Sustainability Evaluation of Viennese Housing Estates in Passive House Standard – A Post Occupancy Reflexion

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Summary

This research covers an analysis of all Viennese housing estates in Passive House (PH) standard that are inhabited since more than two years and a comparison with selected housing estates of the same building period. These reference buildings already fulfill the Low Energy House (LEH) standard. Quantitative and qualitative indicators are used for the evaluation of social, ecological and economic aspects of a Sustainable Development. The average value for living comfort in PH is better than in LEH. A demand exists for intelligent mediation in the adjustment period by means of a network model between planers, facility management and residents as equally important and learning partners. The target actual comparison of useful space heating energy showed good consistency and the average energy savings compared to LEH are 30 kWh/(m².a) useful space heating energy per gross floor area and year. PH-standard has several advantages compared with conventional buildings: Living comfort, energy efficiency, climate protection and energy costs. PH-standard is the basis for energy efficient construction. Further considerable contributions can be achieved by efficient building equipment, efficient household appliances and active solar energy installations. A Post Occupancy Evaluation (POE) including energy monitoring is a very effective tool for quality assurance and also for fine-tuning and increasing energy efficiency as well as for gathering knowledge – closing the feedback loop - for planners and developers.

Social aspects have been evaluated by Alexander Keul (University Salzburg) and economic aspects by Andreas Oberhuber and his team of FGW Vienna (Forschungsgesellschaft für Wohnen, Bauen und Planen) together with WU Vienna (Ph. Kaufmann). Detailed energy measurements of AEE INTEC (W. Wagner) and TU Vienna (T. Bednar) were also taken into account. In-depth analysis of the comparison of calculated energy performance indicators with actually measured consumption values of residential buildings in solarCity Linz Pichling were also taken into account for the evaluation.

Keywords: Passive House; Energy efficiency; Monitoring; Post-Occupancy-Evaluation; Facility Performance Evaluation; Sustainability monitoring; User satisfaction, Life cycle cost

1. Introduction

Currently there are two interesting developments in Austria. On the one hand more than 5,000 PH have been built in Austria and the share of new buildings that comply with the PH-standard is to increase further. All residential buildings that receive state funding are to fulfil the PH-standard by 2015. But critical voices claim that PH are not more sustainable than LEH e.g. due to higher construction costs. On the other hand international and national systems are developed and applied to assess the level of sustainability of buildings. Currently in Austria there are three main rating systems:

- **ÖGNI** (Austrian Green Building Council) based on the German rating system DGNB (Deutsches Gütesiegel für Nachhaltiges Bauen).
- **ÖGNB** (Austrian Sustainable Building Council) based on the Austrian TQB (Total Quality Building) certification.
- **klima:aktiv** is the Austrian climate protection initiative launched by the "Federal Ministry of Agriculture, Forestry, Environment and Water Management", embedded in the Austrian federal climate strategy and focuses on environmental, health and comfort criteria.

The goal of this study was to assess different thermal building standards. Conclusions for sustainable building assessment systems are derived. The POE covers the three dimensions of sustainable development. The main environmental questions were whether current PH reach the target values, how much energy is actually saved compared to conventional residential complexes, and what the most effective approaches are to reduce energy consumption. The social questions covered the perceived living comfort, the user-satisfaction with the building and building services as well as the communication with the facility management. The economic questions focused on the construction costs and their determining factors and moreover on an expanded view of life cycle costs.

Furthermore a goal was to learn from the first generation of residential PH in Vienna for future sustainable housings.

