Programme of actions towards Factor 4 in existing social housings in Europe

Deliverable 7

Potential energy savings for some representative buildings by using the VROM model

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Part 4– The German analysis

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Preliminary remarks:

The VROM model as shown in the deliverable 5 and 8 deals mainly with the envelope of the buildings and cannot be really compared to the 3 other models (even if some comparisons are done between the VROM model and the ASCOT model worked out for Denmark).

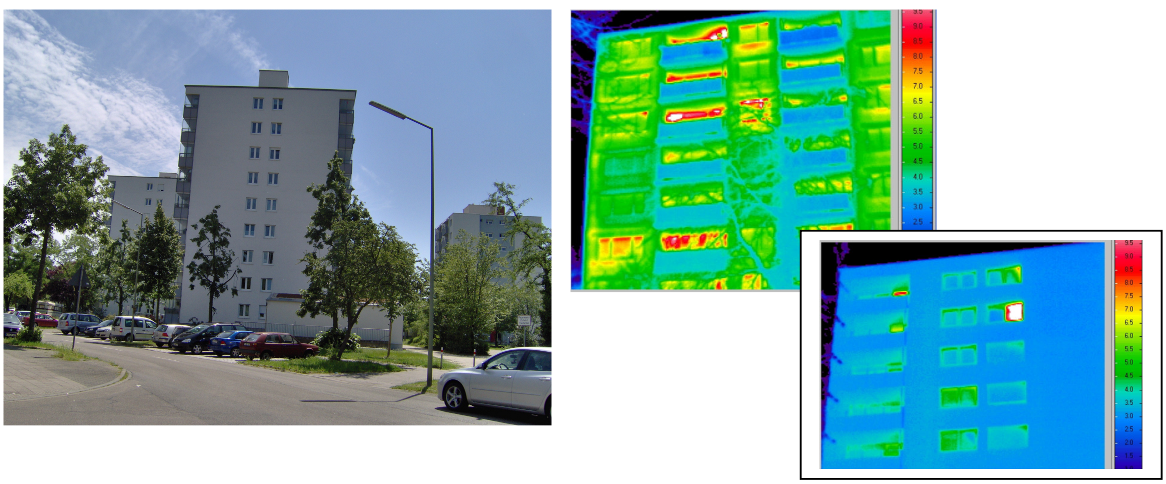
As discussed in deliverables 5 and 8, experiences with existing calculation models for energy conservation measures in dwelling buildings, both from Germany and from the Fctor 4 project, for VoWo led to the conclusion that a model which is able to automatically derive the economically optimized conservation measures for a given building would serve our needs best. Therefore, a new model VROM ("Volkswohnung Retrofit Optimization Model") was developed, which was able to simulate the effects of different energy conservation measures and, using existing cost curves from recent retrofit experiences of VoWo, find the economic optimum of these.

In the following, at first detailed results achieved by applying several models to one defined Case Study - before and after retrofit – are presented to compare the energy consumption calculated by the different models with reality. In the next sub-chapter, the optimization results of VROM are discussed in detail.

Case Study 1: Karlsruhe, Kranichweg 4

1. Basic data

Fig. 1: Case Study 1: Kranichweg 4, Karlsruhe, after retrofit, left; IR-photograph before (upper graph, west façade) and after retrofit (lower graph, east façade), right



The building Kranichweg 4 is characterised by the following data:

year of construction	1967
number of storeys	9
number of dwellings	28
total living area	2.255,4 m^2
year of refurbishment	2006
heating system	central heating plant (gas-boiler), radiators, integrated DHW supply with circulation pipe
climate	Karlsruhe ("nördlicher Oberrheingraben") annual mean temperature: 10,5 °C lowest monthly mean temperature: 1,7 °C design temperature: - 10 °C degree days: Gt_{15}^{19} = 2.500 Kd

The relevant data, which define energy demand and supply of this building are as follows:

		before refurbishment			after refurbishment	
	area (m^2)		wall thickness (cm)	U-value ($W/(m^2.K)$)	insulation thickness (cm)	U-value ($W/(m^2.K)$)
walls	1.191	cavity blocks, no extra insulation	39,5	1,6	14	0,22
roof ceiling	327	massive; 2 cm insulation	15	0,98	18	0,18
basement ceiling	327	massive, no insulation	7	3,27	6,5	0,44
windows	523	double glass (“Isolierverglasung”)		2,8		1,3 (high efficiency windows; U_{glass}=1,1))
heat bridges (balcony, basement perimeter, windows)		no removal	-	-	removal	
total U-value				2,14		0,46

The building was renovated in 2006, leading to a very good new insulation standard. The different measures, as described in the table above, have been “optimized by experience”, meaning that the measures have been chosen in a way that after retrofit a heating demand of about 50 $kWh/m^2.a$ would result, which was considered to be an economic optimum at an energy price of 65 €/MWh. Thickness of insulation primarily is given by the thickness of pre-fabricated PE layers (λ = 0,035 W/m.K, thickness usually 5 cm; some manufacturers have different thicknesses).

