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Economic Appraisal of Energy Efficiency in Buildings Using Cost-Effectiveness Assessment

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Abstract

The aim of this paper is to present a method and a tool based on cost-effectiveness analysis (CEA) for assessing energy efficiency improvements in buildings. The method is based on comparing costs of an energy efficiency improvement with its effects in terms of reduced energy use. In the paper, first a short review of current practices in evaluating the economic efficiency and feasibility of energy efficiency measures is presented. Then a case example is presented with a calculation using a CEA calculation method adapted for energy efficiency improvements in buildings. A systematic appraisal of cost-effectiveness of energy efficiency investments would allow the most economical projects to be implemented first, leading to greater overall economic efficiency.

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Keywords: Construction economics, cost-effectiveness, economic efficiency, energy efficiency, investment appraisal

1. Introduction

The aim of this paper is to present a method based on cost-effectiveness analysis (CEA) for assessing energy efficiency improvements in buildings. Energy efficiency has gained a central role in energy policies of numerous countries. If realized, the targeted changes in the energy efficiency of buildings will, over time, cause drastic effects

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to energy consumption. The effects will radiate, through the building and energy sectors, throughout the whole economy (Tuominen 2013). Therefore, the question of economic efficiency of these changes is an important one.

A literature review of the currently used appraisal methods was conducted to establish. The reviewed literature suggests that currently economic appraisal is often overlooked or only superficially covered when energy efficiency in buildings is studied. A common problem seems to be that many of the methods commonly used have shortcomings to the extent that their use is discouraged in professional financial appraisal literature. Therefore we suggest an alternative approach using CEA and provide a calculation example using a case building. The data for the calculations was acquired from public price data and simulated building energy use from a previous study. This study is part of a work in progress for developing a calculation tool for assessing the cost-effectiveness of energy efficiency measures in buildings.

2. Assessing the current practice

To establish the status of current practice in assessing the economic efficiency and feasibility of energy efficiency improvements, a review of the literature was conducted to find examples of how actual projects on buildings have been evaluated in past research. Leading journals were screened for case studies of efficient building projects to see how economic efficiency was measured. The journals, publishing papers in the field of energy efficient buildings, were searched from ScienceDirect.com. About one hundred highest ranking results were reviewed and among these, the articles that included a case building with energy efficiency features were selected for the review presented here. These criteria produced 18 articles, as listed in Table 1. These 18 papers covered cases from 13 countries.

Table 1. Economic indicators used in the cases studied.

Reference	Location	Indicators used
Llovera et al. (2011)	Andorra	Annual savings in energy costs
Filippin and Beascochea (2007)	Argentina	-
Leckner et al. (2011)	Canada	Payback period; Cumulative cash flow
Chidiac et al. (2011)	Canada	Payback period
Cao et al. (2011)	China	-
Pan et al. (2008)	China	Annual savings in energy costs
Tommerup et al. (2007)	Denmark	-
Kragh and Rose (2011)	Denmark	Investment costs; Annualized investment costs
Jokisalo et al. (2009)	Finland	-
Nikolaidis et al. (2009)	Greece	Internal rate of return; Savings to investment ratio; Payback period
Saitoh et Fujino (2011)	Japan	Annual energy costs
Hamada et al. (2001)	Japan	Annualized lifecycle costs
Bojić et al. (2011)	Serbia	Payback period
Makaka et al. (2008)	South Africa	-
Wall (2006)	Sweden	-
Wang et al. (2009)	UK	-
Parker (2009)	USA	Amortized cost of energy saved
Zhu (2009)	USA	Payback period; Ratio of costs and energy saved

In the body of articles studied, by far the most common economic indicator is the payback period, which was employed in four cases. In addition, one study used cumulative cash flow, which in this case (high initial investment covered with a cash flow of savings in energy costs) produces similar results.

The second most common indicator was annualized costs in one form of other. No particular method was favoured over another, as one case had annualized investment costs were, another annualized life cycle costs and the third amortized costs for energy savings.

