adjust the agreement and especially the generally performance-based base price. The change in power requirements must be determined in order to do so It was determined in the context of the EnOB projects evaluation that the pre-calculated reduction in energy consumption and the reduction of energy costs generally also occurred.

The remaining consequences for the usage costs are heavily influenced by the energy concept. Building technical systems usually require more expenditure for maintenance and service than the components of the heat-swapping shell. This can result in increased maintenance and repair costs if the energy concept leads to an expansion of building services. Initial analyses performed on the EnOB buildings do not indicate significantly higher maintenance costs for energy-efficient buildings however. It is the result of energy concepts, whose objective it is to reduce the expenditure for building services (smaller heat sources, waiving central air conditioning, among other things).

The effects of the sun and glare protection expansion on maintenance and service costs is yet to be analysed.

The cost of maintenance and later replacement investments, especially for new types of components, are difficult to pre-calculate. It is recommended to obtain maintenance or full-maintenance contracts.

Within the framework of economic considerations, the issue is, among other things, pertaining to the relationship of (possibly increased) building costs and (possibly reduced) energy consumption or energy costs. It is recommended to perform the respective analyses by using pre-calculations that are close to realistic consumption to forecast future energy consumption. Furthermore, it is necessary to define expenditure and utilisation from the perspective of the respective actor (i.e. project developer/developer, owner-occupier, lessor, tenant, among others). The determination and interpretation of the "equivalent energy price" is proposed besides the traditional methods of economic calculation, especially for measures for the subsequent improvement of energy performance. To do so, an annual financial expenditure for interest and repayment resulting from the measure is compared to the annual energy conservation. Real or fictional financing conditions will feed into the determination of interest and repayment and a consideration period that can be derived from the lifetime of the measure. For measures regarding maintenance that is taking place regardless, a narrowed view of the overhead caused by energy saving measures minus the regular costs for maintenance from the total expenditure can be calculated. The established equivalent energy price in Cent/saved kWh can be compared to the present or future energy price in Cent/produced or received kWh. In many cases it is already more economical to save energy rather than to continue to use it.

The intense study of sustainability issues results in an increased regard for the life cycle costs. Often times a determination and interpretation of select costs in the life cycle that have an immediate relation to the building and its characteristics and properties are calculated here. For the determination of life cycle costs in a narrower sense, only costs in the sense of payments are included. Results can only be interpreted and compared by taking boundary conditions, system boundaries and conventions into account. This includes assumptions for the period under review, the discount rate or also for the price trend for construction work and energy services. For a life cycle cost calculation in the broader sense, cash inflow is considered as well as payouts. Besides rent, these can also include revenues received from delivering energy to third parties for example (e.g. energy from the integrated photovoltaic system or heat from the own communal heating/power station) and from recycling, during and at the end of the lifetime.

The editors of energy concepts have an additional responsibility for this reason. Besides accurate assessments of future energy expenditures, they must now also provide realistic estimates for the amount of gained energy. The greater incorporation of renewable energy into the supply of apartment buildings must be taken into account for the heating cost allocation.

The description of building's energy performance becomes an important source of information regarding the economic evaluation of buildings. In the rent indexes of several cities (e.g. Darmstadt), surcharges related to energy performance are already included. Even real estate appraisers now take the energy performance of buildings into account. In the current Valuation Ordinance, energy properties are explicitly mentioned as characteristics having an impact on the value of new or renovated buildings. The tendency is for a below average energy performance to become a financial risk with regard to depreciation and value trend.

1.5 Ecological evaluation

Of course the study of energy closely relates to questions regarding resource demand and influences on the environment and is therefore a great influence on the environment-quality of buildings. The main requirement of the Energy Conservation Ordinance is geared towards limiting the use of non-renewable primary energy. Therefore, it clearly orients itself by the objectives of resource conservation. It would be desirable to make this more pronounced in the Energy Performance Certificate for example and in the Energy Conservation Ordinance and really use the designation "primary energy, non-renewable" in the sense of a specification and clarification. Initially this means the resource usage in the usage phase.