The energy demand of the building before and after retrofit (2005 and 2007 respectively) is known and can be compared with the calculated results of the models.

2. Comparison of model results for Case Study 1

For the example of this Case Study, some of the models discussed in deliverable 5 were used to calculate heat balances before and after refurbishment to be able to compare the models according to one defined case.

According to the results of the model runs, the heat energy balances before and after retrofit are as follows:

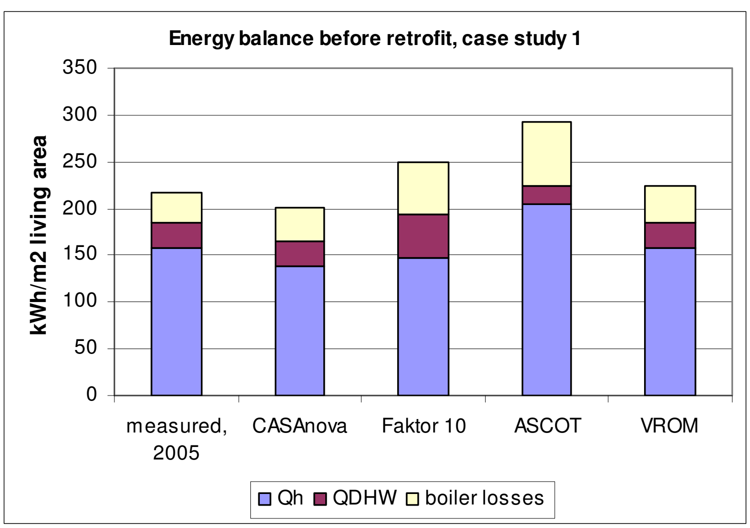
	Case Study 1: heating energy demand									
	before …					… after renovation				
	Q_h	Q_{DHW}	PE	boiler losses	boiler efficiency	Q_h	Q_{DHW}	PE	boiler losses	boiler efficiency
	kWhth /m²	kWhth /m²	kWhth /m²	kWhth /m²		kWhth /m²	kWhth /m²	kWhth /m²	kWhth /m²	
measured, 2005 / 2007	158	27	217	32	0,85	59,6	15,9	85	9,5	0,89
CASAnova 1), 2)	139	27	201	35	0,83	37,1	20	66,4	9,3	0,86
Faktor 10	148	45	250	57	0,77	40	20	69,8	9,8	0,86
VROM 1)	158	27	224	39	0,83	45	20	75,6	10,6	0,86

1) no DHW considered
2) description of models see deliverables 5 and 8.

In the table above, results of some of the models, which have been discussed in deliverable 5 are compared concerning their calculated energy demand (heating demand; DHW only calculated by "Faktor 10"). As some of them consider DHW and some do not, to be able to compare them the results of CASAnova and VROM have been supplemented by a DHW value according to the real DHW demand as measured before and after renovation. The result is shown in fig. 2 (before retrofit) and fig. 3 (after retrofit).

In fig. 2, the model results are compared with the measured values of Case Study 1 from 2005, corrected for standard degree days. The models deliver quite good results compared to the measured value for the heating demand. The demand for DHW is overestimated by the "Faktor 10" model. CASAnova and VROM do not calculate DHW, these values have therefore been supplemented according to the measured value. Accordingly, they are "correct" per definition.

Fig. 2: Comparison of model results for Case Study 1, before retrofit



Remark: a test has been done with the ASCOT model but this one is not suitable for Germany and this comparison should not be done.

In fig. 3, the model results are in addition compared with the detailed demand calculation using a comprehensive planning tool on the basis of EnEV (the actual building code in Germany), which "by law" defines the DHW demand – without distribution losses – to be 12,5 kWh/m^2. Assuming a distribution performance of 70 %, the DHW to be generated by the boiler is 18 kWh/m^2.

