The influence of time-of-use rates on the optimal retrofit strategy for multi-family residences heated with electricity

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Abstract

The profitability of energy conserving retrofits implemented in a building depends of course on the rate or tariff for energy used by the utility. Using a fixed rate, with a constant energy price during the year means that sun collectors and insulation measures will have equal profitability if they save equal amount of energy. In cold climates, as in Sweden, the cost for producing an extra unit of energy differs a lot during the year. In the summer the cost is very low, of the magnitude 0.05 SEK/kWh, while during the winter the cost can be ten times higher. (1 US $ equals app. 6 SEK). If a tariff that reflects this cost is implemented, solar collectors will have ten times less profitability than insulation measures. This paper shows how the optimal retrofit strategy for a building will change if a time-of-use rate is implemented by the utility. This optimal solution is provided by use of the OPERA model which finds the best retrofit strategy for each unique building.

Abstract

Résumé. (Translated by unknown expert.)
La rentabilité des mesures de rénovation des immeubles prise en vue de conserver l'énergie, dépend naturellement des tarifs de l'enterprise d'électricité. L'utilasation d'un tarif fixe (même prix de l'énergie sur toute l'année) fait quecapteurs solaires et mesures d'isolation auront la même rentabilité s'ils permettent d'economiser la même quantité d'énergie. Sous des climats froids, comme in Suéde, le coût de production d'une unité supplémentaire varie beaucoup au cours de l'année. En été le coûteest trés bas, environ 0.05 SEK/kWh, tandis que pendant l'hiver le coût peut être dix fois plus élevé (100 F = 107 SEK). Si l'on applique un tarif reflétant ce coût, les capteurs solaires auront un rentabilité qui est dix fois moindre que celle des mesurs d'isolation. Cet article indique de quell manière la stratégie optimale de la rénovation des habitations peut changer, si l'entreprise d'électricité applique un tarif horo-saisonnier. Cette solution est obtenue par le modèl OPERA, qui trouve la meilleure stratégie de rénovation pour chaque cas particulier.

Abstract

Zusammenfassung. (Translated by unknown expert.)
Die Rentabilität der energiesparenden Renovierungsmassnahmen für Gebäude

hängt natürlich von dem Tarifen des Energieunternehmens ab. Die Verwendung eines festen Tarifes, also eines konstanten Energiepreises über das ganze Jahr bedeutet, dass Sonnenkollektoren und Isolationsmassnahmen dieselbe Rentabilität haben, wenn durch sie dieselbe Energimenge eingespart werden kann. In Gebieten mit kalten Klima, wie in Schweden,schwanken die Produktionskosten fûr eine zusätzliche Energieeinheit im Laufe des Jahres beträchlich. Im Sommer sind die Kosten sehr niedrig, etwa 0.05 SEK/kWh, während sie im Winter zehnmal höher sein können. (100 DM = 364 SEK). Wird ein Tarif angewendet, der diese Kosten wiederspiegelt, so hätten di Sonnenkollektoren eine Rentabilität, di zehnmal geringer ist als jene der Isolationsmassnahmen. Diese Artikel zeigt, wie sich die optimale Renovierungsstrategie fûr Gebäude ändern kann, wenn das Energieunterehmen einen "time-of-the-day or time-of-the-year" Tarif anwendet. Diese Lösung wird durch das OPERA-Modell angeboten, das die beste Renovierungsstrategie für jeden einzelnen Wohnungsfall findet.

INTRODUCTION

Since 1985 a research project is running funded by the Swedish Council for Building Research and the municipality of Malmö in Sweden. The aim of the project is to develop a method which enables one to find the best possible combination of building envelope, installation and heating equipment retrofit measures for each unique multi-family building.

The first problem to adress is to decide how to characterize the best solution. We have found that this is the lowest Life-Cycle Cost, LCC, for the building. The LCC is the sum of the total building cost, the maintenance cost and the running cost. If it is possible to find this lowest LCC no other solution can be found better. Of course there are also certain constraints with this concept. The different costs must be provided in monetary terms, i e money. In this case there are only energy related costs that are considered, aestetical or other reasons for implementing retrofits are excluded from the considerations. In Ref. [1] the LCC concept is dealt with in more detail.