Indirectly, this would achieve a reduction in undesirable effects on the global environment at the same time. Saving non-renewable primary energy generally goes hand in hand with the reduction of CO_2 emissions. In its meaning, the goal of environmental protection and especially climate change has long surpassed that of resource conservation. This is not yet mirrored in the Energy Performance Certificate as giving information about caused emissions remains voluntary. The determination and evaluation of global warming potential (GWP) – here as well in the usage phase at first – is of significance and trending in the ecological assessment. "Net zero energy" concepts are added to or replaced by "Net zero emission" solutions. Information about the emission of climate-relevant gases becomes an important criterion for the sustainability report and builds the foundation for the carbon footprint determination.

The carbon footprint equates to the global warming potential here. It must be determined for the complete life cycle. Indications about the carbon footprint in the use phase are a sensible partial value. It must be indicated which parts of energy consumption are included (building-dependant in the narrower sense of the word, e.g. like EnEV, building-dependant in the broader sense, e.g. incl. lifts or additionally user- and use dependant).

Ecological questions are not just about the effects on the global environment, however. Also of interest are the emissions of locally active air pollutants. These are influenced by the choice of heating system and the energy source.

It is not just the current discussion about "grey energy" (which is used for the manufacture of insulating materials for example and is "objectified" in such) that reminds us that the production of building products and the maintenance of structures is connected to the use of resources and effects on the environment. There are open questions regarding energy or ecological amortisation of, for example, additional thermal insulation. For this reason, an energy concept in the broader sense also considers the choice and ecological evaluation of constructions, products and systems nowadays. It is necessary to be familiar with the methods of the life cycle analysis, including the eco-balance. Information hubs such as www.nachhaltigesbauen.de make data available in the form of eco-balance data and lifetimes that is needed for such. The products and constructions must be additionally assessed regarding their availability, durability and resilience as well as for example demolition and recycling friendliness. While up until now questions regarding construction optimisation were geared towards lasting thermal insulation and seamless moisture transport, now topics regarding the coordination of the lifespan of single layers as well as separability during dismantling and recycling must be considered as well.

Constructions that are responsible for thermal insulation are in part in direct contact with ambient air, indoor air, floor and water. It must be ensured that no pollutants are released into the environment. Such information must also be procured, assessed and included in the planning decisions. Available sources of information are, among others, product information (e.g. the Environmental Product Declarations (EPD), building materials information systems (e.g. WECOBIS) and hazard information systems (e.g. WINGIS). It becomes evident that energy efficient planning and construction is contributing significantly to ecological construction, but it clearly goes beyond the topic of energy efficiency.

Summary

Heeding and implementing principles of sustainable development in construction is also a task for building physics. It becomes an important part of integral planning. This not only relates to a simple appreciation of the importance of building physics however, but comes with a significant expansion of the range of responsibilities. The starting point is always the formulation of requirements for technical and functional quality of the building, which are now supplemented by ecological, economical and social objectives.

Building owners and principals are in need of intensive consultation to achieve a lasting, high-level of satisfaction of future users in the areas of health and comfort, through the formulation of objectives. On this foundation, building physics, in corporation with materials science, building and energy technology among others, can develop an energy concept that fulfils the user requirements with minimal resources and minimal pollution.

In the sense of an integral building- and energy concept, the interactions of design- and urban qualities of the building must be observed just as well as questions regarding economy and depreciation as well as the ecological overall assessment, in close corporation with planners. This results in a slow transition from design and evaluation of the energy efficiency to a significant contribution to the building's sustainability. For this reason, building physicists should intensively study questions regarding sustainability assessments in order to recognize their type and scope of influence and their design options. Table 1 shows how many evaluation criteria of the sustainability assessment system BNB have an immediate relation to the energy topic or expanded relation via other building physical issues. Building physicists are therefore important partners in seeking more sustainability during planning, construction and in the operation of buildings.

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