Fig. 3: Comparison of model results for cases study 1, after retrofit (demand of DHW is not calculated by CASAnova and VROM, here the measured value for 2007 is used)

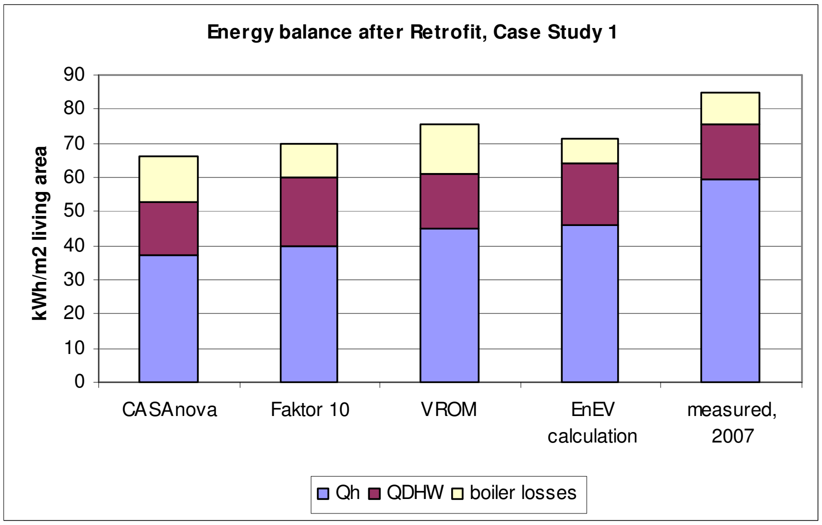


Fig. 3 shows a relatively modest agreement of the model calculations (results of ASCOT are not shown, because no reasonable output was received for the after-retrofit case). According to the consumption measurements for 2007, the real heating demand corresponds best with the EnEV calculation and with VROM - however, the calculated model values for the heating demand are 25 % too low. This result should not be overstressed, since the heating demand is strongly dependent from user behaviour. The fact that the measured heating demand is higher than calculated must be understood as an indication that the user behaviour should be influenced by the housing company, using suited communication means, which is actually done by VoWo in the framework of another research project, SAVE@energy4homes.

Since VROM is delivering plausible results on the heating demand, and since VROM – for VoWo - is superior to the other models in terms of transparency and useful information concerning individual physical parameters and cost structure, VoWo is using VROM to carry out the case studies.

The disadvantage of VROM is that it is dealing with heating demand only - as a function of insulation or other improvements of the building (windows, ventilation, boiler). DHW or household electricity consumption are not considered by VROM. In addition, for the heat supply only boiler exchange is considered by VROM. Also here, consideration of district heating, solar collectors, cogeneration, other renewables is left to the user and has to be treated outside the model.

3. Detailed factor 4 investigation, using VROM for Case Study 1

The big advantage of VROM – and in fact the reason why VoWo has decided to develop this model – is that it delivers automatically that combinations of measures that presents the minimum cost that is necessary to achieve a given improvement in terms of primary energy consumption. (In the approach using the French model SEC, this optimization is made "by experience" → see part 2of deliverable 7). Using this feature, the dependence of total energy cost (sum of capital cost, maintenance cost and energy cost) from the cost structure of different conservation measures can be studied and information about the long-term optimum can be extracted, based on a life cycle analysis.

VROM is described in detail in deliverable 8. Here only results of some model runs of VROM applied to Case Study 1 are presented and the conclusions that are available by these results.

To be able to optimize the costs for envelope insulation, whose thickness theoretically can be varied continuously, the cost structure as a function of thickness must be known. This cost function is to some extent dependent from the building type. The next figure illustrates these envelope cost functions for Case Study 1 as an example, assuming that these costs depend from thickness in a linear form.

