PROFIT OF EXERGY IN THE BUILT ENVIRONMENT

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Summary

In the Netherlands three technical universities are participating in a new research project "Exergy in the built environment", that aims to contribute to sustainable building by investigating the potential financial benefits of exergy saving techniques. Exergy is a concept used in thermodynamics to express the maximum amount of mechanical work that can be obtained from an energy flow or a change of a system in relation to its environment. In contrast to energy, exergy can be destroyed and by that means exergy can express the finiteness of resources better than energy can.

In the building process investors currently use life cycle costing to calculate the returns on their investments in buildings. The life cycle costing method however does not take into account an important organizational issue. Namely, that the stakeholders who benefit from exergy saving techniques not necessarily include the investing stakeholders. The aim of the research on the profit of exergy in the built environment is to develop an improved model to predict the potential added value of exergy saving techniques by linking this thermodynamic concept to building processes and to investment appraisal. In this proposition paper the objectives, methodology and theoretical framework will be explained.

1. Introduction

Since stated by the World Commission on Environment and Development in 1987, sustainable development receives world wide attention. In the building industry the term sustainable building is used to address all techniques and approaches in terms of source efficiency, quality improvements and pollution reduction, *which not compromise the ability for future generations to meet their own needs* (Brundtland et al., 1987).

Within sustainable development and sustainable building the reduction of energy use and lowering the pollution have much attention. In the Dutch building industry innovative techniques, like solar chimneys, heat pumps and mechanical ventilation systems with heat regeneration, are introduced to supply heat efficiently during winter and to keep the heat inside as long as possible by using new types of insulation and heat exchangers. It is even possible to build houses that offer comfortable temperatures without the necessity of any external energy infrastructure to supply them of resources or heat at all; autarkic houses.

However, the Dutch building industry seems to see the national Building Code, with its explicitly stated energy performance, as a guideline for the maximum level of necessary performance. The Building Code should although be considered as a minimal required energy performance. The building industry is rather reluctant to apply these necessary energy saving techniques. Contractors often do not know which broad range of energy saving techniques is available and the direct costs of some of these existing techniques are simply too high, so it seems.

One method to get something implemented in the building industry is to enforce it by law (e.g. building codes, regulations). Another method to get something implemented in the market is by showing its commercial value. A logical motivation will lie in making this task easier to reach by pointing out the financial advantages of the techniques and approaches. Research is therefore needed to explain the financial benefits of exergy saving techniques (including the formerly known energy saving techniques).

Exergy is a concept based on the first and second law of thermodynamics. Exergy is the maximum amount of mechanical work that can be obtained from an energy flow or a change of a system in relation to its environment. In contrast to energy that is only based on the conservation principle of the first law of thermodynamics, exergy can be destroyed. Therefore, exergy can express the finiteness of resources better than energy can. In other words exergy expresses the quality of the quantity energy. The relation between

energy and exergy can, according to Ala-Juusela et al (VTT, 2003), be embedded in a quality factor (see Eq. 1 in combination with Table 1).

$$Exergy = Energy \times Quality\ Factor \tag{1}$$

Table 1 Quality factors for multiple energy sources based on an ambient temperature of 20°C (VTT, 2003)

Source	Quality factor
Mechanical energy	1,00
Electrical energy	1,00
Solar radiation	0,95
Nuclear fuel	1,00
Fossil fuels	0,90
Thermal at 100°C	0,21
Thermal at 40°C	0,06
Thermal at 20°C	0,00

Although there is much thermal energy needed in the built environment to generate a comfortable indoor climate, the exergetic value of heat in an indoor environment of twenty degrees Celsius is very low. When it is twenty degrees Celsius outside, the value even equals zero, because there is no temperature difference between the analyzed system and its environment.

