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THE ECONOMIC CHALLENGES OF DEEP ENERGY RENOVATION - DIFFERENCES, SIMILARITIES AND POSSIBLE SOLUTIONS – OFFICE BUILDING IN GERMANY

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ABSTRACT

Within EBC Annex 61"Business and Technical Concepts for Deep Energy Retrofit of Public Buildings" are developed to increase pace and quality of DER projects in the public sector. Subtask A targets is to assess accomplished DER projects to define find optimized bundles both from energy efficiency and economical perspective in each of the participating countries. Based on the assumptions on Deep Energy Retrofit (DER) defined by the Annex 61 team as a minimum saving of 50% against the baseline, modeling studies for different types of buildings and different climate zones have been done. The target of the modeling was to identify a cost/benefit optimized bundle of technologies to achieve the economically most viable retrofit scenario. Following scenarios and assumptions for all national case studies have been defined:

Scenario 1 (baseline) *represents the pre-1980 standard to describe the building envelope and systems before renovation with the consumption for site energy, heating and electricity.* ***Scenario 2 (base case)*** *is the country specific "business as usual" retrofit; mostly initiated by non- energetic targets the base case scenario only considers the requirements being set up by the national building codes.* ***Scenario 3*** *has to achieve approximately 50% energy reduction to the baseline (scenario 1) and scenario 4 targets to achieve the current national "dream energy standard" (which can be the national definition for NZEB, Plusenergy Standard, Passive House, etc.). Targets to be reached in all scenarios are based on the site energy demand, including all kinds of energy use like DHW, heating, cooling, lighting, household electricity, plug loads etc.*

The result of the modeling will be different U values for the thermal envelope, specific HVAC and supply systems. For each component the investment costs are calculated and a 40 years life- cycle cost analysis (LCA) is prepared considering the global costs and benefits for energy and non- energy related measures. To decide between different scenarios the incremental energy related costs and benefits of each scenario are compared to each other. In this paper the modeling results of the German case study are presented.

The German modeling project is a compact (A/V: 0,38) multi-story office block with three floors and 1,680 m²(18.083 ft²) net floor area in the city of Darmstadt (Hessen), constructed in1962 and situated in ASHRAE c.z.5. The building was refurbished in 2012 and the allowed the calibration of the modeling at the hand of the performance data (scenario 4). The total site energy demand (DHW, heating, supply and household electricity) taken as the baseline was the consumption collected from the utilty bills: 236 kWh/m²yr heating and 20 kWh/m²yr electricity. Compared to EUIs for German office buildings < 10,000 m² the heating consumption is 12% over average, the electricity consumption is 18% below average EUI values for office buildings. Typical for office buildings of that size and age is that air conditioning was only in use for the IT server and the rest rooms but not for the office spaces. Following the requirements of the German national building code for refurbishment of the building stock in scenario 1 (base case) leads to a reduction of 39% of primary energy including plug loads or 41% final energy for heating. In scenario 2 the standards for new building were adopted with significant reduction of thermal bridges, air leakage and 67% primary energy and final energy for heating by 72%. Scenario 4 considered the passive house standard for building stock, and depicts exactly the situation after the refurbishment was accomplished with 76% primary energy savings and 81% final energy for heating savings. Actually achieved was 48 kWh/m²yr heating site energy. Due to the

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improved air- tightness of the the thermal envelope the minimum requirements for indoor airquality required the implementation of a mechanical ventilation system with high efficient heat recovery but without cooling. The assessment of the life- cycle analysis (LCA) showed the best Net Present Value (NPV) for scenario 2 (adoption of building code for new buildings) while the second best is scenario 4 (cost- optimized passive- house scenario). The main difference between the two scenarios is that scenario 2 has only a cheap exhaust air system and scenario 4 has a costly ventilation system with heat recovery. The more insulation for scenario 4 has almost no impact on the NPV because the delta costs are refinanced by the energy savings.

The paper describes the base lining and modeling process, the economic assumptions made for energy prizes, maintenance and other operating costs and consider the investment costs, the cost optimization process. The measure bundles resulting from the modeling are described. The case study will be continued by considering the impact of other cost- benefits than energy savings on the pay back of the project.

1. INTRODUCTION

Many governments worldwide are setting more stringent targets for reductions in energy use in government/public buildings. Buildings constructed more than 20 years ago with less ambitious energy targets account for a major share of energy used by the building stock. However, the funding and "know-how" (applied knowledge) available for owner-directed energy retrofit projects has not kept pace with the new requirements. In the typical decision making process the building owner comes to the conclusion that a refurbishment following the targets of the building code (minimum requirements) also provides the most cost- effective solution; thus the majority of refurbishments is not considered as a DER and end up with an average reduction of energy use between 10 and 20%. Previous research conducted under IEA EBC[1] Annex 46 identified and analyzed more than 400 energy efficiency measures that can be used when buildings are retrofitted. Measures include those related to the building envelope, mechanical and lighting systems, energy generation and distribution, internal processes, etc. Implementation of some individual measures (such as building envelope insulation, improved air-tightness, co-generation, etc.) can significantly reduce building heating and cooling loads or minimization of energy waste, but require significant investments with long paybacks. However, when a limited number of "core technologies" are implemented together ("bundled"), they can significantly reduce energy use for a smaller investment, thereby providing a faster payback. Also reliable data from accomplished DER is sparely available which does not allow for evaluating the exactness of modeling approaches for DER especially when a bundle of energy efficiency measures is applicated. In IEA Annex 61 EBC Subtask A modeling efforts in different countries were made to set up a methodology for the determination of such cost- optimized DER bundles. For the modeling each participant selected one typical building and modeled 4 scenarios: baseline with national building codes from 1970-80; least-requirement according to the national building code for renovation of the building stock; -50% of baseline consumption and a "dream- scenario" i.e. passive house standard.

2. German Modeling Building

2.1 Description of the building, installations and usage

The German building modeled is an existing office building in Darmstadt, Germany. The building is composed by prefabricated large concrete panel elements, and it describes a typical building and construction in Germany during the period 1960-80. Before the refurbishment all necessary data of the existing building were collected in an on- site assessment.

Tab.1. Characterisation of the German modeling case study

[1] International Energy Agency, Implementing Agreement Energy Conservation in Buildings, Annex 46

Number of floors	3
Net area	1,680 m², (18083 ft²)
Heated area	1,680 m², (18083 ft²)
Number of zones	10
Compactness: Building envelope/ volume,	0.38
Usage of building	Office (8 am- 7 pm), 5d/week

Fig. 6. Front view from the Street on the southern part of the building before refurbishment (German case study)

- Ventilation system:

The rest rooms of the buildings were equipped with 3 exhaust air system (3,000 m³/hr/ 3,900 m³/hr and 5,000 m³/hr with constant air- flow, with a electrical load for the fans in total 8 kWel and an annual usage of 8.000 h/a. The three rest room areas and the street side office rooms on each floor where connected by a vertical concrete exhaust air from basement to roof top. In the office areas windows could be opened for airing purposes. The building had a high leakage rate; measurements showed that a sufficient air quality in terms of CO_2 content was achieved; the indoor climate conditions required by German building codes did not require additional air conditioning and cooling systems. Cooling was only in established in the IT server room. However building users complained about natural air draft at the windows and cold wall surfaces in winter.