2. Methodology

All Viennese Housing Estates in PH-standard that are inhabited since more than two years were analysed regarding the three dimensions of sustainable development:

- **Environment:** Analysis of the utilisation phase regarding final energy consumption (delivered energy according to EN 15603) and corresponding greenhouse gas emissions. The actual performance of PH was compared to a selected group of residential units from the same construction period (2005-2007). The reference buildings already comply with the LEH-standard, which is mandatory for residential projects for since about 10 years. The energy monitoring covers 1367 apartments in total with 492 apartments in PH-standard. Data sources were energy suppliers, AEE INTEC (W. Wagner) and the Technical University of Vienna (T. Bednar).
- **Social aspects:** The POE by Alexander Keul (University Salzburg) investigated six buildings with 425 residential units. The questionnaire was completed by 225 residents, which resulted in a response rate of 53 %. 156 apartments in existing buildings in Vienna served as a statistical baseline. Mean resident age, household size, and residential unit size were comparable between PH and reference buildings; there was greater variation in the number of children [2].
- **Economy:** Construcion costs have been analysied by Andreas Oberhuber and his team of FGW Vienna (Forschungsgesellschaft für Wohnen, Bauen und Planen) together with WU Vienna (Ph. Kaufmann). According to the method of discounted present values the life cycle costs of 25 housing estates in PH- and LEH-standard have been analysed. The method of discounted present values is used by the German assessment system for sustainable buildings BNB (Bewertungssystem Nachhaltiges Bauen für Bundesgebäude), which was developed from the German Federal Ministry of Transport, Building and Urban Develop-

ment in cooperation with the German Sustainable Building Council (DGNB). The assessment with a silver rating is obligatory for all new federal buildings in Germany.

3. Sustainability Evaluation

Many assessment systems for buildings originated form ecology and environmental driven issues. The first criteria sets focused on energy efficiency and building materials as well as their environmental impact. In the course of time the criteria sets have been expanded to technical, socio-cultural and site qualities. Quite recently, economic aspects and process quality have been added. In face of increasing criteria the assessment becomes more complex and costly. In consideration of the comprehensive amount of supporting documents these systems are rather applicable for new buildings than for the existing building stock. Furthermore efforts are done to extend the assessment system with further criteria. It seems appropriate to harmonize the criteria systems to the planning processes, construction processes and building operation.

The analysis of the operation phase is crucial to adapt the assessment system and create an applicable rating system for the building stock. This study analyses energy efficient residential buildings based on mandatory documents, energy monitoring and additional social and economic investigations. In a further step the findings should deliver suggestions for a refinement of the assessment of existing buildings.

3.1 Target-actual-comparison of space heating

According to EN 15603 measured values for space heating demand are not directly comparable to calculated energy demand figures, due to differences in the way the values are determined. Measured values contain the cumulative aspects of climate, user behaviour (e.g. indoor air temperature, shading and window ventilation), performance of HVAC-equipment, etc. compared to standard conditions of the calculated figures. The research study of the solarCity Linz Pichling [3] addressed these differences and an in-depth investigation was done [4]. The main findings were:

- Monthly thermal balances of the heating energy demand compared to measured consumption values as well as additional monitoring suggests an indoor air temperature higher than the standard value of 20 °C. A standard indoor air temperature of 23 °C seems realistic.
- Due to annual climate fluctuations, climate adjustment should be performed on the calculated demand values. The climate model should be based on measured values for ambient temperature and for radiation gathered from neighboring meteorological stations.
- The monthly heating energy demand is underestimated, especially from February to April and to a smaller extent from September to October. Different scenarios have been analyzed, regarding the shading factor and the utilization factor of solar heat gains. It consequently seems to be reasonable that in the calculation methods the extent of shading should be higher than in the standard. This effect could be caused by user behavior but is also influenced by the volume of the building. Housing estates tend to have a lower utilization factor for passive solar gains than single family houses. Solar gains are especially useable locally and do not cover the whole building to the same extent. The absolute sum of all energy demands calculated per apartment is lower than the value calculated for the whole building [6].