To generate the proper indoor climate of approximately twenty degrees Celsius, a fossil fuel named natural gas is commonly being used in The Netherlands. This fuel can be burned at high temperatures; therefore the generated thermal exergy will almost equal its formal internal energy. However, the generated high thermal exergy does not match the needed low thermal exergy for the indoor climate. The principle of using high quality sources in degrading steps, so called cascade principle, can be introduced to make efficient use of fossil fuels. Another possibility is, of course, to use alternative (renewable) sources for heating residential and commercial real estate.

2. Research objective

The planned research is aimed to contribute to the adoption of exergy saving techniques in the built environment by giving insights in their financial consequences. These techniques will help to lower the amount of harmful emissions and can provide the correct quality (in terms of the ability to generate mechanical work) and quantity of energy, expressed by exergy, in a more effective way. The relation between thermodynamics, economics, and sustainable development has been described most challenging by Valero et. al. (1993):

Developing techniques for designing efficient and cost-effective energy systems is one of the foremost challenges energy engineers face. In a world with finite natural resources and increasing energy demand by developing countries, it becomes increasingly important to understand mechanisms which degrade energy and resources and to develop systematic approaches for improving the design of energy systems and reducing the impact on the environment. The second law of thermodynamics combined with economics represents a very powerful tool for the systematic study and optimization of energy systems.

In a time of governmental deregulation, improvements in adopting exergy saving techniques need to be facilitated by specifying the financial benefits for the stakeholders in the building process. The main research question can be stated as a single line question in the following way:

What are the financial benefits of exergetic optimization of real estate?

Although there is a common awareness of the ecological and social benefits or other externalities of exergy saving techniques, the financial costs and benefits will be the major point of concern in the decision making process on investments in real estate. In the process of addressing this concern the financial benefits of exergetic optimization will be mainly approached from the investor's and user's point of view.

The appraisal of exergy saving investments does take the benefits during utilization into account (for example in the method of life cycle costing), but stakeholders in the building processes often do not communicate about, or take the time to weigh, the costs and benefits of life cycle investments. Furthermore the methods for calculating the yearly cash flows do not incorporate all benefits of exergy saving techniques yet. The main contribution of this research can be found in offering a model to overcome these two aspects.

3. Societal relevance

Given that many modern (starting somewhere during the industrial revolution) emissions harm the environment and given that the supply of fossil fuels is finite, the adoption of exergy saving techniques is of

great importance. It can help to use the supply of fossil fuels more effective or to use sustainable sources that do not harm the environment.

The fact that the building industry and the built environment as a whole are, according to the EPBD (EC, 2002), responsible for at least forty percent of the total energy consumption, and the given fact of an increasing number of restrictions on the energy consumption of buildings, make it interesting and wise to stimulate techniques that can reduce the exergy consumption in a cost effective way.

The Return on Investments (RoI) in exergy saving techniques will mostly benefit the user of the building. This user is in most cases not the same person or corporation as the constructor who paid for the investments during the construction phase. During the habitation of a dwelling or the use of an office some actions will be undertaken by the user to lower the energy consumption. Until 2003 there were different subsidies to trigger these users e.g. to insulate their buildings, most users however do not know which level of adoption of energetic techniques is attractive from a financial and/or energetic point of view.

Current developments that can stimulate customer awareness on the energy consumption of buildings, involve the Dutch Energy Performance Coefficient (EPC) and the European Energy Performance Building Directive (EPBD):

- The EPC expresses the energy efficiency of buildings and is included in the Dutch Building Code (2003) regarding building licenses for new buildings. Its introduction was in 1995 for dwellings and it gradually lowers the building related energy use of all new buildings by lowering the numerical value of the coefficient from 1.5 in 1995 to 0.8 in 2006. The energy performance of offices and other utilities has been regulated and lowered since 1998.

- The EPBD passed the European parliament and council at 16 December 2002 and should have been converted in laws by the member states since 4 January 2006. Twenty one European countries were however not able to finish the preparations in time. The Dutch government has introduced the derived laws on the certified energy performance of existing buildings and inspections of heating and cooling systems at the first of January 2008.

