LULEÅ TEKNISKA UNIVERSITET

2002:09

DOCTORAL THESIS

Green Procurement of Buildings
Estimation of Environmental Impact and Life-Cycle Cost

Eva Sterner

Doctoral thesis

Institutionen för Väg- och vattenbyggnad
Avdelningen för Stålbyggnad

2002:09 • ISSN: 1402-1544 • ISRN: LTU-DT--02/09--SE

DOCTORAL THESIS

Green Procurement of Buildings

Estimation of life-cycle cost and environmental impact

EVA STERNER

Department of Civil and Mining Engineering
Division of Steel Structures

PREFACE

The financial support to perform this thesis is mainly from the Foundation for Strategic Research (SSF) which forms part of the Swedish National Graduate School and Research programme, ***Competitive Building***. Also SBUF and PEAB have contributed with support which is gratefully acknowledged. Other financial supporters during the years are LE Lundberg scholarship found and SBI.

My extra special thanks to my supervisors Professor Ove Lagerqvist and Professor Bernt Johansson at the Division of Steel Structures for all the encouragement over the years which have made it possible for me to continue all the way. Also the confidence you have instilled has meant so very much.

After spending all these years at Luleå University of Technology the number of people that have supported me in my work are great and I want to thank every one of you. In particular I would like to thank my friends and Steel Stars at the division of Steel Structures. Katarina, Eva and Emma who with I shared many breakfast club meetings and discussions about life. Patrik who have given me advises about almost everything. Anders O who I have tortured in my spinning classes. Anders S, Milan, Tomas who I have shared so many laughs with. To Jonas and Mattias who just have started, I wish you the best of luck. A 'special' thanks to Carlos who during these last months have helped, encouraged and supported me in every way possible.

I am also incredibly grateful to Professor Ray Cole at the University of British Columbia, Canada for giving me the opportunity to visit his department and arranging my stay so well.

To all my friends and colleagues in Competitive building. It has been a great privilege to get to know you all. I will always remember the good times we have had together. To all of you that are still struggling good luck with your thesis work!

Finally, I would like to thank my parents, there are no words that can express how grateful I am to you.

Eva Sterner

Luleå, April 2002

ABSTRACT

This thesis focuses on environmental impact reduction and life-cycle cost estimations in building procurement. The aim for this work is to give a contribution toward the understanding of whether costs and environmental impact of a building can be integrated in a, from the users perspective, practical model applied for tender evaluation. The model can be used to evaluate different solutions in the design phase. Specifically this is aimed at:

- Increase knowledge about integration of economical and environmental aspects from a life-cycle perspective in relation to buildings.
- Provide recommendations for procurement of cost effective and environmental aware buildings.

In the first part, green procurement of buildings were investigated through a questionnaire followed by interviews. Environmental requirements were analysed in relation to reduction of environmental impact and to not prevent more cost effective construction processes. It was found that requirements for construction, waste reduction and choice of building materials were well represented. Several requirements were also obstacles for a more cost-effective construction without benefiting the environment. The environmental impact from operation, as energy use, was however not considered to any larger extent. Energy use is currently considered to be the major source of environmental impact and governmental authorities in Sweden and EU advocate reductions in this regard. To encourage a development of innovative solutions in this area, clients should provide the incitements. Here it is suggested that the integration of environmental impact assessment with life-cycle cost estimation in tender evaluation provide such incitement.

In the second part, life-cycle cost estimations and the extent of their use by clients was established by a questionnaire survey in Sweden and a seminar in Canada. The result showed that Swedish clients consider life-cycle cost estimations mainly in design and to a limited extent in procurement and tender evaluation. In general, the cost elements considered are investment, energy and maintenance costs. Limitations for a wider uptake were also identified as lack of access to reliable input data and restricted experiences in use of the method. In the context of environmental design it was further found particularly important to use life-cycle cost approaches to motivate possible initial cost increases that lead to lower operating costs.

In the third part a case study where the life-cycle cost of three environmentally designed buildings was compared with three similar conventional buildings. Results showed that the environmentally designed buildings were in the same

cost range as the conventional buildings even though the latter had considerably lower initial costs. A sensitivity analysis was used to examine uncertainties in the result. The environmental impact from energy use was established through a classification of emissions into environmental impact categories. This showed that the environmentally designed buildings in the case study had a significantly lower impact than the conventional buildings.