Considering these findings the measured consumption values of useful energy correspond very well with the calculated demand values for 23 °C indoor air temperature. In several monitoring results of AEE INTEC the measured indoor air temperature in dwellings is between 22-24 °C during the heating period. Figure 1 shows the target-actual-comparison for space heating, final delivered energy and useful energy. The Equipment losses have to be investigated more in detail and are so far underestimated for PH. The average annual energy consumption of PH is 17 kWh/(m².a) delivered district heating per gross floor area. About 30 kWh/(m².a) or two-thirds of energy are saved compared with conventional housing estates of the same construction period. It has to be kept in mind that the reference buildings already have very good energy performance. Compared with older housing estates completed in 1985 the PH-standard saves about 55 kWh/(m².a).

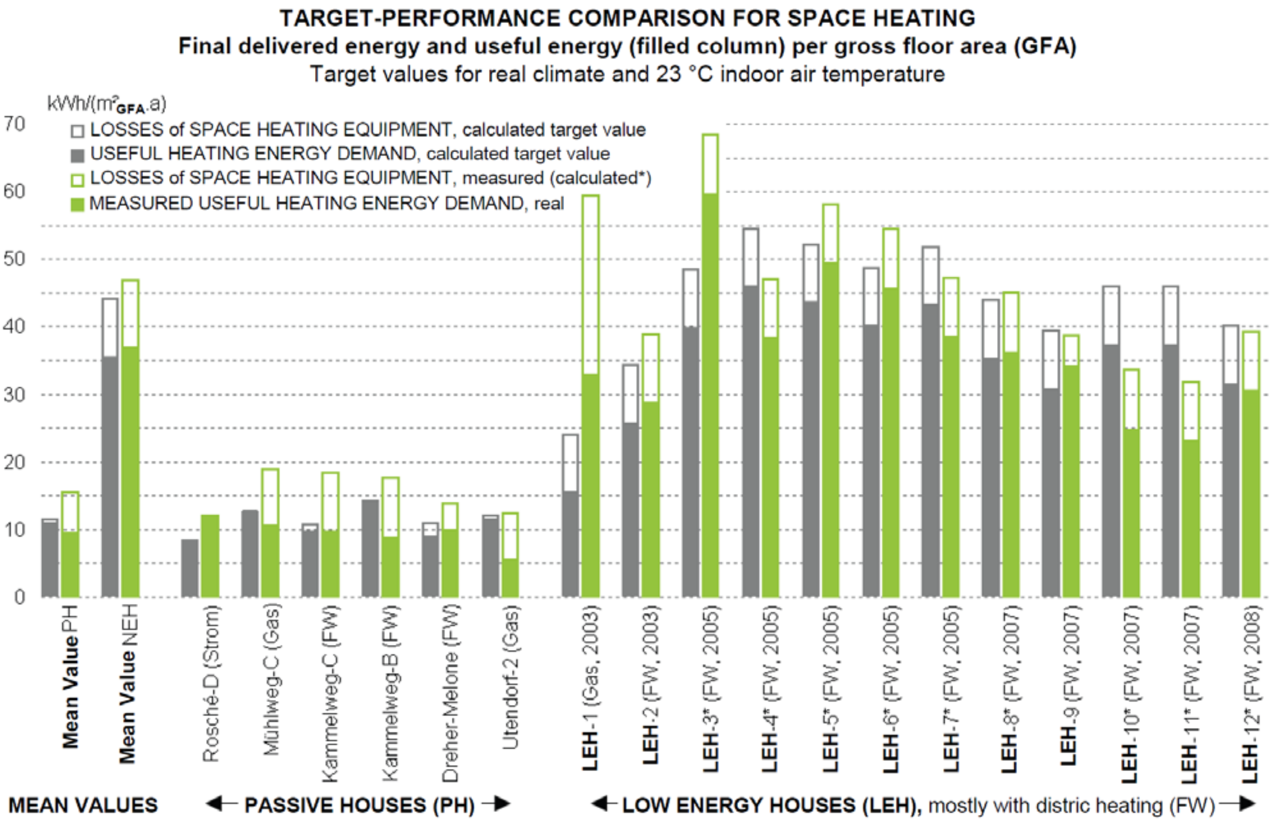

Fig.1: Target-Actual-Comparison for space heating. Final delivered energy and useful energy per gross floor area

3.2 Final energy consumption and greenhouse gas emissions for space heating and domestic hot water generation

The delivered final energy for space heating and domestic hot water was analysed, excluding electric energy for ventilation and circulation pumps. Referring to 2006, the PH-standard saves about 30 kWh/(m².a). For households, this means savings of about 2.5 MWh, 230 € and 500 kg of greenhouse gases per year (Figure 2).