Nearly equally common were annual savings in energy costs, which were presented in two cases. In one case annual energy costs were shown instead. In two cases ratios were used, namely the savings to investment ratio and the ratio of costs and energy saved. Finally, for one case an internal rate of return was calculated, and for yet another one simply the total investment cost as a lump sum was presented.

Seven out of the eighteen or 39 % of the studies did not include economic appraisal of the projects at all. This is not meant as a criticism of the studies, that may indeed have other strong merits, but it does show that economic efficiency seemed not to be of major interest in these studies.

In cases where economy was studied, the first obvious observation is that a great variety of methods is in use. This is not good considering the intercomparability of the studies. A great deal of work would be required to determine which projects were the most economically sound ones.

Moreover, the methods chosen have a number of shortcomings. So much so that, in fact, their use is discouraged in professional financial appraisal literature (see e.g. Brealey et al. 2007). The payback period for instance, the most popular indicator used in the studies covered, is considered a method of analysis with serious limitations because it does not account for the time value of money, risk and other important considerations such as opportunity costs. Annualized costs, the second most popular indicator, is not well suited for projects with a very long or unknown lifespan. Yet buildings are often used for as long as a hundred years and almost never the lifespan is decided beforehand.

All of the methods used are limited to the scope of the project itself, none include externalities or the social dimension. This is the case even though many studies explicitly mention external effects and environmentalism as a major justification for better energy efficiency. All these shortcomings justify the search for a common methodology better suited to the task.

3. Alternative methods for assessing costs and benefits

The most common method for assessing the costs and benefits of a project is cost-benefit analysis (CBA), which attempts to measure the benefits and costs of a project in terms of money. The aim of assigning these monetary values is to find out what the maximum amount the society is willing to pay for the project. Because CBA uses monetary values for all costs, revenues and effects of the project, and sums them up into net present value (NPV), it gives as a result a single figure that univocally describes the net sum total of all the attributes of the project. If the NPV is positive, then the net effects are beneficial, and the project should be undertaken. In this sense, it is an extension to the social level of the NPV decision rule generally in use in corporate finance (e.g. Brealey et al. 2007).

However, considering energy efficiency in buildings the CBA approach has two major drawbacks:

- CBA gives as a result a single number that answers the yes-or-no question of whether a given project should be undertaken. This is undoubtedly very useful if that is what we are interested in. However, in the context of sustainable building projects, we are more interested in finding out how economical the project is at reaching its sustainability goals compared to the other alternatives we might have as a developer, client, authority or some other role.
- CBA requires that all outcomes of the project be given monetary values. This is not likely to be easy. The external costs of energy in general and the climatic effects of CO_2 emissions in particular are notoriously difficult to valuate monetarily. Studying energy efficiency of buildings typically concentrates heavily on both energy savings and CO_2 emissions control.

Therefore, the method suggested here is based on cost-effectiveness analysis (CEA) rather than CBA. Even though CBA has a justified role for other purposes, CEA is the preferred method when the benefits or disbenefits are difficult to value. Also, it is well suited for comparing alternative projects with the similar objectives quantified in physical terms. As an added benefit CEA is not sensitive to changes in energy prices, one of largest sources of uncertainty in evaluating energy efficiency investments, as they are excluded from the calculation.

CEA tends to be significantly less costly and time-consuming than its most obvious alternatives, cost-benefit analysis and multi-criteria analysis (OECD 2007). It can be used to identify the alternative that, for a given output level, minimizes the costs or, alternatively, for a given cost, maximizes the desired results (European Commission 2009). These qualities make CEA well suited for the economic appraisal of energy efficiency in buildings.

In CEA a physical quantity representing the desired outcome is selected. Then a cost for achieving the said outcome is calculated. A cost-effectiveness analysis will usually take place in four stages (European Commission 2009):

1. Definition of objectives and choice of the quantities measured.
2. Cost assessment. Generally, only direct monetary resources are included, although other costs and revenues can also be monetized and included. Naturally the measured outcomes cannot be included so as not to count them twice. The NPV method is used to calculate present value for the costs.
3. Measuring impacts, meaning the physical quantities of the desired outcomes.
4. Calculating unit cost for outcomes by dividing costs with impacts.
5. The cost per unit output and outcome are assessed through the simple division of costs by outcomes. Thus CEA makes explicit the relationship between inputs and outputs, that is, the value for money one gets from the project in terms of the desired outcomes.