The certification of the energy performance of existing buildings can result in recognition of their energy use. An appreciation of a good energy performance can positively affect the market value and therefore the financial benefits of an exergy saving measure will be higher.

4. Scientific relevance

By focusing on the financial benefits of exergy saving measures in real estate objects the research takes place in an area, in which three scientific fields overlap; building processes, economics and thermodynamics (see Figure 1). The relevant theories for these three fields shall now be addressed.
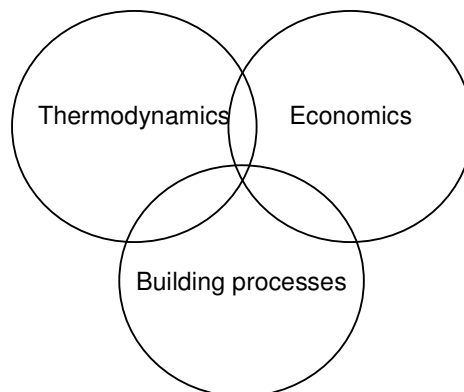

Figure 1 The research will be conducted in an interdisciplinary field relating thermodynamics and economics in interaction with the building process.

4.1 Building processes

In the Netherlands the implementation of energy saving measures in real estate is at this moment mainly enforced by law (Building Code, 2003). Although investments by commissioning commercial organizations or private persons are mainly weighed by their financial returns and technical aspects (Vermeulen et al., 2006), it seems that the goal realization or development in sustainable building by the temporary organization of the building process also can be stimulated by respectively transactional or transformational leadership (Bossink, 1998). It is not only important to do research on the financial benefits and technical aspects, but also on the organization of the stakeholders in the building process.

Research of Van Soest (2005) e.g. shows, that an increase of environmental taxes and quotas does not necessarily induce early adoption of energy saving technologies in firms. This seems to conflict with the findings of Vermeulen et al. (2006), where the economic assessment is one of the main variables. According

to their findings the use of subsidies effected especially the economic assessment of young innovations. The research of Van Soest had a focus on one single firm that is both the investor and user of the object. However, in case that user and investor are different parties the cost benefit considerations might be different for both parties. As a consequence their decision to adopt specific energy saving technologies and techniques will most likely also differ.

In the first part of the research a stakeholder analysis needs to clarify where in the process the objectives for reducing the exergy consumption are developed and where their financial consequences are addressed. It is important to know at which moments in the design, construction and utilization phase, intervention to adopt the exergy saving technologies is possible. The influence of the stakeholders and uncertainty in the early phases of the building process in relation to the project's value generation has been studied before by Kolltveit et al. (2004), but this research did not specifically focus on energy or exergy saving techniques. Therefore this research can make an innovative contribution by specifying the opportunities and restraints in adopting energy saving techniques in building processes.

4.2 Thermodynamics

The basic methods of energy and exergy analysis from the field of thermodynamics are generally used to optimize the designs of power plants, but in recent years some building related installations have been analyzed, for example heat pumps (Ozgener et al., 2005; Ucar et al., 2006). Methods to address the costs and benefits of exergetic optimization processes are referred to as thermoeconomics (Szargut, 1988) or exergoeconomics (Tsatsaronis, 1985).

The possibilities to reduce energy consumption and to save exergy in the built environment are numerous. An average dwelling in the Netherlands uses for example 1,736 m^3 natural gas and 3,346 kWh electricity each year (SenterNovem, 2006). The efficiencies of many exergy saving techniques have been addressed e.g by Gustafsson (2000), Xiaowu et al. (2005) and Nagano et al. (2006). A preliminary literature study on exergy saving techniques however shows that so far, little research has been done on passive solar systems. This research will contribute to this research on exergy saving techniques by conducting an experimental study of a passive solar system.