PH cause a more balanced energy consumption throughout a year, which is favourable for the supply of district heating. This also causes lower greenhouse gas factors in case of a monthly calculation. The annual greenhouse gas emissions of PH are approx. 8 kg CO_2-equivalent per m² and not dependent on the energy carrier (district heating, gas, electricity). The major energy flow of new LEH is transmission losses. The PH-concept effectively reduces this energy flow by 23 kWh/(m².a). Further energy savings of 10-15 kWh/(m².a) could be achieved by optimised equipment for heating and hot water. About 10 kWh/(m².a) energy savings have been documented for solar thermal installations. Even higher yields are possible for solar space heating with large-scale collectors. Heat recovery from waste water enables minor extra savings within housing estates but might be an appropriate concept for building quarters.

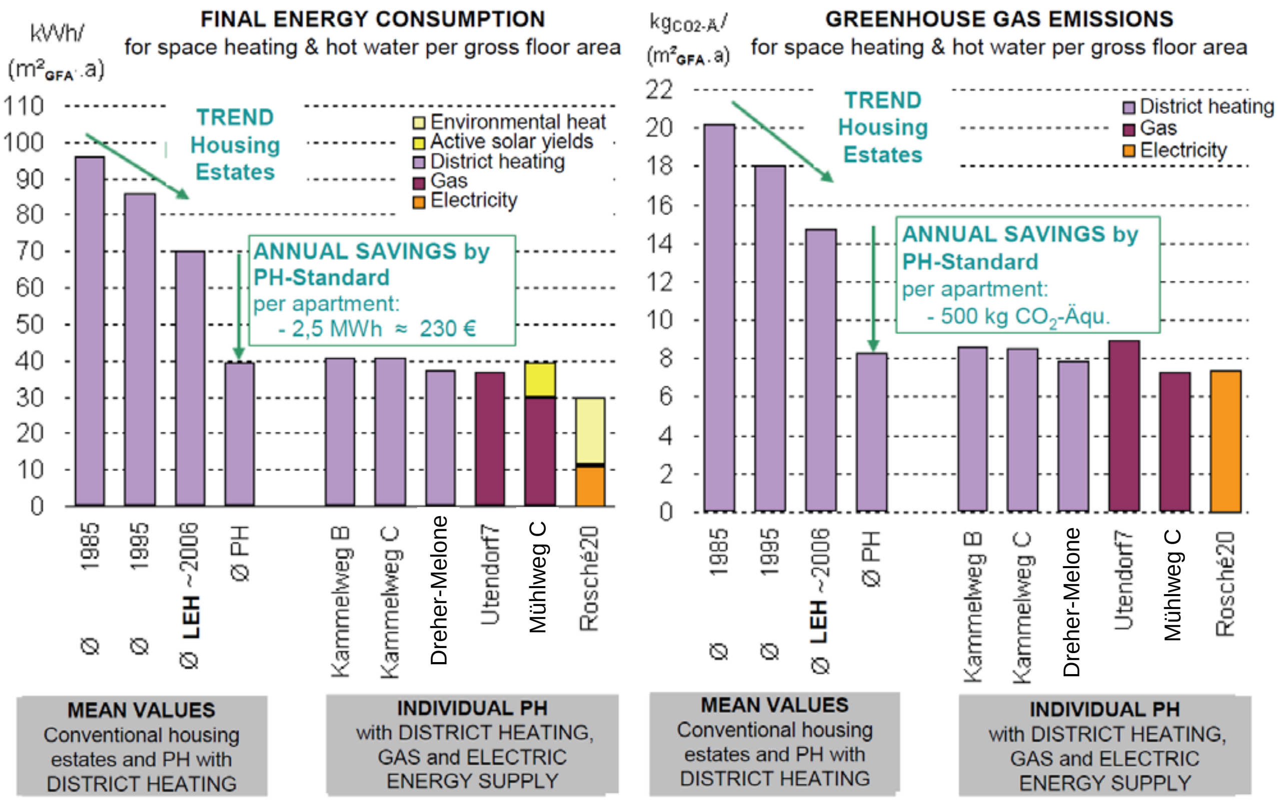

Fig. 2: Space heating and hot water - final delivered energy and greenhouse gas emissions. Conversion factors: District Heating: 192 g/kWh, Gas 250 g/kWh, Electricity 617 g/kWh

3.3 Electrical energy consumption

The average total electricity consumption was 34 kWh/(m_{GFA}^2.a) for buildings without heat pumps and electrical heaters. Ventilation systems in PH consumed between 3 to 5,5 kWh/(m_{GFA}^2.a) for the conveyance of air.