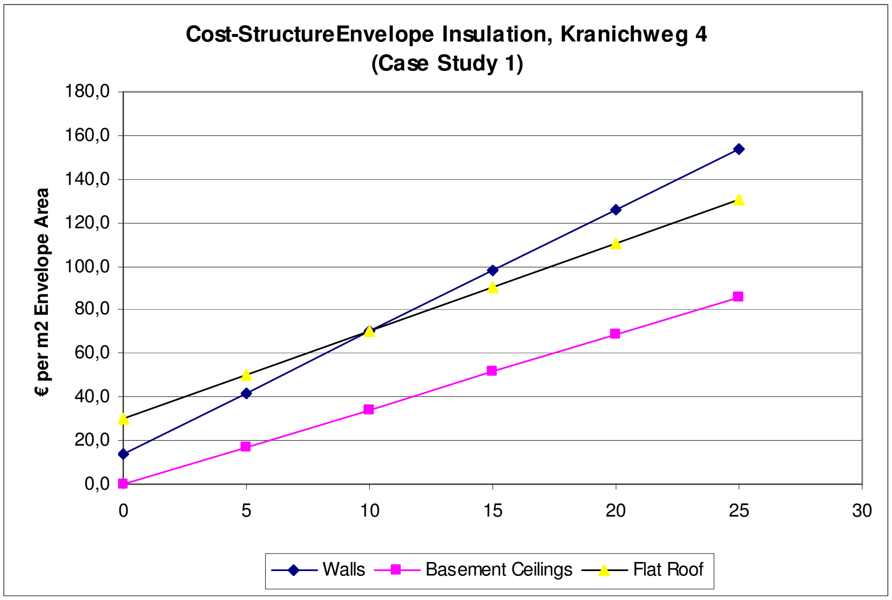
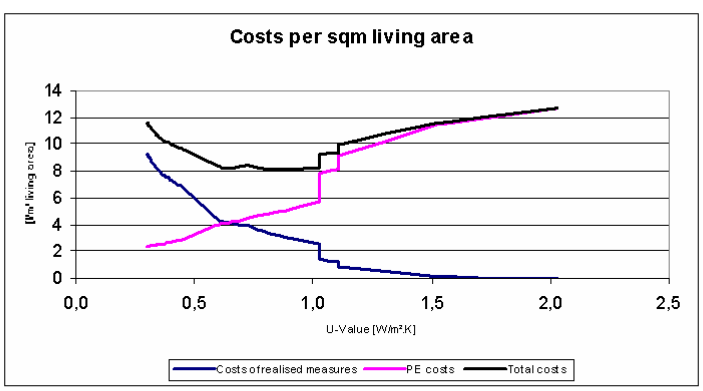


Fig. 4a: Cost structure of envelope insulation as a function of insulation thickness, Case Study 1

One result of an optimization run for Case Study 1 (Kranichweg 4) for a given end energy price (65 €/MWh) is shown next:

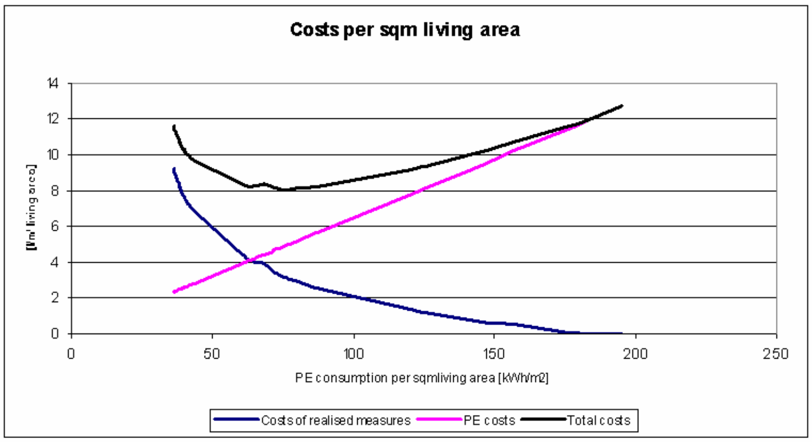
Fig. 4b: Case Study 1: least-cost path of energy conservation measures as a function of mean U-value of the building, demonstrating the increasing cost of conservation measures and decreasing energy cost (€/m^2), leading to a total cost minimum at a mean U-value of 0,88 W/m^2.K (primary energy price 65 €/MWh).



The cost minimum shown in fig. 4b is rather flat. It includes insulation of wall and basement ceiling as well as removal of heat bridges and replacement of the existing boiler by a condensing boiler and the installation of a mechanical ventilation system (the latter two measures cause the two steps in the curves of fig. 4, because both measures reduce energy demand, but do not influence the U-value, which is the x-axis in this illustration). Additional insulation of the flat roof and replacement of the existing windows by high efficient windows increase the total cost compared to the cost minimum, therefore these two measures are on the left side of the cost minimum. However, comparison with the initial total cost (at an energy price 65 €/MWh) shows that including new windows and insulation of the flat roof results in less total cost compared with energy cost before retrofit – and reduce the total primary energy consumption (= end energy consumption) for heating demand appreciably.