4.3 Economics

A basic method to specify the financial costs and benefits of real estate investments is Life Cycle Costing (LCC). It recognizes that the total cost of ownership of a product is not solely reflected in its purchase price. The purchase of certain products should in other words be considered as an investment for which both benefits and additional costs are incurred over the life of the product (McEachron et al., 1978). Although there are some difficulties still to overcome (see e.g. Gluch et al., 2004), this method can be used for the analysis of design options regarding conventional energy efficiency. Lutz et al. (2006) used it for example for weighing the costs of residential furnaces and boilers and Gustafsson (2000) optimized insulation thickness.

LCC has been improved from an environmental point of view by integrating the product's or investment's results from Life Cycle Analysis (LCA) and the customer's willingness-to-pay for the related environmental improvements (Bovea et al., 2004, Banfi et al., 2006). However, despite these improved LCC methods, there are still possibilities for further improvements. The application does not take into account the possibilities of increasing the value of real estate by means of improving its efficient energy performance. Although this aspect is related to the willingness-to-pay principle, it is the first time that financial data from the existing building stock can be related to energy performance certificates based on the European Building Directive on Energy Performance.

Furthermore, in the case of residential real estate the availability of fuel resources are not accounted for in LCC yet, although the prices of car fuels for example are strongly related to their availability. Alanne (et al., 2006) performed a first study on the reliability of decentralized energy systems and Awerbuch (2000) already addressed the urgency to improve the traditional valuation models by introducing the Capital Asset Pricing Model (CAPM) for investments in photovoltaics. CAPM explains the relationship between risk and the investor-required return rate for an asset. Awerbuch's statement "by ignoring financial risk, lenders and investors understate the value of PV projects relative to fossil alternatives" and his suggested solution to use the portfolio theory of Markowitz (1952) to relate cost and risk contribution of alternative resources, offer a basis to investigate the value of the quality of energy; the so called exergy. At this point the economic aspect of the research can be linked with the already mentioned thermoeconomics or exergoeconomics.

5. Research methodology

Three research questions regarding the building process, the field of thermodynamics and field of economics are defined to achieve the objective of the research. This research methodology is based on Verschuren et al. (1999). The first research question will focus on the building process and the relevance of (conventional) energy saving techniques for stakeholders within this process.

Question 1: Which opportunities and restraints during the development of real estate can be distinguished in adopting energy saving techniques?

To combine the advantages from the collective thermodynamic and economic approach on exergy saving techniques the building process and its stakeholders need to be described. Four different project types in describing the processes can be distinguished:

1. Residential real estate developed by private ownership;
2. Residential real estate developed by housing corporations;
3. Commercial real estate developed by investors;
4. (Commercial) real estate developed by the government.

Research on building processes for residential real estate in relation to sustainable measurements has been done by De Man (1983) and Bossink (1998) for example. Research of Vermeulen et. al. (2006) has a focus on commercial real estate. To reflect on the international context of this first research question it is possible to use the research of Lo et al. (2006) on the opinions of building professionals in Hong Kong and Shenyang on sustainable measures.

The interaction between the stakeholders can be based on different management structures; traditional management structure, construction management structure and project management structure (Best et al., 1999). Is it the customer or client who makes the decisions or is the adoption driven by the design of the architect? Relations between the stakeholders will be overviewed to identify certain bottle necks or changes for the implementation of sustainable techniques in building processes.

This first question refers also to the possibilities for the stakeholders to introduce certain techniques to save exergy in the building process. The building process is described by the Jellema series (Woude et al., 1997) for the Dutch situation for example. Internationally reference can be made to Pietroforte (1996), Arditi et al. (1998), Winch (2002) and Turin (2003). The possibilities to interfere in the design and building process are often bound to the first phases of the project (Kolltveit et al., 2004).The quality of the product resulting from the building process is strongly driven by the Dutch Building Code. This law specifies a minimum quality level for all buildings and is therefore an important aspect in the adoption of energy saving techniques in the built environment (Building Code, 2003; NNI, 2004). Buildings must have a certain energy performance, which makes investments in energy saving techniques necessary. Which techniques are being used for which reasons? What are the best practices in relation to these regulations?