- Heating and heating distribution:

The building was heated by two gas boilers with a capacity of 500 kW each, built in 1992. The boiler was providing heating and domestic hot water; the heating water temperature was controlled by a out- door-temperature based control system with a maximum heating temperature of 90°C at the assumed minimum outdoor temperature of -12°C in this climate zone. The heating pumps were at constant speed.

The heating distribution was by steel pipes distributed in a duct system in 4 building zones, steel radiators equipped with thermostats allowing for individual control of each zone. The insulation was a mineral wool dimensioned at ¼ of the pipe diameter.

- Domestic hot water

The existing DHW was a centralized system with the boiler as a heating source at constant temperature of 70°C. German building codes require at least once a week a temperature of > 70°C to provide hygienic minimum requirements which is targeting legionella colonies in the boiler and the distribution system; however in most of the buildings this temperature is permanently given. The DHW is distributed in two distribution steel pipe systems: one is responsible for the transport of the DHW and the second, which is the DHW circulation provides the minimum circulation of DHW for hygienic purposes and the first response on DHW demand. 18% of heating site energy was required for DHW.

- Lighting System:

Mainly the building was equipped with white- reflector T8 fluorescent lamps with 15 W el/m² average in office spaces, 10 W el/m² average in floor space.

- Construction

The thermal transmittances of the building envelope have been:

External walls 1,310 m² : $U_{wall} \approx 1.36$ W/m^2·K,
Roof-ceilings 692 m²: $U_{roof} \approx 0.7$ W/m^2·K;
Windows: 352 m²: $U_{window} \approx 3.3$ W/ m^2·K;
Basement: 620m²: $U_{basement} \approx 0.52$ W/ m^2·K;

The building envelope contained multiple structural thermal bridges (jalousie niches, window, doors, roof- wall intersections etc.).

2.2 Simulation process

Energy performance of reference buildings was simulated by using the energy and indoor climate simulation program Passive House Planning Package (PHPP). This software is meticulously validated, allows the modelling of internal and solar loads, of outdoor climate and HVAC systems.

The German Test Reference Year (ASHRAE c.z. 5, Würzburg) is used for outdoor climate conditions (design temperature for heating measuring -15 ºC (5°F)).

The refurbishment of the building however was already carried out according to Scenario 4 (Passive House) in 2012; performance data exists for at least two complete years after the refurbishment. At this point the modling could be back- calibrated at the hand of the performance data before and afer refurbishment; for this modelling approach different scenarios were assessed:

- Scenario 1 with the basic requirements of German building code for existing buildings,
- Scenario 6 to approach "-50% of baseline"
- Scenario 2 /3/4/5 targeting more than 70% of savings in different DER measure bundles.

The modelling was carried out with PHPP[2] which is providing monthly site and source energy balance calculation in the common Excel format and is mostly in use for the certification of low energy and NZEB in Germany.

One of the research targets in this modelling effort was to improve the accuracy of the modelling process. Findings from the assessment of 8 accomplished DER projects[3] shows that in more of 50% of the cases the

[2] PHPP: Passive House Planning Tool, PHI, Darmstadt 2010-2015

predicted performance of the modelling process is actually not met; in more of 40% the energy performance exceeds more than 10% of the predictions.

In most of the modelling processes the information loop between the modelling and the actual performance is not closed. This is even the case in existing buildings where a back calibration at the hand of the actual performance data of the pre- refurbishment status is not carried out. The effect has been described by IWU [4] in the "Modelling Rebound and Prebound Effect". Also in this modelling process the rebound effect has been assessed: by setting up the modelling at the hand of the building construction and the U- values, air leakage, internal gains, and usage data the calculated baseline is more than 30% higher than the actual measured and climate adjusted baseline consumption provided in the utility bills. As the building has been already refurbished a second back calibration of the modelling was carried out at the hand of actual performance of the building from the accomplished scenario 4).

The back calibration was carried out in an iterative process at the hand of the following parameters; the back calibration was carried out until the measured and climate adjusted consumption before and after the refurbishment was exactly depicted in the modeling tool.

- usage parameters: reduction of the hours of usage in office space zones:
- indoor temperature profiles: the assumed indoor temperature for the usage time of office spaces had to be reduced in accordance to the reduced hours of usage; in the modelling calculation two temperature profiles are assumed: the "in use" temperature profile which is in the office space 21°C and the "stand-by" which is set at 18°C. To calibrate the model the "stand-by" and "in- use" temperature profiles for the office zone had to be reduced; also the hours per day in which the "in use" temperature profiles was assumed for the calculation had to be reduced.
- Internal loads: the assumptions for the internal heating loads had to be increased; they are considered by 0.024 kh/d and 2.3 W/m². The internal loads contribute reduce the heating demand during the heating season; the heating season is considered 212 d/yr for high- isolated scenarios and 365 d/yr, for the pre-refurbished building. The heating period of the good insulated passive house is much shorter than in the less insulated buidings. The internal gains are only taken into account in the heating period depending on the insulation level of the building.
- Ventilation airflow is assumed with 0.365 1/hr for the renovated building
- Target indoor temperature: 20°C in office spaces and gang halls
- Indoor temperature in summer: 25°C
- Internal heat gains building users : 1.26 W/m²
- The consumption of domestic hot water (DHW) was not separately metered in the pre- refurbished building and had to be estimated 10 l per capita and day. With regard to the minimal consumption, high losses in the distributions the DHW system was replaced by detached small electric instantaneous water heaters.
- The usage of heating energy (site energy) and electricity (site energy) for different refurbishment scenarios takes into account the energy for space heating, ventilation, domestic hot water, all electricity (including lighting and appliances (plug loads)) and energy losses.

[3] Assessment of 8 accomplished DER projects in 8 German public buildings, EDLIG, 2014 (German)
[4] Prebound und Rebound in der energetischen Modellierung, IWU Darmstadt, 2013 (German)

2.3 Economic modeling

The drivers of a decision making process on a building which is has arrived at the end of its life cycle are mostly related to the future purpose of the buildings but do not consider the energetic options in the first step. German building codes allow “maintenance refurbishments” if minor constructive measures are foreseen. A maintenance refurbishment considers concrete refurbishments, partly replacement of HVAC components, painting etc. In comparison to that a major repurposing concept that requires major constructive measures at the building envelope and in the building floor space entails that the minimum energetic requirements of the German Energy Saving Ordonnance (EnEV[5]) has to be considered (which is the scenario 1 in our modelling scenarios). However, a major repurposing concept has to be considered as a once-in- a – life- cycle opportunity to enhance the the energetic quality of the building beyond the minimum requirements. The decision making process of this modelling project considers a decision making between “maintenance refurbishment” and an energetic refurbishment in different scenarios.