The forth part deals with the development of a tender evaluation model integrating life-cycle cost with environmental impact as a monetary term. By using the model clients can award contractors that develop buildings that are cost effective with low environmental impact.

Based on the results and conclusions presented in this thesis a number of general recommendations to clients are given:

- To improve the effectiveness of environmental requirements in procurement clearly stipulated preferably measurable requirements should be used.
- Requirements concerning materials should be limited to avoid the use of hazardous materials. Other requirements will limit the competition and increase costs.
- To motivate energy reductions, reduced operating costs and environmental impact, clients are recommended to evaluate tenders based on life-cycle cost estimations.

SAMMANFATTNING

Föreliggande avhandling behandlar miljöanpassad upphandling av byggnader med fokus på livscykelkostnader och miljöpåverkan. Syftet är att öka förståelsen för hur kostnader och miljöpåverkan kan integreras i en för användaren praktisk modell för anbudsvärdering samt för utvärdering av olika alternativa lösningar vid projektering. Mer specifikt innebär detta att:

- Öka kunskapen om integrering av kostnader och miljöpåverkan från ett livscykelperspektiv, relaterat till byggnader.
- Utgöra rekommendationer för upphandling av kostnadseffektiva och miljöanpassade byggnader.

I den inledande studien undersöktes miljöanpassad upphandling genom en enkätstudie samt efterföljande intervjuer. Miljökrav analyserades i förhållande till reducerad miljöpåverkan utan att hindra utvecklingen av mer kostnadseffektiva metoder. Miljökrav relaterade till byggande, avfall och material var vanligast förekommande. Flera miljökrav som inte bidrar till reducerad miljöpåverkan identifierades. Få miljökrav ställdes vidare på driftskedet. Byggherrar bör bidra med incitament för att driva utvecklingen inom detta område framåt. Förslaget som ges här är att miljöpåverkan och livscykelkostnader integreras i en modell och används för utvärdering av anbud.

I den andra delen undersöktes i vilken utsträckning byggherrar beaktar livscykelkostnader vid upphandling och anbudsvärdering. Användningen visade sig vara begränsad vid anbudsvärdering vilket har flera orsaker som t.ex. avsaknad av indata samt erfarenheter av att använda livscykelkostnader som beslutsunderlag.

I den tredje delen genomfördes en fallstudie där tre miljöanpassade byggnader jämfördes med tre liknande konventionella byggnader. Trots att de miljöanpassade byggnaderna hade högre initiala kostnader visade det sig att dessa ur ett livscykel perspektiv var ekonomiskt fördelaktigare. Vidare var miljöpåverkan från de miljöanpassade byggnaderna betydligt lägre än för de konventionella.

Den sista delen inkluderar utvecklingen av den anbudsvärderingsmodell som inledningsvis föreslogs. Genom att integrera livscykelkostnader och miljöpåverkan i anbudsvärderingen kan byggherren ge incitament till utveckling inom området.

Baserat på slutsatser och resultat ges ett antal generella rekommendationer till byggherrar:

- För att öka effekten av att ställda miljökrav bör dessa vara klart definierade och helst mätbara.
- Miljökrav som ställs på material bör endast syfta till att undvika skadliga eller farliga ämnen, övriga krav kan hindra konkurrensen med ökade kostnader som följd.
- För att motivera utvecklingen mot energieffektiva lösningar, reducerade driftskostnader och minskad miljöpåverkan rekommenderas byggherrar att värdera anbud baserat på livscykelkostnader.

LIST OF PUBLICATIONS

This thesis is based on the following papers referred to by Roman numerals I-IV in the text.

I Sterner, E. (2001). Green procurement of buildings: a study of Swedish clients considerations. Construction management and economics, 20 (1), 21-30.

II Cole, R., Sterner E. (2000). Reconciling theory and practice of life-cycle costing. Building Research and Information, 28 (5/6), 368-375.

III Sterner, E. (2000). Life cycle costing and its use in the Swedish building sector. Building Research and Information, 28 (5/6), 387-393.