By conducting a literature study and interviewing stakeholders the necessary insights will be collected for answering this first research question. The content of the interviews will be based on mentioned theoretical references. An interview is one of the most important sources for case study research (Yin, 2003).

Question 2: What is energetic and exergetic optimization of real estate objects?

It has already been mentioned that more than forty percent of the energy consumption in Europe can be assigned to the building industry. The second research question will focus on the possibilities of lowering this energy consumption and of applying exergy saving techniques to match the provided quality of energy with the quality needed. The appropriate science for this goal can be referred to as thermal-fluid sciences, which can be studied under the subcategories of thermodynamics, heat transfer, and fluid mechanics (Çengel et al., 2005).

The first law of thermodynamics on conservation of energy is commonly known, but the second law is less familiar. Society needs to become more familiar with the possibilities of exergetic analyses in the built environment. A literature study on this concept will be conducted. Important sources are the thesis of Cornelissen (1997) on "Thermodynamics and sustainable development" and the "Fundamentals of thermal fluid sciences" written by Çengel et al. (2005).

The exergy consumption of the built environment can only be reduced effectively, when the current conventional energy consumption of buildings is known. To get a grip on the potentials of exergy saving in the existing building stock a preliminary study has been made of three commercial real estate objects. For the explorative research among residential real estate there are eight houses available constructed in the years 1913, 1925, 1939, 1948, 1964, 1972, 1982, 1992. By using the standardized data on energy consumption (Novem, 2003, SenterNovem, 2006), the normalised method to compute the building related Energy Performance Coefficient (NNI, 2004) and the actual energy consumption data, it is possible to analyse the potential energetic benefits in real estate objects. It is important to reflect on the effectiveness on past policies and regulations which influenced the physical state of buildings.

There are many studies available on specific energy and exergy saving technologies. The Network of International Society for Low Exergy Systems in Buildings listed many possibilities to lower the exergy consumption of buildings (VTT, 2003), however several of these techniques have not been tested or analyzed yet. This research can contribute to existing studies by performing an energy and exergy analysis on an exergy saving technique that has not yet been analyzed. A literature study will be made of the existing energetic and exergetic analyzed parts of buildings (e.g. Gustafsson, 2000; Xiaowu et al., 2005; Ucar et al., 2006; Nagano et al., 2006). In this research one promising and innovative technique will be thermodynamically analyzed and tested to address the benefits of the concept of exergy in practice (this technique will also be used for testing the model on financial benefits of exergy saving techniques). A first

scan of the available theory showed that passive solar (ventilation) systems are not well represented yet. An experimental case study on a passive solar system seems promising.

Question 3: What model can be developed to express the financial benefits of exergy saving techniques?

The third research question will refer to the economic element of the research. As a basis standard investment appraisal methods will be used. In this research the focus will be on, like expressed in Figure 2, (1) the stakeholders involved at the moment of the decision to invest and (2) the variables that form the cash flow. Two new variables will be introduced in the second in depth study: (A) the actual market value of the real estate object and (B) the price of the reduced form of exergy as a result of the depletion of fossil fuels.
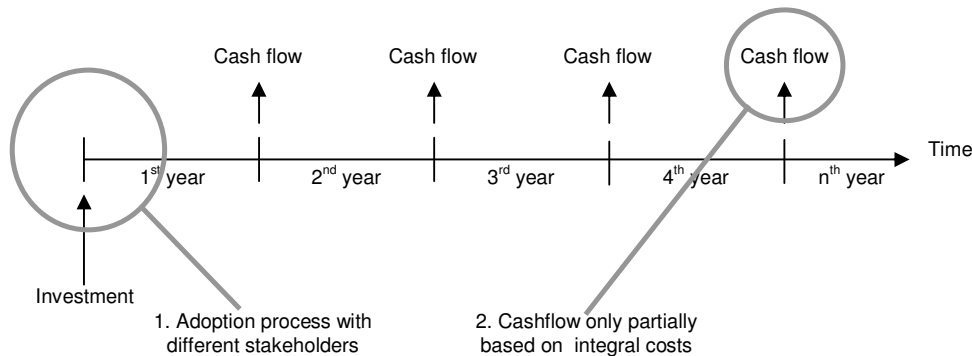