- Investment cost data bases: The investment costs were taken from refurbishment cost databases and cost data collected from the accomplished refurbishment of this specific building (scenario 4). The data bases distinguish between different measures in construction and HVAC and consider the total specific costs per m² including costs for the equipment, labour and the VAT of 19%. However these data may only be considered as average values as the cost spread of the cost elements has to be considered with regard to the
- The month and the region in which the project is considered to be implemented. Investment costs for the assessed modeling scenarios are taken from different databases of evaluated refurbishment costs: (Passive House Institute, 2008/14) is referring to the accounted investment costs of numerous conducted refurbishment projects of the Passive House Institute in residential and non- residential buildings. The Scenario 3 investment costs have been taken from a recently accomplished tendering process. In 2014 the refurbishment costs for projects carried out in the Federal building stock was collected in (BBSR, 06/2014).
- Within the German research project EDLIG[6] (energy services for deep refurbishments) KEA collected and evaluated at least 15 different projects with regard to the investment costs (KEA/ EDLIG evaluation 2014). In general the availability of reliable investment data is costly in terms of labour with only a few published evaluation reports available. In further research work, databases will have to be populated with estimated and verified investment costs for all crucial building types.
- The investment costs is provided on the level of single components; the cost cutting effects of measure bundles and of carrying out a project in one stage is not yet depicted in cost data bases. In this case the cost data for the scenario 4) bundle was available. A comparison to cost databases shows that the sum of single components averages >20% higher investment costs than actually achieved in scenario 4).
- For the decision making process between a maintenance refurbishment and different energetic scenarios investment costs are distinguished into measures which are necessary for the maintenance and those additional costs which are necessary to achieve the different energetic scenarios. The “maintenance costs” are painting, plastering, scaffolds, a new roof cladding, concrete refurbishments, replacement of technical equipment etc. but with no energetic improvement. Energetic related costs save energy in the future, like the thermal insulation of a wall or roof. In the case of the windows it is assumed that it is an energetic improvment.
- Life time period of measure bundles: The life time period has been derived from the averaged individual life time periods given for each measure in the German industrial standard VDI 2067[7]. To calculate the average life time periods for each scenario the individual life time periods of the considered components are weighted

[5] Energieeinsparverordnung EnEV 2014, Berlin, 2014 (German)
[6] www.edlig.de
[7] VDI 2067, Blatt 1, Beuth Verlag, Berlin 1993- 2014

at the hand of the investment costs of the measures in comparison to the total investment of each scenario. To simplify the comparison of the scenarios an average life time period of 33 years is assumed for all scenarios. The economic balance considers the costs and savings in the average life time period of 33 years. Components with a shorter life time period such as lighting and shading systems are considered with end of life- cycle maintenance costs. A re- investment of compontents with an average life time period < 33 years are not considerd; neiter are residual values of installations with an average life time period > 33 years. As these installations contain the major part of the investments (70- 80% in the scenarios) this assumptions are disadvantaging the scenarios with high level insulation.

Measure	Life time period /years	Average annual maintenance costs in % of investment costs
Wall insulation	50	0,75%
Windows	30	0,75%
Ventilation systems (unit and ducts)	27	2,5%
Lighting systems	20	3%
Shadings	20	4%

Tab.2. Life time periods and average maintenance costs according to VDI 2067

- Capital costs: The economic model assumes that the investment is 100% funded by bank loans with a loan period of 20 years with fixed interest rates. As usually fixed interest rates are limited to 20 years; so this financing model assumes that after 20 years, no further payments of loan pay back or interest rates will take place and 100% of the investment and the interest rates as well are paid back. The market offers low interest rates for loans with 15- 20 years payback period (but not yet for 33 years), the interest rate was chosen with 2.5% (20 years fixed).
- Energy Savings: The calculated energy savings of each scenario are accounted with a site energy heating price of 0.1 €/kWh and electricity 0.29 €/kWh including energy taxes and VAT of 19% in year one. In the sensitivity analysis the energy cost savings are calculated with price increasing rates of 2 % and 4%. The measure bundle has after year 20 still a residual value which generates value: the building is still in use until the year 33. All savings are accounted from the year 0-33.
- Maintenance cost savings: The replacement of existing and worn out installations and constructions is accounted to the life- cycle cost analysis. In most of the cases owners of small and medium sized building do not account data on the maintenance costs appropriately. In this modelling project the maintenance costs are calculated on the basis of the industrial standard VDI 2067 (ref. Tab. 2.) which provides empiric data for maintenance costs for some of the major construction and HVAC equipment as a percentage of the investment costs of newly installed equipment. These percentage values are considered as average values over the life time period (see above); at the start of the life time period the value is assumed to be 0, in the mid of the life time period it equates the average value given in the standard and at the end of the life time period it is considered to be double of this average value. In the case of this modelling approach 0.5% of the new investment costs are accounted for the avoided maintenance costs for the existing wall, roof, windows

and HVAC installation. An additional saving potential from the avoided maintenance which results from downsizing the HVAC equipment was not accounted.

- Other potential savings: other potential savings such as avoided insurance and operation costs were not accounted.

2.4 Cost- benefits analysis:

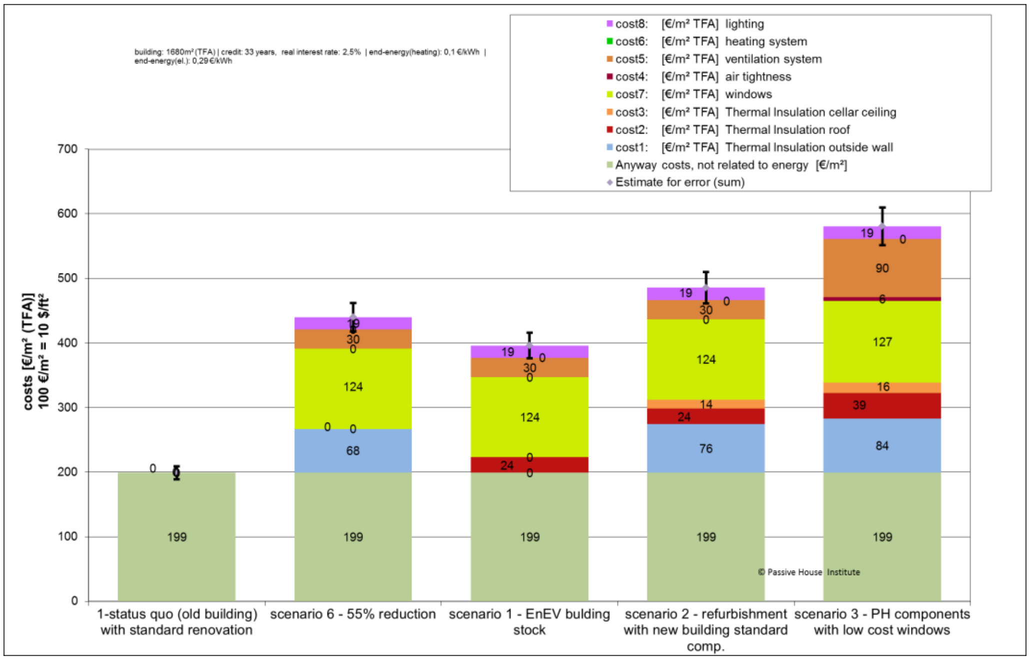
The economic calculations are focused on a 33 years period of costs and savings, based on calculated investment costs (3 scenarios), for verified investment costs from the accomplished project (scenario 4). These investment costs are transferred into annual costs by annuities which are based on a discount rate of 2.5% (fixed), no residual value and a time period of 20 years. From year 20- 33 only re- investment related costs appear and savings are still collected. Other additional costs such as maintenance of new installations and operation are not accounted. The annual savings do include the energy cost savings and avoided maintenance.