The consumption of electricity was also investigated in the evaluation [3] of solarCity Linz Pichling with 1298 apartments in PH-standard, LEH-standard and below LEH-standard. The average electricity consumption was 33 kWh/(m_{GFA}^2.a) in total and 25 kWh/(m_{GFA}^2.a) for conventional non-PH apartments. PH apartments had approximately the same consumption values as conventional apartments. Therefore the electrical energy consumption for the decentral ventilation units of PH was approximately on the same level as for conventional sanitary ventilation, with about 1.7 kWh/(m^2_{GFA}.a) according to measurements of the University of Wuppertal [5]. Buildings with a less energy efficient ventilation system, in terms of electrical energy for the ventilators, caused an additional energy consumption of about 4 kWh/(m^2.a) compared to conventional apartments. Very few apartments in LEH had electric boilers for hot water supply, which caused an additional energy consumption of about 15 kWh/(m^2.a). These results are shown in figure 3.

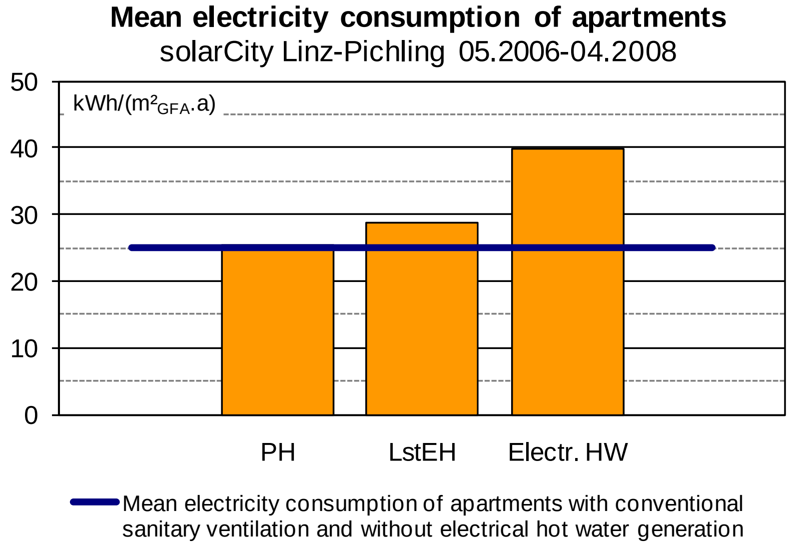

Fig. 3: Mean electricity consumption of apartments with decentral fresh air ventilation units in Passive House standard (PH) and in Lowest Energy Houses standard (LstEH) as well as apartments without fresh air ventilation units but with electrical domestic hot water generation (Electr. HW). Comparison with conventional apartments (blue line).

3.4 Social Aspects – Post-Occupancy-Evaluation

The reasons why residents selected an apartment was primarily the location and furthermore the energy efficiency. The Tenants are hardly a "green bloc" in terms of their environmental awareness; rather they are a socially mainstream group.