There are a variety of methods for conducting CEA, here the three most common ones are introduced, as presented by European Commission (2009) and OECD (2007): the unit investment cost (UIC), unit annual cost (UAC), and dynamic generation cost (DGC).

Unit investment cost is the simplest and most common method, where the total investment cost I is divided with the effects E_1 achieved in the first year of operation:

$$UIC = \frac{I}{E_1} \tag{1}$$

This indicator, though simple and quick to calculate, has a number of drawbacks. First, it does not account for operation and maintenance (O&M) costs. One can easily give an example that a more expensive device is preferred due to low operating and maintenance costs. Second, it does not account for differences in projects with different lifetimes. It is possible that a more expensive device will serve longer than a cheaper one; yet UIC will always give preference to the latter. Third, UIC is not sensitive to changes in the profile of the environmental effect. It may occur that a reduction in pollution will change over the lifetime of an investment. Although UIC is commonly used, OECD (2007) has recommended that UIC should not be used in professional cost-effectiveness analyses.

Unit annual cost is a more sophisticated indicator compared to UIC that uses annualized values for investment costs, O&M costs and the outcomes. Capital costs are annualized using discounting and for O&M costs and outcomes average annual values are used. It is defined as

$$UAC = \frac{C_{avg} + I_{annual}}{E_{avg}} \tag{2}$$

where C_{avg} is the average annual O&M cost, E_{avg} is the average annual effect achieved and I_{annual} is the annualized investment cost defined as

$$I_{annual} = I\frac{d}{1-(1+d)^{-n}} \tag{3}$$

where I is the total investment cost, d is the discount rate and n is the lifetime of the project. UAC, compared with UIC, gives good estimates of the true long term average costs when the effects are distributed evenly over the life-time of the project.

UAC has, however, one major drawback in that it does not take into account the time value of the effects, even though it does that for the costs. In other words, while the costs are discounted, the outcomes are not. Dynamic generation cost attempts to overcome this drawback. It is defined as the ratio between discounted costs and discounted outcomes of the project. Despite the discounting, the outcomes are not monetised, but are expressed in physical units. DGC is expressed by equation (4),

$$DGC = \frac{\sum_{n=0}^{N} \frac{I_n + C_n}{(1+d)^n}}{\sum_{n=0}^{N} \frac{E_n}{(1+d)^n}} \tag{4}$$

where I_n is the investment expenditure, C_n is O&M cost and E_n is the effect for year n, d is the discount rate and N is the lifetime of the investment. DGC is recommended by the OECD (2007) as the ideal measure of cost-effectiveness. It has all advantages of UAC and is also sensitive to changes in the distribution of the environmental effect over time. Therefore DGC gives the best estimate of long-run average costs and it is the method selected for use in this paper.