IV Sterner, E. (2002). Combining life-cycle cost and environmental impact: a case study and model for tender evaluation. Submitted for publication in Construction management and economics.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 GENERAL

Investments within the building sector are important for the long-term increase in prosperity. In Sweden building investments accounted for roughly 10 % of the total GDP from 1977 to 1999, which is lower than the average of 11.2 % for the OECD countries (The Swedish Construction Federation, 2002). One reason is the severe recession the Swedish building sector faced during most of the 1990s where especially housing projects were affected due to profoundly reduced governmental subsidies. This among other things has lead to the public perception that building costs are too high. Other main causes for high costs are taxes and fees along with a poor productivity development (Johansson, 1997). A substantial challenge for the building sector is therefore to reduce the costs of building, operation and maintenance. At the same time, according to the outline of the Swedish environmental politics, the environmental merits have to be improved. However, environmental performance can be difficult to motivate without presentation of economic benefits. Therefore, one important modification is to shift the focus from production and initial costs to a system thinking including life-cycle costs. Interest in life-cycle cost estimations also seems to increase as ecological sustainability of the sector is discussed. In a dialogue, Bygga/Bo (Build/Live, 2000) between representatives from real estate companies, municipalities and the Swedish government represented by the Swedish Environmental Advisory Council, a vision, goals and strategies for a sustainable building and facility management have been presented. One of seven task groups investigated life-cycle costing. Life-cycle costing is also advocated in a recent report by the Committee for Ecological Sustainable Procurement (2001a). From a national economic perspective operation and maintenance costs of buildings are of great importance. The now existing buildings in Sweden have an area of approximately 650 million m^2 and the total building related investments are approximately 197 billions SEK annually where costs for maintenance and repair represent 37 % (The Swedish Construction Federation, 2002).

Reasons for the building sector to be politically targeted for ecological sustainable development are many as for instance the large potential to save resources and energy, most of the generated waste goes to landfill, possibilities to improve materials and construction methods which address health and environmental risks. In theory, accomplishments in form of investigations to develop targets and guidelines are profound but the implementation and widespread general practice is less examined. The societies requirements or wishes in form of guidelines by legal bodies and national legislation are important both as a driving force for development and as a basis for research. Environmental research is in this sense subjective as influenced by different opinions, viewpoints and prevailing paradigms. Further international agreements influence the national politics and must be considered. Lack of possibilities to find exact answers to critical questions, as for instance emissions effect on the climate complicates and scenarios of the future is therefore often used as input. In this thesis national legislation, goals and the building sectors voluntary work is regarded as the contextual driving forces presented in the background to establish why and how the building sector is proceeding its work.

1.2 BACKGROUND-CONTEXTUAL BOUNDARIES

There are several environmental effects caused by construction and operation of buildings. One of the most urgent is the contribution to climate change by use of energy. In general the climate effect has emerged as an immediate problem since the relation between greenhouse gases and increased global temperatures was discovered which mainly is consequence of increased use of fossil fuels. In buildings roughly 40% of the total energy (heat and electricity) is used and related transports, construction work and manufacturing of material increase this further. The emissions are believed to contribute to a warmer climate which can increase melting of glaciers, give more vigorous hydrological cycles translating into variable climate with extreme wind effects and flooding (Swedish EPA, 1995a). A consequence might then be the necessity of population movements with enormous economical effects.

The climate problem has been addressed internationally at a UN Conference on the Environment and Development held in Rio de Janeiro 1992 where 156 countries agreed to stabilise CO_2 emissions to the same level as in 1990. Sweden ratified the convention in 1993 and at the same time adopted guidelines for a Swedish climate policy. In Kyoto 1997 targets for reduced CO_2 emissions were developed and an agreement was reached through the Kyoto protocol. Intentions are to globally reduce climate-effecting emissions by 5% during a period of 10 years. The EU, who negotiated as a single group, is required to reduce emissions by 8% under the terms where Sweden is allowed an increase of 4% (National Board for Industrial and Technical Development, 1997).

1.2.1 SUSTAINABLE DEVELOPMENT

The World Commission on Environment and Development (1987), also called the Brundtland Commission, has defined sustainable development as development that 'meets our present needs without compromising the ability of future generations to meet theirs.' Sustainability has environmental, social and economical dimensions, embraces all aspects of human activity (e.g., industry, transportation, food production etc.), and spans local actions through to redressing the major inequities that exists between developed and developing nations (Cole, 1999). Applying sustainability on construction generates a broad concept starting in the planning and design stage continuing to the deconstruction of the building. This aims at ‘creating a healthy built environment using resource-efficient, ecological based principles’ (Kilbert, 1994). Hill and Bowen (1997) suggest four attributes of sustainable construction: social, economic, biophysical and technical.