Five of four PH projects had clearly better resident satisfaction values than the reference buildings (Fig. 4). Three PH projects even reached a satisfaction level that is often observed for detached single family houses. One PH was basically on conventional level but improved in the following year 2008/09 because of optimization measures of the heating and ventilation equipment. The level of satisfaction corresponded with the quality of communication with the building management as well as with the quality of explanation of building services technology and PH technology. Problems were noticeable in the technical regulation and adaptation phase after moving in. The adjustment phase to the ventilation and heating system at the beginning of occupancy was critical. PH information was rated good, but has potential for improvement. A short operating instruction or checklist would be helpful.

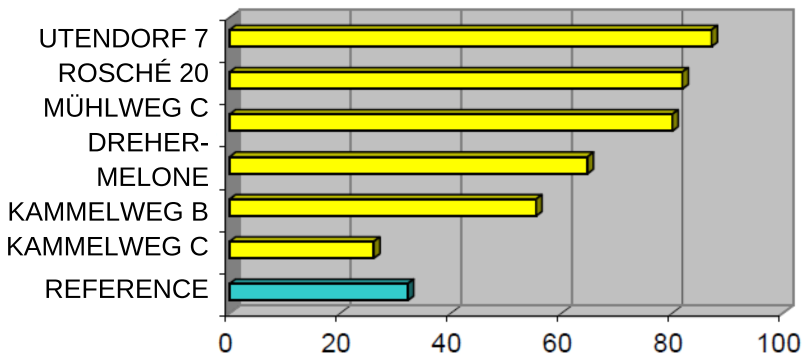

Fig. 4: Share of very high resident satisfaction (percent) in six PH projects (yellow) and in reference buildings (blue) [2]

The longer people live in PH, the better they rate living. The PH “Utendorfstrasse” was evaluated three times between 2006 and 2008. The first POE was performed shortly after the beginning of occupancy during the sensitive adjustment phase and 77 % of the residents rated a high satisfaction level. In the following evaluation the satisfaction level increased to 84 % and finally reached 94 % in the third evaluation [1].

3.5 Economy – construction costs and life cycle costs

Usually the estimation of construction costs is the major factor for decision on construction concepts, energy concepts and building materials. The aim of the economic analysis was to identify determining factors for construction costs and life cycle costs and to show differences between PH and LEH.