Another problem is to decide how to deal with costs emerging in the future. Here we have used the present value method which transfers all the future costs to a base year, in our case to the present year. This will also cause problems in order to choose a proper discount rate and optimization period. Unfortunately, there are no ultimate choices for these parameters and thus the calculations are elaborated first for a base case with 5 % real discount rate and 50 years of optimization time. The calculations after this can be elaborated for other values in order to perform a sensitivity analyzis. In Ref. [2] this is dealt with in more detail.

There are also problems with the optimization methods. In our case we have used derivative methods for insulation measures, which can be treated as continous functions while e g window optimization are dealt with by the direct search concept. More about optimization methods can be found in Ref. [3].

The ideas discussed above and others have been set together in a mathematical model called OPERA.(This is an abbreviation for OPtimal Energy Retrofit Advisory model.) The model is implemented in a NORD 570 machine and the code is written in FORTRAN. Solving the model for the base case provides an optimal, or almost optimal, solution in about 30 seconds. Some further work with the model makes it possible to reach the optimum point with the accuracy required. For most cases only the first part is necessary. The program after this continues with the calculation for a number of different discount rates and optimization times in order to provide a sensitivity analyzis.

The OPERA model deals with ten different heating systems and eight different envelope and ventilation retrofits. Two of the heating systems deal with electricity heating, one with a fixed rate and the other with a differential one.

DIFFERENTIAL RATES

The production of electricity in Sweden, is utilized in several different facilities and thus at different short range marginal costs. Hydro electrical plants operate during the summer to a very low cost while the cost for producing an extra unit of energy, using gas turbines during the winter, is much higher. Ordinary rates for the consumer do not reflect this production cost and thus an energy unit, for the consumer, has the same value, no matter when the unit is used. This will lead to the implementation of energy conserving measures during the summer, which is of no interest for the utility. The utility however, wants conservation measures during peak load conditions, because the energy, on the margin, in such a case is produced to a high marginal cost. Thus, if a rate is introduced that reflects this production cost, a more desireable behavior can be estimated from the consumer, i e saving energy during the winter.

The perfect solution would be if the producer could inform the consumer of the price instantaneously. Such a rate is called a Cost Differential Rate, CDR. Equipment for doing this is present now, but is not in common use. The information is sent to the consumer through the ordinary electricity grid, and thus the consumer can deside, at each moment, if the cost for using electricity is to high or not.

A more common system is to introduce a rate that has fixed prices depending on the time of the day or the year. Such a rate is called a Time Differential Rate, TDR. This rate does not reflect the production cost with an absolute accuracy, but it is much better than the ordinary fixed rate.

NORMALIZATION

In order to compare a fixed rate with a differential one it is important that the rates are normalized. This means that the level of the rate is the same as before, the utility gets the same income whether the rate is fixed or differentiated. The normalization has to be elaborated for identical thermal loads because the load will influence the normalized price.

Further information about differential rates, normalization etc can be found in Refs. [4], [5] and [6].

CASE STUDY

During this research project, a group called the 7 - builders group, has been of big importance. The members of the group, come from 7 different building companies, working in Malmö, as well as in the rest of the country. Also members of the group, are representatives for the municipality in Malmö. Knowledge from these members has been implemented in the model and further has information about proper input data to the model, been discussed during the group meetings. A number of buildings have been analyzed by use of the OPERA model. Two of them are presented in Refs. [7] and [8]. In this paper a third one is presented sited in the block Ansgarius in Malmö.

The emphasis in this paper is not to show the optimal retrofit solution for the building but instead to present the influence of a differential electricity rate. The best strategy is not to implement electricity heating with a number of envelope and ventilation retrofits but instead to install a bivalent heating system, with an oil-boiler and a heat pump. This heating system shall only be combined with a few cheap envelope retrofits, such as attic floor insulation or weatherstripping. The calculations presented here, however, are elaborated as a part of an OPERA running trying to find the optimal solution.