4. Calculation tool for cost-effectiveness assessment

To apply the DGC method to the case of energy efficiency in buildings, an Excel calculation tool by the name VTT-CEA was developed by the first author to this paper. Cost-effectiveness assessment conducted with the tool takes place in the succession of the five stages presented in section 3, with data collected and entered to the tool. The tool takes as inputs costs and energy consumption figures for each project year from three categories: (1) investment, (2) operation and maintenance and (3) renovation and refurbishment. An example of a view for data input is presented in Fig. 1. For cost data, as far as possible, principles of life-cycle costing are followed.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Project year	0	1	2	3	4	5	6	7	8	9	10	11	12
2	**Additional costs of the project** (compar	Unit =	USD	All costs and incomes are in terms of calculation year 0's currency with no correction for inflation or NPV.										
3	**1 Investments**	Includes the costs during the investment phase, such as planning, preparation, building, comissioning, etc.												
4	LEDs: 10	490												
5	8 Advanced Fan coil	1280												
6	Free Cooling System through vents: 10	500												
7	Glazed solar thermal collectors: 3	1590												
8	Tank: 2 (Efficient)	1900												
9	Shading Systems: 8 (1.5X0.5)	420												
10	External reflective paint (Wall and Roof)	1951,2												
11	Double wall of half red-brick. 12cm red-brick+ 5 cm air gap + 12cm red-brick	24148,8												
12	Double low-e window (6 (1X1.2) + 3 balconies (1.2X2.1) per floor)	2952												
13	PV: 18	3960												
14	Batteries: 36	10024,56												
15	Inverter: 1	248,74												
16														
17														
18														
19	Annual total	49465,3	0	0	0	0	0	0	0	0	0	0	0	0
20	Reference case* annual total	26357,8	0	0	0	0	0	0	0	0	0	0	0	0
21	Annual total in NPV	49465,3	0	0	0	0	0	0	0	0	0	0	0	0
22	Reference total in NPV	26357,8	0	0	0	0	0	0	0	0	0	0	0	0
23	Difference in NPV	23107,5	0	0	0	0	0	0	0	0	0	0	0	0

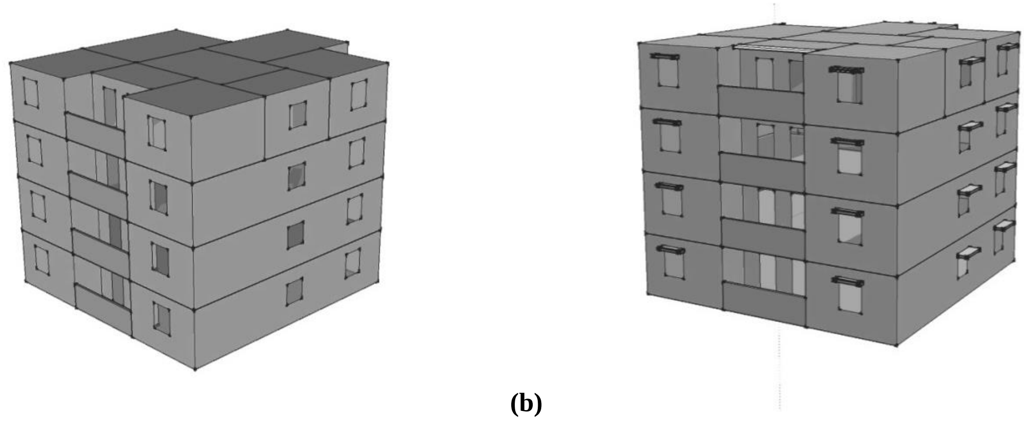
Fig. 1. Typical example of a view from the VTT-CEA tool for cost data input.

An energy efficiency improvement is either assessed independently or compared with a reference case. The reference case represents the same or essentially similar project when it is realized with no particular attention to energy efficiency.

As in the DGC method both energy and costs are discounted, the selected discount rate has importance. A real discount rate is used, which can be calculated by subtracting the inflation rate from the nominal discount rate. In accordance with the recommendation from US NREL (Short et al. 1995) when knowledge of a specific investor is unavailable the default rate is set at 10 %. As a result the tool yields the DGC, according to equation 4, for energy saved meaning how much money was spent in terms of NPV per kWh saved.

5. Case building

A cost effectiveness calculation was conducted using the VTT-CEA tool. As a case building, a typical new apartment building in New Borg el Arab City (NBC) in Alexandria, Egypt, was selected. The case building is based on the technical analysis conducted by Reda et al. (2015). It is a four-storey building, each floor having one apartment. The building is presented in Fig. 2, (a) for BAU and (b) for LIS. The aim is to compare a typically constructed apartment building, called business as usual (BAU), with a scenario where the same building is realized with a number of selected low-investment energy efficiency measures, called low investment scenario (LIS).



(a) **(b)**

Fig. 2. View of the geometry of the modelled buildings, (a) BAU and (b) LIS with shading elements visible.