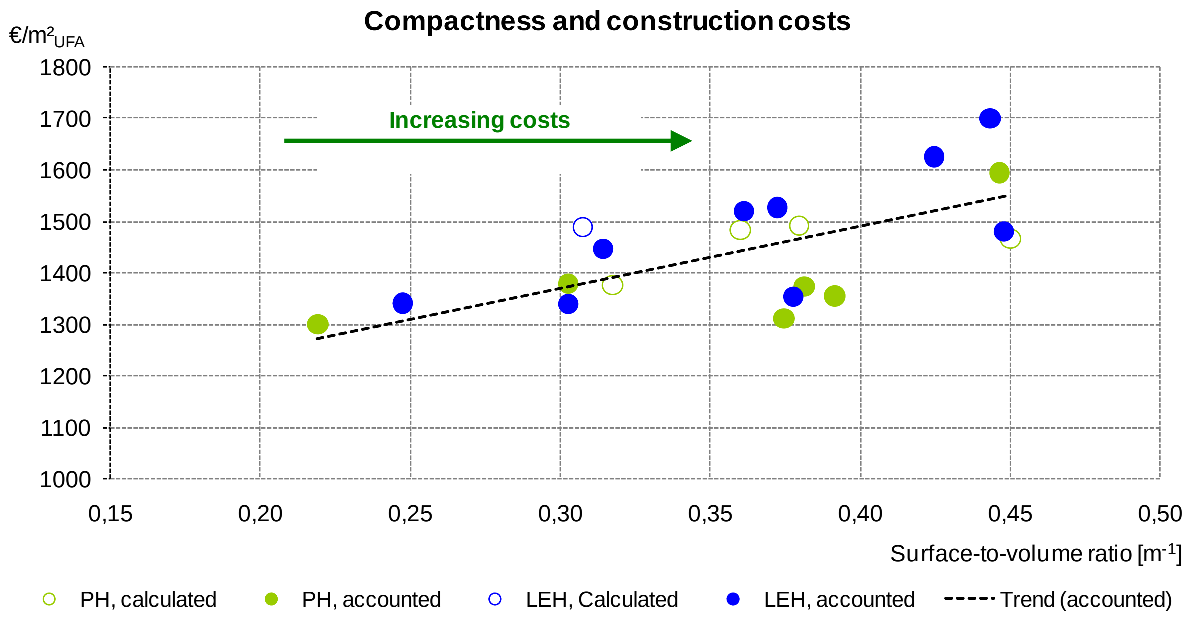

Fig. 5: Construction costs per useable floor area and compactness

The most important cost factors for all investigated PH and LEH was the size and compactness. Figure 5 shows the relation between compactness and construction costs. Less important was the date of completion and the energy efficiency class. PH had roughly the same construction costs as LEH. Additional costs of 15 % - 25 % were observed for less compact residential houses.

The analysis of individual PH, by comparing actual costs with calculated costs for a LEH variant, showed additional construction costs of 4 % - 12 % for PH-standard. The higher figure (12 %) was mainly due to cost-intensive decentralized ventilation systems for the first generation of PH housing estates. Central ventilation systems caused only small or no additional costs. Low additional costs in the range of 5 % were documented for two PH projects. In the future additional costs will be in the range of 4 % - 6 % due to favourable price trends for decentralized ventilation systems and triple glazed windows.

Life cycle cost (LCC) calculations were done according to the method of discounted present values, which is used by the German rating systems BNB and DGNB with the following general conditions:

- Time frame of 50 years
- Discount rate (interest rate): 5.5 %
- Annual rise in prices: general 2 %, energy 4 %

Varying factors were construction costs and energy demand for space heating. A strong correlation of compactness and costs could be observed for all buildings. Concerning LCC the heating energy demand showed a good correlation (Fig. 6). The LCC of PH were 2 % - 11 % lower compared to LEH. The findings are quite sensitive to the specified rates for discount and rising prices. The observed correlations remain in trend but the differences are higher or lower depending on the rates.