The thermal load

The OPERA model calculates the thermal load in the building using energy balances. The geometry, thermal status of the building envelope, the climate etc are input data. The number of degree hours is calculated for each month using monthly mean temperatures and one degree hour is generated if the outside temperature is lower than the desired inside temperature, in this case 21 °C. The energy balance for the existing building is shown in Table 1.

Month	Degree hours	Energy losses	Free energy	Hot water energy	Resulting energy
Jan	15 996	76 475	4 352	8 333	80 456
Feb	14 712	70 339	4 352	8 333	74 321
Mar	14 582	69 717	4 352	8 333	73 698
Apr	10 800	51 634	4 352	8 333	55 615
May	7 440	35 570	4 352	8 333	39 551
Jun	4 320	20 653	4 352	8 333	24 634
Jul	2 827	13 516	4 352	8 333	17 497
Aug	3 199	15 295	4 352	8 333	19 276
Sep	5 400	25 817	4 352	8 333	29 798
Oct	9 002	43 039	4 352	8 333	47 021
Nov	11 592	55 420	4 352	8 333	59 401
Dec	14 136	67 583	4 352	8 333	71 564
Sum	114 007	545 067	52 224	100 000	592 838

Table 1: Energy balance for the existing building Ansgarius, Malmö

OPERA has calculated the thermal losses in the building to 4 780.9 W/°C and thus

$$15996 \times 4.7809 = 76475\text{kWh}$$

The free energycomes from appliances. Experience from monitoring the gains from solar radiation implies that this many times is overestimated, see Ref. [9].

No solar radiation is thus present in the input data here. The resulting energy demand is calculated as

$$76475 - 4352 + 8333 = 80456\text{kWh}$$

The tariffs and normalization

In Malmö there are two different TDR tariffs for low voltage applications. Which one to use depends on the current required. In this case study the thermal load in the building is 167.3 kW. The tariff thus is as follows:

Fixed fee	=	5 000 SEK
Subscription fee	=	60 SEK/kW
Power fee	=	170 SEK/kW
Energy fee,		
Nov - March, Mon - Fri, 06 - 22	=	0.392 SEK/kWh
Nov - March, otherwise	=	0.252 SEK/kWh
Apr, Sep, Oct, Mon-Fri, 06 - 22	=	0.252 SEK/kWh
April, Sep, Oct, otherwise	=	0.242 SEK/kWh
May - Aug, Mon - Fri, 06 - 22	=	0.242 SEK/kWh
May - Aug, otherwise	=	0.187 SEK/kWh

However, such a rate cannot be implemented, *in extenso*, in the OPERA model, monthly mean values are required. Using information from normal consumers made it possible to transfer the energy fees above to:

Energy fee,		
Nov - March	=	0.314 SEK/kWh
April, Sept and Oct	=	0.236 SEK/kWh
May - Aug	=	0.204 SEK/kWh

Now it is possible to calculate the annual cost as:

Fixed fee,		=	5 000 SEK
Subscription fee,	167.33 × 60	=	10 039 SEK
Power fee,	167.33 × 170	=	28 446 SEK
Energy fee,	0.314 × 80 457 + ...	=	164 716 SEK
Sum		=	208 202 SEK

If this sum is devided by the total energy amount an average price will emerge as:

$$\frac{208202}{592838} = 0.351\text{SEK/kWh}$$

This average price shows the normalized fixed rate that shall be compared with the differential one.

Implementing a retrofit

If a retrofit is implemented, in order to decrease the energy demand, the thermal load gets lower, and thus it is possible that the applicable rate is changed. In this case that is exactely what happens. The OPERA model initially assumes that the heat through e g the attic floor equals 0 kWh. After that the energy balance once again is calculated and the estimated proper rate is chosen. The optimal insulation thickness is calculated using the marginal cost due to this estimated rate. This is so because the optimal level of insulation mostly will lead to very thoroughly insulated building parts if it is found profitable. In this case it was found optimal to implement approximately 0.35 meter mineral wool insulation. The thermal load will by this decrease from 167 to 153 kW. If the attic floor heat loss is totally neglected the load equals 151 kW, and thus it is better to use 151 kW for this estimated rate than 167 kW, which was the situation in the existing building.