Figure 2 Model showing two problems regarding investments in exergy saving techniques.

When the principles of conventional capital budgeting methods are used on building related investments, they are commonly referred to as life cycle costing. Life cycle costs can be used for the appraisal of exergy saving investments by taking into account the direct costs, the yearly costs of maintenance and the yearly costs of (fossil) fuels. A conceptual discussion given by Gluch et al. (2004) offers important shortcomings to overcome, before adoption of life cycle costing in the building industry can be further stimulated. Not withstanding these shortcomings, the LCC method is commonly used for comparing designs in civil engineering projects (e.g. Noortwijk et al., 2004; Zen, 2005; Singh et al., 2005; Ugwu et al., 2005) and it is also used for environmental orientated investments (e.g. Reich, 2005; Nakamura et al., 2006). Theory on the basics of life cycle costing (originally developed at the American Department of Defense) is offered by McEachron et al. (1978) and Stern (1978).

Two financial benefits of exergy saving techniques are not yet addressed in the theory on the traditional life cycle costs. The first is the willingness-to-pay for real estate that consumes less exergy than conventional real estate. Research on the value development of real estate regarding their energy performance in the past will be conducted by comparing the actual market values of the case objects with the investment costs of specific energy saving techniques. Papers in the field of willingness-to-pay are for example Banfi et al. (2006) and Bovea et al. (2003). The second category of financial benefits is related to the depletion of fossil fuels. With a fixed demand for fossil fuels; the scarcity will increase and therefore the price. By analyzing the energy prices it is possible to specify an interest rate for the yearly positive cash flows generated through exergy saving.

The third research question also involves the applicability of the model for the stakeholders in the building process. The costs and benefits of the exergy saving investment are not in the hands of one and the same stakeholder. In principle there are two possible solutions to deal with this aspect; (1) the model needs to incorporate this separation or (2) the building process needs to incorporate the exergy saving investment appraisal. Depending on the results of the first research question a solution or manual can be offered as a spin off of this research.

6. Conclusions

Based on the existing debates in society on the depletion of fossil fuels, energy consumption, and carbon dioxide emissions, the time is there to introduce the concept of exergy within a broader community. The national Dutch research project "Exergy in the built environment" will introduce this concept in the building industry by providing tools and catching applications, that give insights in the advantages regarding comfort (people), the environment (planet) and economy (profit).

The presented research will focus on the financial benefits. At this moment the prices of multiple energy forms are based on a combination of production costs, governmental surcharges, and market principles. The quality of the energy form, expressed by exergy, is not incorporated in the price setting.

Furthermore, building processes are in general not accommodated to stimulate investments in techniques that reduce the energy and exergy consumption. Stakeholders that invest in a lower energy consumption

and stakeholders that financially benefit from these investments, should be brought together within the buildings process or the indirect financial relation should be brought to the surface.

By offering more insights in the cash flows that are generated by installed energy saving techniques in existing buildings and by smoothening building processes, we expect to be able to stimulate the adoption of more and newer exergy saving techniques. Summarizing, this research will comprise:

- Investigating the possibilities to save exergy in the built environment by conducting an experimental study on passive solar systems;
- Investigating decisive considerations to adopt exergy saving techniques to adopt exergy saving techniques from a multiple stakeholder perspective;
- Developing an improved model to estimate the added value of implementing exergy saving techniques, considering their life-cycle costs and benefits.

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