The buildings were modelled in TRNSYS in accordance with the technologies selected for the scenarios shown in Table 2. Only technical systems that are different between the two cases are listed, otherwise the buildings are the same. The BAU scenario is based on the minimum requirements of the Egyptian energy code, while the LIS was designed to include only simple and affordable energy efficiency measures.

Table 2. List of technologies in the two scenarios including price and replacement interval estimates used in the calculation. Numbers are given per apartment.

Scenario	System name	Investment cost (USD)	Interval for replacing the system (years)	Reference
BAU	Double red brick wall with an air gap	4914	-	Egyptian Ministry of Housing (2014)
	Incandescent (6) and fluorescent lights (24)	87	1 (incandescent), 10 (fluorescent)	Alliance to save energy (2011)
	Advanced fan coils (13) for air circulation	2080	20	Alibaba (2014a)
	Regular hot water storage tank	1500	20	Alibaba (2014b)
	Total	8581		
LIS	Insulated building envelope	6037	-	Egyptian Ministry of Housing (2014)
	External reflective paint	488	10	Egyptian Ministry of Housing (2014)
	Shading system for windows	420	20	Egyptian Ministry of Housing (2014)
	Fluorescent lights (30)	105	10	Alliance to save energy (2011)
	Free flow vents and advanced fan coils (8)	1780	20	Alibaba (2014a)
	Efficient hot water storage tank	1900	20	Alibaba (2014c)
	Unglazed solar thermal collector system	1250	20	Egyptsolar (2014)
	Total	11980		

In both cases an air to water heat pump was included for supplying cooling and heating energy. Energy modelling in Reda et al. (2015) gives an annual electricity consumption of 4750 kWh for each apartment in BAU and 2675 kWh in LIS. More technical details about the systems are available in (Reda et al. 2015).

From the point of view of the CEA calculation, the BAU scenario serves as the reference case, DGC being calculated for LIS. Table 2 gives the cost estimates used for the CEA calculation as well as the intervals for system replacements per apartment. Additionally it is assumed that in LIS on average one work day annually is used by an unskilled worker cleaning the rooftop systems and one workday by skilled professionals, such as an electrician, on system check-ups, totalling 40 USD/a using typical local costs. The calculation is made with a 10 % discount rate for 1 year of investments and 50 years of operating, maintenance and replacement costs.

6. Results and conclusions

A calculation tool for cost-effectiveness assessment of energy efficiency measures in buildings was developed and a CEA calculation on an apartment building in Egypt was conducted as an example. The tool calculates the dynamic generation cost for energy saved in the building. The result was that the measures under consideration in a low investment scenario had a cost of 0.21 USD/kWh for energy saved. Electricity price in Egypt is heavily subsidised and even after recent price hikes is expected to settle at 0.07 USD/kWh (Kalin 2014). It would therefore appear that the combination of energy efficiency measures studied in LIS is not at present economically sensible from a pure investment calculation perspective. However, further cuts in subsidies are expected. In EU countries the average electricity price was 0.25 USD/kWh in 2013 (Eurostat 2014), which would suffice to make the investment profitable. Moreover, the positive effects of reduced pollution, climatic effects and consumption of non-renewable resources may justify the somewhat higher cost.

The case example highlights the usefulness of the CEA method in comparing the costs and benefits of energy efficiency investments in buildings. The main benefit is that it produces as an end result a single number, price of energy saved, that is understandable and concentrates to the essential issue: the cost of achieving the desired results. As it represents unit cost for energy, it can be easily compared with other projects as well as electricity prices in the grid or the cheapest renewable alternative. It also allows follow-ups on the project by comparing the values during the planning and operation of the project. The data needed for calculating it is not markedly dissimilar from the data needed for regular project budgeting and would, therefore, mostly be collected in any case. CEA can accommodate an arbitrarily long project life-span and it includes discounting, therefore accounting for risk and avoiding common problems with many presently used appraisal methods. Finally, CEA removes the major source of uncertainty in the assessment of energy efficiency, namely future energy prices, because energy is measured in native units rather than money. These qualities would seem to allow the CEA method to solve many presently commonly faced problems in appraising energy efficiency investments in buildings.

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