A more convenient representation of the same result is given by the development of the specific primary energy consumption (kWh/m^2) as a function of the conservation measures:

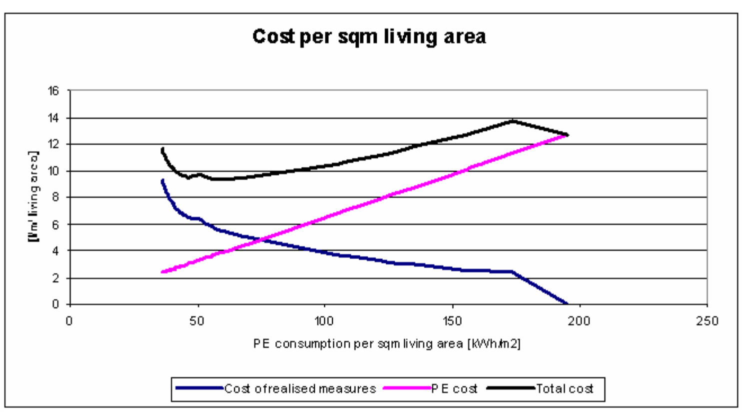
Fig. 5: Same result as fig. 4b, using the specific primary energy consumption per sqm as x-axis



As fig. 5 shows, there is a cost minimum at 59 kWh/m^2 primary energy consumption (heating and DHW), corresponding to about 50 kWh/m^2 heating demand. Following the idea above and including windows replacement and roof insulation, the energy consumption drops below 45 kWh/m^2 (or heating demand below 40 kWh/m^2), which really is a “low energy building”. However, realizing these additional measures would increase the total cost by 20 % from 8,10 to 9,70 €/m^2.

An integral refurbishment without replacement of the existing (old) windows is not reasonable. Therefore, VROM allows to enforce realisation of such a measure independently from its economic feasibility. The resulting calculation is shown next:

Fig. 6: VROM run with enforced windows replacement: the model realises this measure first (leading to an increase of total cost) and then optimises all other measures.



The model in addition to optimization allows – besides searching for the absolute cost minimum – to preset a defined value of end energy consumption that should be achieved with minimum cost. In this case the calculations run as before, but that combination of conservation measures is provided by VROM, which allows to achieve the pre-defined end energy consumption with the least cost. The following table shows an overview of the results, all achieved with fixed energy price of 65 €/MWh and 3,5 % interest rate.

		cost minimum	**with enforced windows replacement**	**target: 50 kWh/m² end energy consumption**	**target: 45 kWh/m²**	**target: 40 kWh/m²**	**realised**
wall	cm	5	5	8	8	13	14
basement ceiling	cm	5	5	8	8	11	6,5
flat roof	cm	0	0	2	8	13	18
windows replacement		no	yes	yes	yes	yes	yes
total U-value	W/m².K	0,88	0,73	0,73	0,46	0,37	0,43
end energy consumption	kWh/m².a	77	59,6	50	45	40	42
total end energy cost	€/m².a	8,10	9,35	9,58	9,60	10,26	11,35

Table 1: Overview over results of VROM runs (65 €/MWh)

Tab. 1 shows that the energy conservation measures that have been implemented in 2006 for Case Study 1 were highly ambitious but did not quite verify a least cost combination. However, it came close to the minimum at a target of about 40 kWh/m² specific heating demand, which is roughly a "factor 4" in terms of heating demand, compared with the heating demand before retrofit .

Varying the end energy price, it turns out that the optimum of energy conservation measures – not surprisingly – depends rather strongly from this price. Using end energy prices of 35, 65, 95and 120 €/MWh, the economic optimum goes as shown in table 2 (Windows replacement enforced in any case):

end energy price	U-value at cost minimum	end energy consumption
35 €/MWh	0,93	107,0
65 €/MWh	0,73	59,4
95 €/MWh	0,48	45,6
120 €/MWh	0,46	44,8

Table 2: Optimum of conservation measures depend on energy price

As table 2 shows, there is a "saturation price", where increasing energy price does not deliver much increased energy conservation measures. For the building type represented by Case Study 1, this "saturation" in terms of mean U-value is in the range of 0,45 W/m².K:

Fig. 7: Optimized mean U-value as a function of energy prize level, Case Study 1

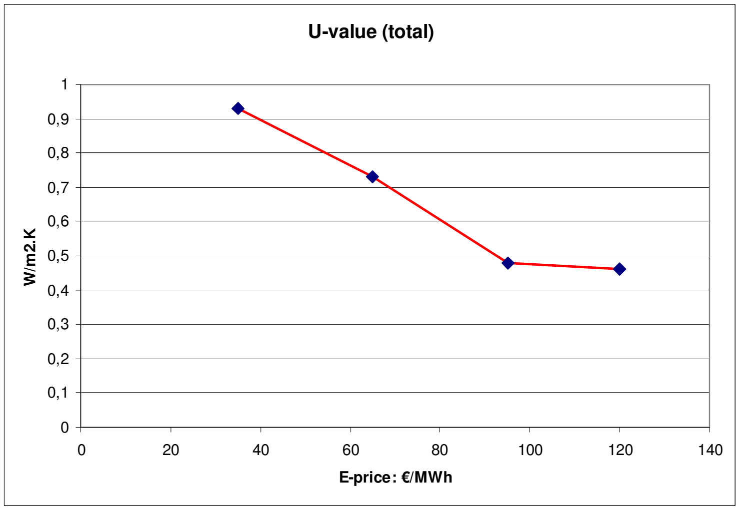
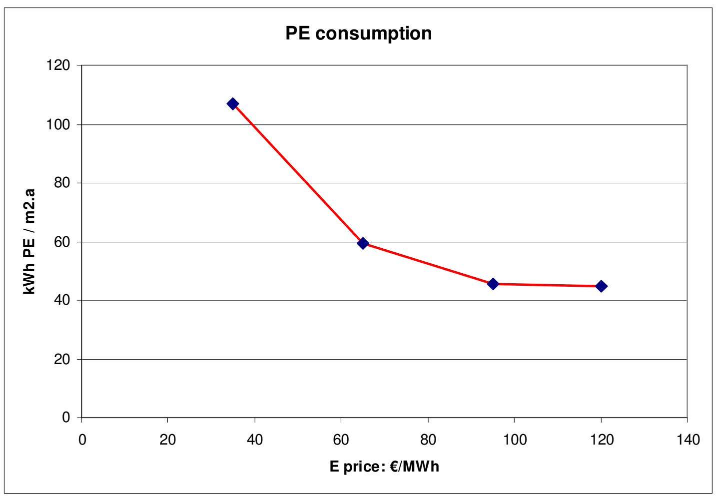
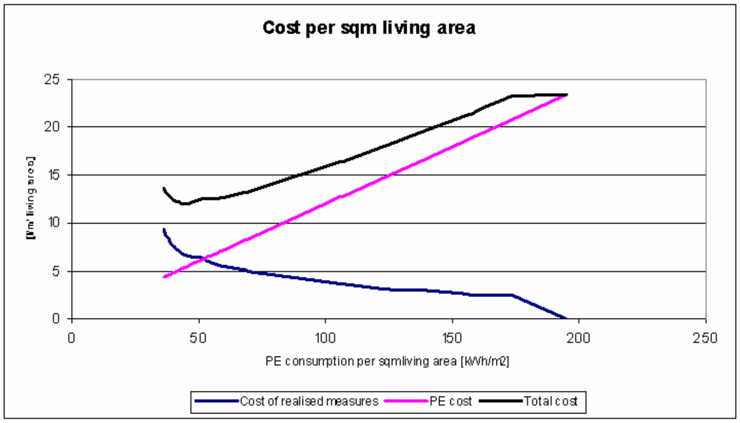


Fig. 8: Resulting specific primary energy consumption as a result of the optimized U-values according to fig. 7



At such a high price of 120 €/MWh, an optimised combination of energy conservation measures will cut the total energy cost compared to the state without retrofit by a factor of 2, as fig. 9 shows. Such a high prize may seem unrealistic. However, if the present market prize of raw oil (> 120 $/bl) would be sustained, a price of about 90 €/MWh would be true already today. The results have shown here and elsewhere in this report show that it is really important to improve the energy performance in the social housing sector to reduce the burden to be expected from skyrocketing end energy prices.

Fig. 9: VROM run with an energy price of 120 €/MWh



Concluding, VROM is a useful means to examine the least-cost combination of energy conservation measures for dwelling buildings, assuming that the cost structures of the modelled measures are correct. VROM can thus contribute to an optimized long-term refurbishment strategy of VoWo, providing the best conservation strategy for every building type.