The cost- benefit analysis is in this study focused on the costs only, other value benefits such as increased building values, increased tenant rates are not assessed here. The assessment method should in this case only provide information which of the measure bundles serves the best cost benefit. The price increasing scenarios and interest rates should be considered. From the 4 optional methods (discounted cash- flow, annuity- method, dynamic payback period and the net present value) the net present value method was chosen: the net present values of all annual costs and all cost savings are accounted on today´s net present value by using the cumulated discount rates. If the difference between the net present values of savings and costs is positive.

Tab. 3. Corner points of the economic modelling of the German case study

Loan pay back period n	[a]	20
Life time period ∅ N	[a]	33
Interest rate/discount rate i	[%]	2,5
Avoided maintanance costs for replaced installations in % of new investment costs	[%/a]	0,5
Price increasing rates	[%/a]	0, 2, 4
Energy price district heating	[€/kWh]	0,10
Energy price electricity	[€/kWh]	0,29

Tab.4. Specific investment costs of measures and measure bundles of the German case study



This graph shows the investment costs per m² of the total heated floor area, splitted in maintainance costs and the energy related costs for the different measures. The same amount of maintainance investment costs is considered for all scenarios. The major differences can be found in the context of the wall and roof insulation, air tightness and different air ventilation systems. As in scenario 1 no wall insulation is realised and the other measures are on a low level it is the one with the lowest investment costs. The other scenarios are more expensive because of the more complex measures.

2.5 Description of the modeling scenarios

The plug loads were reduced significantly, by replacing old computers and tube screens trough energy efficient installations, the installation of an energy-efficient server and by the complete reduction of private coffee-machines, electric kettles and refrigerators in the office-rooms. In the modelling calculation it is assumed that the plug-loads in all scenarios are kept the same, only the electricity for lighting, ventilation and warm-water-supply and auxiliary electricity has been adjusted where needed. No cooling load is foreseen as in any scenario the minimum requirements for indoor climate conditions (air exchange rate per hour and m² and peak indoor temperatures) defined in the building code regulations was achieved. After the refurbishment the building has been connected to district heating (73% CHP and 27% oil peak load boiler).

Tab.5. Technical description of scenarios (SI Unit) of German case studies

	0 Base-line old building as built 1962	Scenario 1 EnEV building stock	Scenario 2 EnEV standard for new buildings	Scenario 3 Passive House with low cost PVC window frames	Scenario 4 Passive House (as refurbished)	Scenario 6 55 % reduction
Roof (λ=0,035 W/m K) insulation thickness / U value	no improvement	160 mm/ U=0.2 W/m²K	160 mm/ U=0.2 W/m²K	400 mm/ U=0.085 W/m²K	400 mm/ U=0.085 W/m²K	no improvement
Wall (λ=0,032 W/m K),	0	-	140 mm/	300 mm/	300 mm/	60 mm/

insulation thickness/ U-value			U=0.24 W/m²K	U=0.11 W/m²K	U=0.11 W/m²K	U=0.5 W/m²K
basement ceiling	-	-	85 mm/ U=0.3 W/m²K	120 mm/ U=0.23 W/m²K	120 mm/ U=0.23 W/m²K	-
venetian blind cassette	-	-	-	80 mm	80 mm	-
Windows:						
U values for glass		U_g=1.3 W/m²K	U_g=1.3 W/m²K	U_g=0.64 W/m²K	U_g=0.64 W/m²K	U_g=1,3 W/m²K
U values window (average of frame and glass)		U_w =1.3 W/m²K	U_w=1.3 W/m²K	U_w=0.74 W/m²K	U_w=0.74 W/m²K	U_w=1.3 W/m²K
Ventilation	exhaust air system only in rooms to the street	exhaust air system	exhaust air system	ventilation with heat recovery	ventilation with heat recovery	exhaust air system
generation of warm-water	heating boiler					
Light system						
lightening control	Manual	presence detector	presence detector	presence detector	presence detector	presence detector
natural night ventilation in Summer for cooling		X	X	X	X	X
Cooling system for server	X	X	X	-	-	X
sun protection		X	X	X	X	X

2.5.1 Scenario: Baseline

Energy performances of four different energetic scenarios were compared to the buildings' pre- refurbishment state (energy consumption, U- values, air leakage rate, and thermal bridges). In the first iterations of the modeling process the modeled demand in the baseline scenario did not meet the monitored consumption (rebound effect). This has been adjusted by modifying the usage and ventilation parameters of the building before refurbishment. The calculated specific site energy consumption for heating is 236 kWh/m²yr, the electricity consumption (incl. plug loads and excl. IT server) is 20 kWh/ m²yr. In comparison to that the measured and climate adjusted consumption for heating was 216 kWh/m²yr, the electricity consumption (with plug loads) equated to 20 kWh/m²yr.

2.5.2 Scenario 1: EnEV building stock –minimum requirement according to the German Energy Saving Ordonannce

The EnEV 2014 (current German Energy Saving Ordonnance) standard for refurbishments in the building stock allows that U-values of components are allowed to exceed 40% of the standards for new buildings. To design a modeling concept, the measures were focused on the insulation of the rooftop (160 mm/U- value: 0.2 W/m²K and the replacement of windows (Uw= 1.3 W/m²K) resulting to energy savings of nearly 40%. The ventilation of this building is redesigned as an exhaust air system in which the ventilation system transports the used air outside the building. The selection of window exchange without wall insulation may create thermal bridges at the window slab and should not be followed up by the thermal wall insulation[8]. Common to all scenarios is the replacement of the centralized boiler supported domestic hot water supply by a decentralized, electric flow type heater.