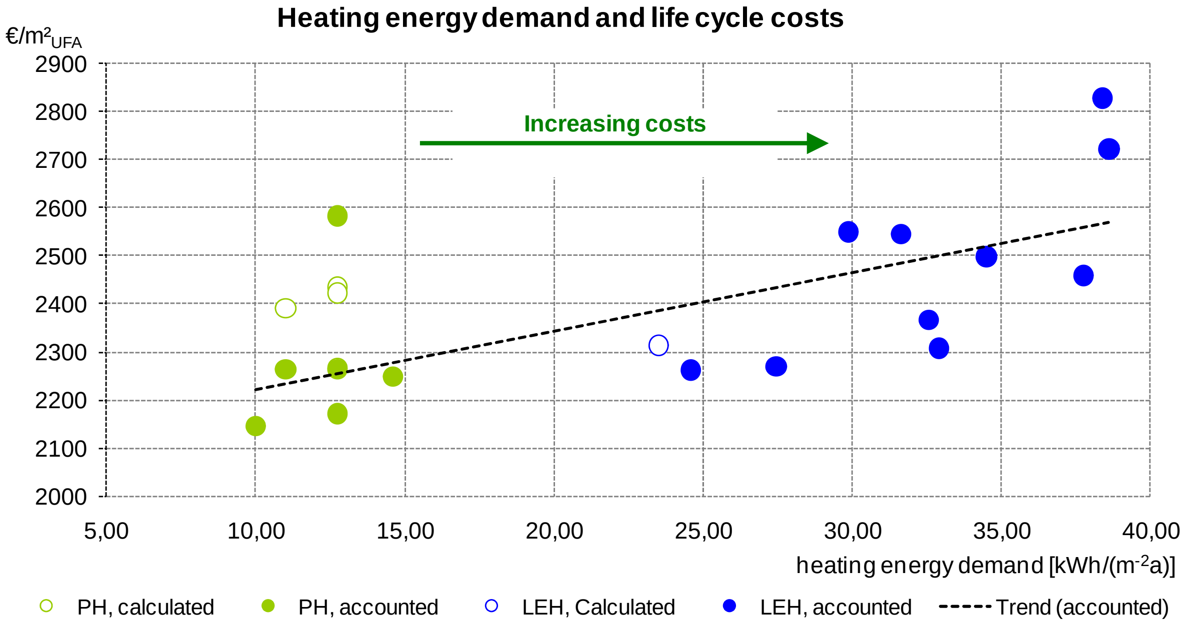

Fig. 6: Useful energy demand for space heating and life cycle costs per useful floor area

4. Conclusions

PH-standard for new buildings creates benefits in living comfort, energy efficiency, climate protection and energy costs with economically justifiable construction costs. PH with a an energy efficient ventilation system – in terms of electrical energy for the ventilators – cause no remarkable additional electrical energy consumption compared to conventional buildings with common sanitary ventilation. Important aspects for the optimization of electrical energy consumption were:

- the quality of the ventilation concept: e.g. the air distribution concept
- the quality of the implementation: especially the energy efficiency of the fans and air distribution
- the operation phase: adjustment to actual demand for fresh air depending on occupancy rate and seasonal demands
- the quality of maintenance: interval of filter change

It is suggested to start with the optimization of the ventilation system already in a very early planning stage. The calculation and optimisation of pressure losses should be carried out in the draft stage of the planning process to optimise the air distribution system regarding pipe length and diameter. A more detailed calculation should be carried out for the preparation of the call for tenders and finally for the completed building accompanied by electricity measurement. The optimisation of pressure losses in ventilation system should not be less important than the optimisation of thermal bridges.

PH-standard is the basis for energy efficient construction. Further considerable contributions can be achieved by efficient building equipment (ventilation and circulation pumps) and active solar energy utilization. Newly built PH-Buildings have important indirect contributions for climate protection due to learning effects for thermal refurbishment to PH-standard.

To fulfil the envisaged goals of sustainable buildings the most important findings and recommendations for future housing projects and assessment systems:

- New buildings should be constructed in PH-standard. Otherwise they could become objects for refurbishment in the future which will result in higher life cycle costs, e.g. due to insufficient insulation or due to mould problems.
- More attention should be paid to the planning process. Well planned buildings feature high user satisfaction, low energy demand and low amount of maintenance at acceptable construction costs. Relevant indicators for an assessment at an early stage are compactness, size and energy demand for heating and ventilation.
- Obligatory monitoring for all subsidized buildings is suggested, as well as a publicly visible information signs for the final energy demand. Energy monitoring is not just quality assurance but also fine-tuning and increase of energy efficiency. The cooperation with socio-scientific analysis provides synergy effects and delivers new knowledge for developers, planners, energy suppliers and administration.
- Provision of information and technical mediation supports the PH concept and raise user satisfaction. The adjustment phase to the ventilation and heating system at the beginning of occupancy was critical. A short operating instruction or checklist would be helpful.

Rating systems for buildings like LEED, BREEAM, DGNB, etc. are used more often in recent times. Primarily these rating systems are focused on new buildings and take calculated demand figures, simulations and other verification of the planning stage as proof of quality. As a meaningful measure and validation of the assessment a post occupancy evaluation is suggested. For the German BNB system (Bewertungssystem Nachhaltiges Bauen für Bundesgebäude), which is used for all federal buildings, suitable criteria for the operating phase have already been drafted.

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