The rate that shall be applied if the attic floor will be retrofitted is presented below:

Subscription fee	=	8 400 SEK
Energy fee,		
Nov - March, Mon - Fri, 06 - 22	=	0.437 SEK/kWh
Otherwise	=	0.237 SEK/kWh

This new rate will result in a normalized energy price equalling 0.317 SEK/kWh. The money saved, as a net present value is thus 1.02 MSEK, which shall be compared to the calculations for the first normalized rate which equals 0.4 MSEK. This means that just by changing the applicable rate in this case will save 600 000 SEK for the subscriber.

Unfortunately, the next retrofit is dealt with in exactely the same way by OPERA. The new LCC after the retrofit is implemented is compared to the LCC calculated for the original building with no retrofits at all. OPERA thus will change the rate once again and thus a much too high saving is estimated, 0.65 compared to approximately 0.02 MSEK. In this case, where the rate is changed so much it is not possible to add the savings for different retrofits to each other. The combination and order of implementation will influence the optimal new LCC.

However, OPERA will tell the operator that two different rates are used during the process, and further the retrofit combination is calculated at the end of the program. It is thus possible to evaluate the optimization process in detail. In the case above, with the normalized fixed rate with an energy price of 0.35 SEK/kWh, the resulting LCC is calculated to 5.58 MSEK. The combination of retrofits results in a LCC of 5.60 MSEK and thus the difference is only 0.3 %. The original LCC is 8.12 MSEK and thus a severe improvement is achived by the retrofits. If the differential rate is implemented, the LCC will decrease from 8.12 to 5.48 MSEK for the retrofit combination found optimal.

The change of rates however, makes it more difficult to show the influence of the differential rate implementation. Fourtunately it is possible to force OPERA to choose only one of the rates. In the following the latter of the rates is used because that is the one to choose after the first retrofit is implemented. A new normalization thus has to be elaborated, resulting in 0.3018 SEK/kWh. It shall be noted here that the subscription fee has to be abolished in order to show the influence of differentiation.

When OPERA calculates on the attic floor insulation above the heat transferred through the attic, first is supposed to not exist. An energy balance is elaborated and a new normalized price is calculated. If the thermal load during high price conditions is decreased this normalized price will decrease. However, this decrease is very small because almost all the heat is consumed during the high price period. The new value is 0.3016 SEK/kWh and it is obvious that it is lower but only to a very small degree. OPERA after this also calculates the price on the margin for the attic floor retrofit. Now there is only a climate load, the hot water production is excluded. This will result in a higher normalized price, 0.3035 SEK/kWh and once again it is obvious that the influence is very small.

However, implementing a differential rate will lead to more insulation because of the higher normalized price but the influence for most cases can be neglected. If peak load energy saving shall be encouraged it is thus necessary to increase the level of the rate.

The most important result of implementing a differential rate is the fact that competing energy producing facilities, such as exhaust air heat pumps or solar collectors, will have their profitability decreased considerably. Solar collectors will save energy mostly during low price periods while exhaust air heat pumps have a 100 duration, with a constant energy production during the year. Unfortunately, the profitability will increase if the level of the rate is raised, in order to encourage peak load saving. It seems thus that it is very hard to design a rate that at the same time will be an incentive for peak load savings and disadvantage competing energy production in the building.

In the Table 2 the result from an OPERA running is presented:

	Fixed rate	Diff rate
LCC original building	7.15	7.15
Savings:		
Attic floor insulation	0.33	0.33
Ext wall insulation	1.03	1.04
Better windows	0.20	0.21
Weatherstripping	0.00	0.10
Exhaust air heat pump	0.35	0.17
New LCC	5.24	5.30

Table 2: LCC and savings with fixed and differential rates in MSEK

From Table 2 it is also obvious that weatherstripping not always is profitable. It can be better to choose a little bigger exhaust air heat pump which takes care of the heat in the higher ventilation flow.

Conclusions

The preceding discussion shows that a differential rate that reflects the cost for producing the energy will lead to peak load savings, however to a very small degree, and more important to disadvantage competing energy production in the building, by use of e g exhaust air heat pumps. If peak load saving is of importance the level of the rate has to be increased, but in such a case also competing energy production will be encouraged.

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