2.5.3 Scenario 2: EnEV new building standard

This renovation scenario represents the U-value criteria that are required for EnEV 2014 (German Energy Saving Ordonnance) building code. The EnEV targets a low energy standard for new buildings which is defined by minimum requirements for average U values U_m and a target values for the source energy demand. To achieve these conditions wall and basement insulation has to be applicated. The application of the standard for new buildings already leads to significant heating energy savings -75% and total site-energy savings of 71%.

2.5.4 Scenario 3: Passive House with low cost windows

This renovation scenario represents the criteria for major renovation on the Passive House level achieving savings of about 86% heating energy. This scenario does not account for new technical solutions but is the cost optimized version of scenario 4, the refurbished building in its current status. Scenario 3 takes into account that since 2011 the costs for triple glazed and specifically insulated passive house windows (U_M= 0.74 W/m²K (0.14BTU/hft²°F) has been decreased significantly. In scenario 3 and 4 a two- duct- ventilation system with separated fresh and exhaust air circuits, heating heat exchanger and a heating recovery system is implemented. In Scenario 3 and 4 it is assumed, that, the ventilation system is dedicated to be used as a stand- alone installation for heating purposes and may replace the existing radiator based heating distribution completely. The cost saving effects of closing down the existing radiators and the distribution duct work for heating hot water is however not considered in the economic modelling of scenario 3 and 4. In bothpassive house scenarios cooling is not needed to achieve the indoor climate conditions required by the building codes. .

2.5.5 Scenario 4: Passive House (current situation)

This renovation scenario represents the criteria for major renovation on the Passive House and equates the technical concept of scenario 3; the calculation predicted site energy heating savings of 86%; the acutally measured energy savings accounted to 78%.

2.5.6 Scenario 6: “50% reduction” to baseline

This scenario represents the reduction of 55 % which to achieve is requiring only a partial refurbishment with new triple glazed windows, an exhaust ventilation system, decentralized DHW and adding a thin external wall insulation 6 cm (U= 0.5 W/m²K). This thin insulation is not according to the EnEV building stock regulations where the minimum thickness is 10 cm of insulation. The same effect is taking place if the bundle of measures is chosen to be new windows with a roof top insulation.

2.6 Optimization of bundles:

Optimization of energy conservation measures means to find a minimum of total cost, which is this modelling approach the sum of energy costs, capital costs, and maintenance costs. To find this minimum, the cost structures of the measures under consideration and their effect in terms of energy savings must be known. Of course, the result of any optimization calculation will depend on the underlying energy prizes.To optimize the bundles the single measures, their investment costs and their impact on the energy performance are evaluated.

[8] EuroPHit, project description, PHI, Darmstadt, 2013

Considering energy conservation measures for buildings, the first issue is to find a cost-efficient combination of thermal insulation measures which are windows, and measures in the thermal envelope on external walls, basements and roof tops to reduce the heat losses through the envelope.

The optimization process can be carried out at the hand of the modeling, which requires a rather arduous iteration process. In this Darmstadt case study the first approach was carried out at the hand of an estimative U- value based method and in a one- step iteration of of modeling results from different scenarios.

3.6.1 Estimative Method

The estimative method refers to a simplified method using the degree days approach, considering that the heating degree days are a function of the average Um-value of the building's envelopes: with lower Um-value, the number of heating degree days is reduced, linearly in a first approximation, which leads to a (slightly) non-linear function of qh(Um). Here, in addition to the transfer losses qT, also ventilation losses are included, using a ventilation rate of nV = 0.6 h-1.

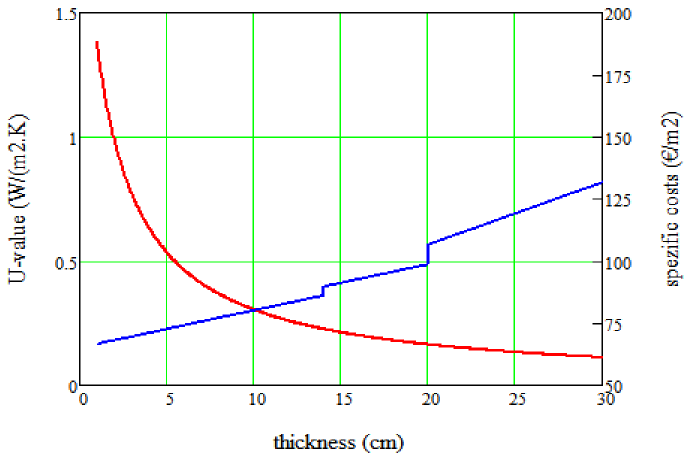


Fig. 2. U-value of external wall (red curve and left vertical scale) and insulation costs (right vertical scale) as function of thickness (heat transfer coefficient = 0.035 W/m.K).

The calculation of this estimative method is depicted at the hand of the wall insulation. Here the heat transfer loss is directly proportional to the U-value. Figure 3.6.1 shows that the benefit of additional insulation (the decreasing U-value) decreases with thickness, while the costs increase more or less linearly. The discrepance between the decreasing impact (saved Energie per floor space) and the steadily increasing investment costs creates a cost-benefit equation with a cost minimum at a performance maximum at a cartain thickness *d* of the insulation. The specific heat transfer losses of the external wall, for example, as function of its U-value Uw are proportional to Uw times the temperature difference □T between indoor and outdoor temperature. Over the heating period, with varying outdoor temperatures and fixed indoor temperature Ti = 20 °C, the annual heat loss qT, using the degree days approach, is given by:

(3.6.1) $$q_T = \frac{24}{1000} \cdot U_W \cdot H_{15}$$ kWh/m^2.yr,

with the number of degree days, H15 (Kd), depending on the climate in the given location, for a building with heating limit temperature Th = 15 °C (59°F). In the specific case study H15 = 2,050 Kd is chosen. The benefit of an additional insulation of thickness d with resulting U-value U(d) is the amount qT(d) by which the heat losses (per 1 m^2) are reduced.

(3.6.2) $$\Delta q_T = \frac{24}{1000} \cdot \left(U_W - U(d) \right) \cdot H_{15} \quad \text{kWh/m}^2\text{yr.}$$

Remark: In this modeling case study the embedded energy ee is not considered. If taken into account for large insulation thickness, the energy content of the insulation material, the embedded energy ee(d) (kWh/m^2) must be subtracted from the energy savings δqT of Equation (3.6.2).

Employing the cost structures described above, a "least-cost" path of these measures can be derived. This least-cost path is achieved by a stepwise comparison of the capital, energy and in this case maintenance costs of every possible saving measure.

As each of the data points for captital/energy and total costs represents one specific measure bundle, the quantitative result of this model is a list of measures that contribute to the combination of measures that are implemented to achieve the minimized total heating costs (capital costs plus energy costs) of the considered building or building type.

2.6.2. Iterative NPV optimization

The iterative NPV considers the results of the energetic and economic modeling results for each scenario. By the assessment of the energetic contribution and the investment costs the most cost effective measures were identified. In the iterative method a comparsion of Net Present Values of the part of life- cycle costs which are considered: energy, maintenance and capital costs. In this modeling effort the results were optimized by NPV optimization; the results are shown and discussed in Fig.10, Fig. 11.

To prepare for the fine tuning of the results it has to be considered which measures contributes in which way to the energy efficiency and at which costs.

In a first approach the impact of each measure is assessed by comparing specific energy savings to the U values of measures in different scenarios for this case study. Fig.3.shows the relation between the U values of different measures and their energy savings. Increasing the U value of the wall by 0.1 induces energy savings of 9 kWh/m²yr. A comparable ratio can be achieved by increasing the roof top insulation by 0.1. In the case of the window this value is at 7 kWh/m²yr. In the case of the basement ceiling insulation the ratio is at 5 kWh/m²yr.

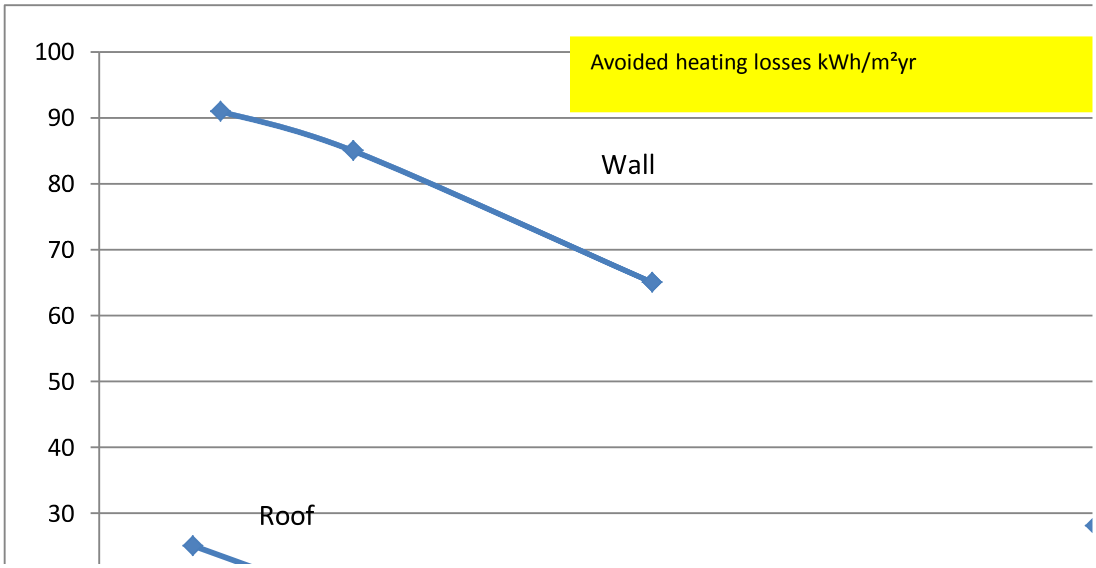


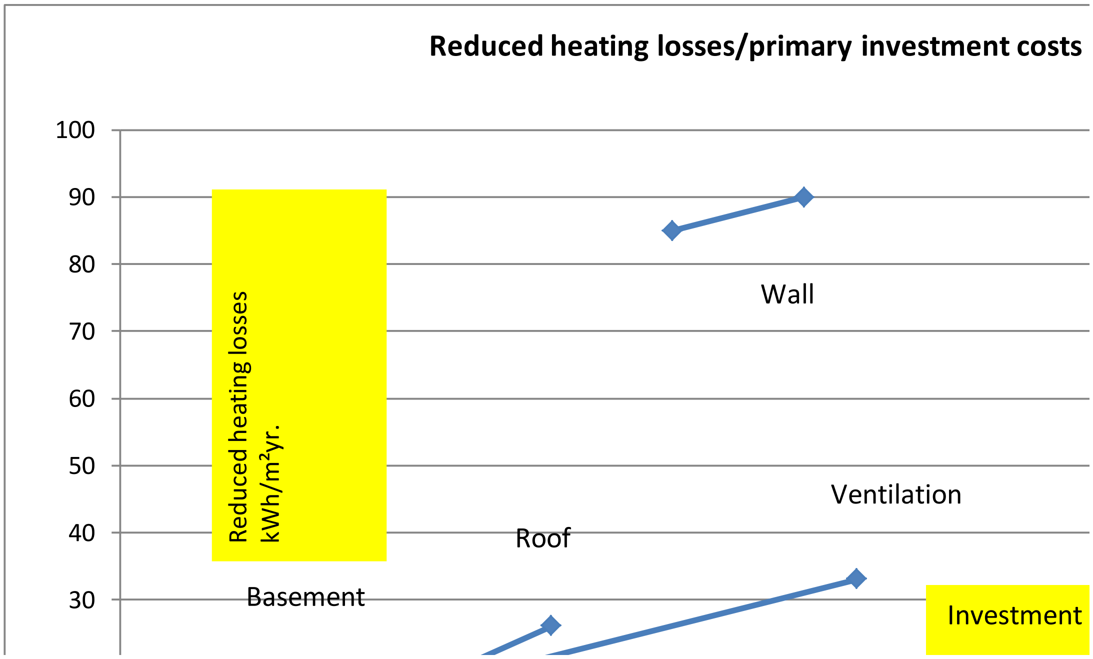
Fig. 3. Energy savings per U value improvement in the Darmstadt case study

In a second step the investment costs of thermal insulation measures and their impact on the energy balance of the specific building are assessed in Fig. 3.6.3. It shows the investment costs per m² heated floor space of different modeled measures and the energy savings per heated floor space and delivers the ratio of annual energy saving per m² and € investment costs.

The highly- cost efficient external wall insulation also is responsible for the largest amount of savings. However the impact per additional primary investment between the right (Passive House) side of the wall insulation curve and the left side (building code for new buildings) is comparably small: additional 30 €/m² (2.9 €/ft²) investment costs only contributes to 8 kWh/m²yr (2.9 kBtu/ft²yr) of energy savings. A comparable ratio is achieved with the roof insulation (flat roof).

The investment in a high efficient ventilation system with heat recovery shows a minor additional investment compared to an exhaust air ventilation system.

Fig.4. Investment costs and heating loss reduction in the German case study (1960 office building, 1,680m², compactness A/V: 0.38; before refurbishment: U wall=1.36, U roof= 0.7, U window= 3.3 W/m²K and 236 kWh/m²a heating)



2.8 Primary or Source energy calculation:

At the hand of the site energy balance the fuel specific source energy pe is calculated with reference to National databases for pe factors GEMIS[9] which considers a global emmissions model for integrated systems; the pe of electricity refers to the German electricity mix. To single out the impact of the ECM bundle the calculation has to be done for the first time after accomplishing the building concept with a reference energy supply: in this case study, the determined supply system was district heating.

Tab. 6. Fuel-specific pe and CO_2 equivalent factors (including all GHG emissions) used in Germany (Jank, 2015)10

	Primary energy factors
	kWh**PE** /kWhEE
Lignite	1.21
Hard coal	1.08
Natural gas	1.12
Heating oil	1.11
Wood chips	0.06
Wood pellets	0.14
Thermal solar	0.15
Photovoltaics (PV)	0.61
Wind	0.06
Electricity mix 2014	2.13

[9] GEMIS database,global emmission model for integrated systems, gemis.de; 2014

[10] R. Jank and Kuklinski, R., Integriertes Quartiers-Energiekonzept Rintheim – Methoden, Erfahrungen, Ergebnisse; Fraunhofer Verlag, Stuttgart (2015)

Tab. 7. Site and Source Energy EUIs

	Baseline (Scenario 0)		Minimum Standard (Scenario 1)		DER (50%) (Scenario 6)		Passive House (Scenario 3/4)	
	ΔE, %		ΔE, %		ΔE,%		ΔE,%	
Energy	site	source	Site	Source	site	Source	site	Source
calculated energy savings [%]	**0**	**0**	40%	39 %	55%	53%	81%	76%
calculated energy savings [kWh/ m²yr]	**0**	**0**	**103**	**119**	**142**	**163**	**208**	**235**
EUI [kWh/m²yr]) energy consumption calculated	**256**	**307**	**153**	**188**	**114**	**145**	**48**	**72**

2.9 Results of the German modeling approach

With regard to the implementation of the case study results in a practical decision making process two NPV have to be considered:

- The first one considers only the energy related investment and capital costs also energy and maintenance cost savings in the net present values (NPV); this is to determine the energetic level and assumes, as it is in this case study, that the maintenance related investment costs are given and have to be financed anyway to keep the building in its functionality. This perspective is relevant i.e. if a government provides funding for a repurpousing (seed money) and the energy related measures have to be funded in an EPC.
- The second one considers that the global investment and capital costs have to be accounted and out-balanced by the energy and maintenance cost savings
- Capital costs consider a funding of 100% of the investment costs by loans with an interest rate of 2.5% and a pay off period of 20 years.

a) Comparison of net- present values (NPVs) of energy related investments, costs and benefits:

This scenario could support decision making process if the basic costs are funded by a different source which is not related to the energy and not- energy related cost savings and have not to be taken into account.

- All NPVs are positive- for all scenarios the NPVs of savings are larger than the NPVs of costs which means they are cost effective within 33 years of calculation term
- The best NPV is generated by the EnEV building code for new buildings followed by the cost- optimized passive house scenario

Four main parameters of the economic modeling are influencing the positive NPV results:

- The long time period of the economic model in which the costs and savings are collected
- The over- average price for heating energy- actually 0,1 €/kWh
- The fixed interest/discount rate over the complete time period of 20 years financing period

The sensitivity analysis with lower price for heating energy (0,06 €/kWh) and assumed that annual costs for the maintenance of 0,025 % of new investment costs is taken into account the NPV of all scenarios and price scenarios is still positive but reduced to 25% of the NPV generated without these adjustments. 33 years is still a long time period which will not be attractive for short and medium term capital.

Fig.5. NPV of different scenarios of energy related investment costs per m² of the case study

This graph shows the Net Present Values (NPV) for the refurbishment of the scenarios 1,2,3 and 6. It is the sum of the savings of energy and maintainance costs deducting the energy related cost for the refurbishment in 33 years. All values are discounted to the present value. The different colors of thecolums show the NPV for different energy price increase scenarios. (Blue = 0% energy price increase, red = 2%, green = 4%).

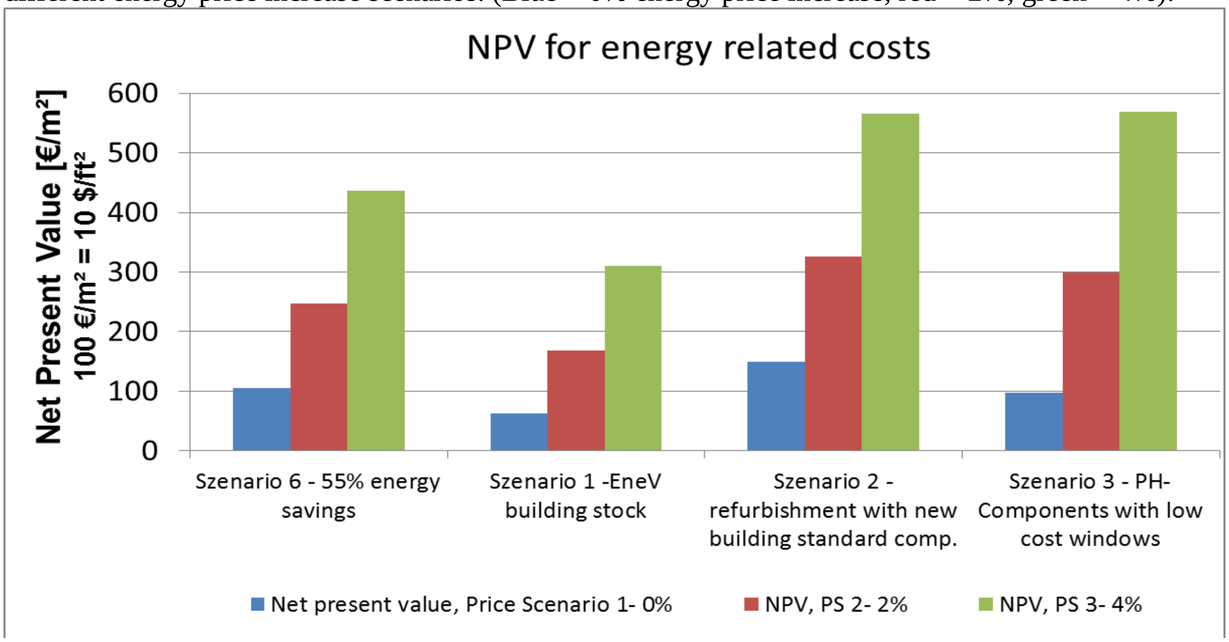
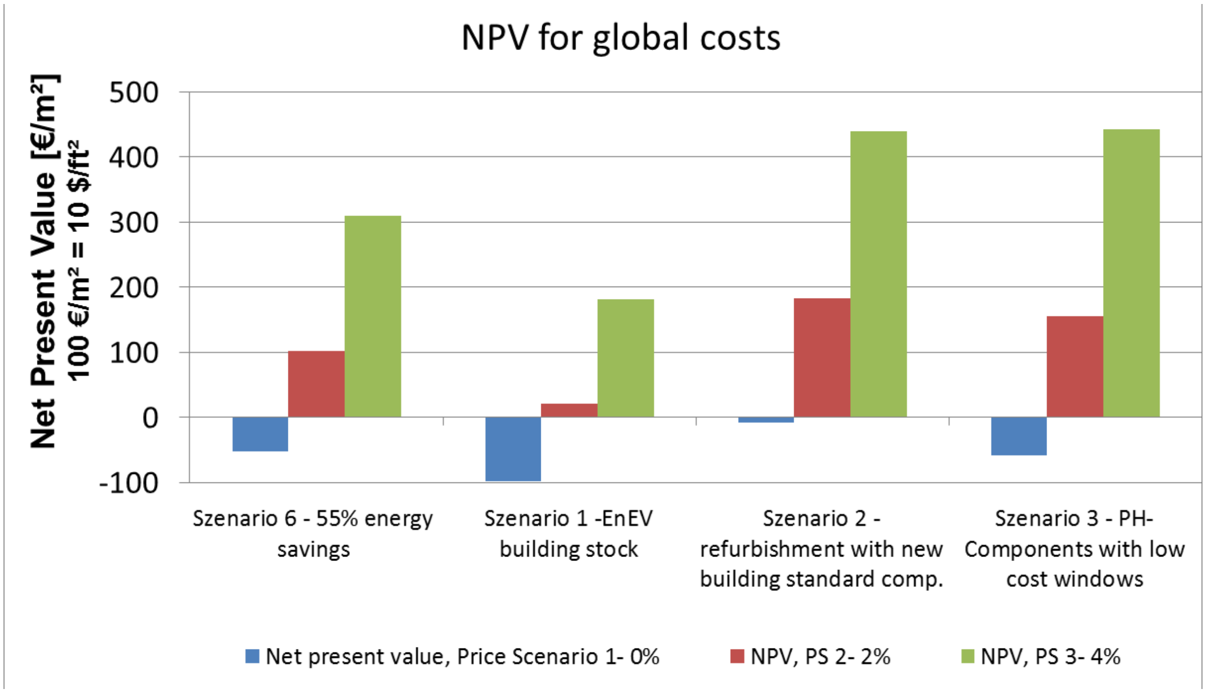


Fig. 11. NPV of different scenarios of global investment costs per m² of the German case study

This graph shows the Net Present Values (NPV) for the refurbishment of the scenarios 1,2,3 and 6. It is the sum of the savings of energy and maintainance costs deducting the global cost for the refurbishment in 33 years. All values are discounted to the present value. The different colors of the Colums show the NPV for different energy price increase scenarios. (Blue = 0% energy price increase, red = 2%, green = 4%)



b) Comparison of global cost NPV:

In this scenario the total investment costs, energy related and basic costs together are accounted for decision making. This is the case in most of the business and funding models, as it assumes that all costs are funded and will have to be paid back completely to an investor, bank, funds or ESCO.

- Except price Scenario 1 without energy price increase all NPVs are positive- for all scenarios the NPVs of savings are larger than the NPVs of costs
- The best NPV is generated by the EnEV building code for new buildings (Scenario 2) which is followed by the cost optimized PH scenario (Scenario 3)

If the calculation is carried out with lower price for heating energy (0,06 €/kWh) and assumed that annual costs for the maintenance of 0,025 % of new investment costs is taken into account the NPV of all scenarios is in price scenario 1 (no price increase) negative. When calculating a 2% price increase most scenarios (except for scenario 1) turn into positive. The payback period of the best scenarios is in a range of 33- 37 years.

2.10 Summary and conclusions for German case study

This research work was done under IEA EBC Annex 61 “Business and Technical Models for DER” which targets the identification of high efficient measure bundles for deep retrofit project. KEA collected some 20 well documented building refurbishment projects and picked an office building from the 1960´s which was refurbished in 2011/12 into Passive House standard. For this building a modelling case study was set up to calculate at least three different scenarios (minimum requirements by German building code, - 55% and a passive house scenario). An additional scenario was created by optimizing the cost effectiveness of the DER measure bundle at the hand of the NPV. The NPV was calculated from the capital, energy and maintenance costs of each scenario. The economic model focuses the average life time period of the measure bundles of 33 years. It is assumed that, due to

national use the loan payback period will be not more than 20 years in which the investment loan including interest rates is completely paid back.
The technical and economic assessment of the scenarios shows the following results:

- The standard scenario which fulfils the requirements given by national building code EnEV 2014 for refurbishment of the building stock with refurbishing only a part of the building construction. In our case, just to show a technical sub- optimal solution, a refurbishment of windows and the roof would be sufficient. With energy savings of 40% this scenario is also not economical competitive to more ambitious measure bundles.
- For the "-55%", which is scenario 6 the results are more competitive. To comply with – 50% a partial refurbishment which foresees the window and a shallow layer of insulation either on the roof or the wall will be sufficient. In our case the thin wall insulation from Scenario 6 would save 55% of heating but would not comply with the national building code and should not be considered.
- The EnEV 2014 building code for new buildings and the cost optimized Passive House standard both lead to deep refurbishments (> 70% of energy savings according to BPIE definition) and lead to competitive economical results. These two scenarios would pay back the total investment as well as only the energy related part of the investment.
- This economic equation does not show the benefits of the higher comfort of the air ventilation system with heat recovery, with almost room temperature of the fresh incoming air and a reliable air exchange.

However, from these results a general conclusion cannot be derived: premises, U values, building usage etc. have to be considered on the level of the individual building. For this building type the EnEV 2014 for new buildings and the cost optimized Passive House standard would be an economical competitive solution in which the total costs of the energetic refurbishment would be paid back from energy cost and maintenance cost savings in 25- 35 years. Both solutions would comply with the EU strategy to accelerate the energy efficiency in buildings by deep retrofit projects with savings > 70%. Also these two solutions could be used for EPC related deep retrofit business models.

List of Tables and Figures

Literature List

Footnote Nr.	Title, author, year, language (DE: German)
1	PHPP Passive House Planning Tool, PHI, Darmstadt 2010- 15
2	Assessment of 8 accomplished DER projects in 8 German public buildings, EDLIG, 2014 (DE)
3	Prebound und Rebound Effekt in der energetischen Modellierung, IWU Darmstadt, 2013 (DE)
4	EnEV German energy efficiency ordonnance, 2014, Berlin (DE)
5	VDI 2067, German industrial standard 2067, Paper 1, Beuth Verlag, Berlin 1993- 2014
6	EuroPHit project description, PHI, Darmstadt, 2013
7	GEMIS database (Global emission model for integrated systems), gemis.de, 2014 (DE)
8	Integriertes Quartiers- Energiekonzept Rintheim- Methoden, Erfahrungen, Ergebnisse, Fraunhofer Verlag Stuttgart, 2015
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