- Social attributes are suggested for instance to include improvement of the quality of human life by ensuring secure and adequate consumption of basic needs, which are defined as food, clothing, shelter, health, and education.

- Economic principles of sustainable construction can for instance include use of full-cost accounting methods to set prices and tariffs for goods and services that fully reflect social and biophysical costs to achieve more equitable development and more efficient use of resources.

- Ecological or biophysical sustainability is used to include the atmosphere, land, underground resources, the marine environment, flora, fauna and the built environment. The aim is to reduce the use of water, energy, materials and land at each stage of a projects life cycle.

- Technical sustainable construction can include constructing durable, reliable and functional structures. Furthermore it is important that the construction of buildings are done in such a way that it is possible to adapt them to suite other purposes without resorting to demolition.

Construction activity will always involve some undesirable environmental impact but the intention from the client/contractor is obviously not to do this. Therefore applying goals for sustainable construction should aim to reduce the extent to which this will happen.

1.2.2 NATIONAL GOALS FOR SWEDEN

Sweden takes an active part in reducing both global and local environmental impact and is internationally aiming to be a driving force and a model for ecological sustainable development. Governmental initiatives are addressing the subject in legislation and all laws concerning environment is collected in a new law the Environmental Code (1998). The Environmental Code provides a co-ordinated, stringent and broad environmental legislation with a view to promote sustainable development which today is one of the parliaments greatest challenges. Moreover, the Swedish Government has decided on three overall environmental objectives for ecologically sustainable development:

- Protection of the environment: to reduce environmental impact to a level not exceeding the environment's natural capacity.
- Sustainable supplies: to conserve the long-term productive capacity of forests, soils and water resources, and to use a greater proportion of renewable materials.
- Efficient resource utilisation: to use energy and other natural resources much more efficiently than today.

These three objectives have served as a basis for development of the following 15 national Environmental Quality Objectives (EQO) presented in a Government Bill (1997) and later accepted by the parliament in 1999. The objectives aims at reducing the environmental impact to sustainable levels within one generation, i.e. to the year 2020.

1. Clean air
2. High quality groundwater
3. Sustainable lakes and watercourses
4. Flourishing wetlands
5. A balanced marine environment, sustainable costal areas and archipelagos
6. No eutrophication
7. Natural acidification only
8. Sustainable forests
9. A varied agricultural landscape
10. A magnificent mountain landscape
11. A good urban environment
12. A non-toxic environment
13. A safe radiation environment
14. A protective ozone layer
15. Limited influence on climatic change

To make the goals usable they have to be specified which have been done by presentation of between one to eight sub goals for each EQO's (Governmental Bill, 2001). The sub goal was accepted by the parliament in the same year.

Many objectives are related to construction but to a varied extent. The most relevant objectives should be 6, 7, 11, 12, 13, 14 and 15. The motives are: building products may include hazardous substances (objective 12); a source of radiation is radon in buildings (objective 13); emissions from e.g. energy use can have an effect as environmental impact (objectives 6, 7, 14, 15). Objective 11 is related to cultural assets that are to be protected and developed but also to environmental impact.

The National Board of Housing, Building, and Planning carried the main responsibility for development of strategies and sub goals for this objective. Sector goals have been determined and are related to energy efficiency, improved indoor climate and resource use (National Board of Housing, Building, and Planning, 2001). In a report from Statistics Sweden and Swedish EPA (2000) an evaluation of the current development, in relation to the EQO is made. For objective 11 the progression is pessimistic since it states that: no definite change have occurred related to reduced environmental impact, it is not realistic to think that changes are made by 2010 and that the measures taken indicate that achievements can not be done by 2020.

1.2.3 THE BUILDING SECTORS VOLUNTARY UNDERTAKING

The environmental impact of construction has been addressed both at national and international levels and the outline of the Swedish environmental politics recommends the building sector to progress its environmental merits. A great determination for improvements has been shown in resent years and nowadays the building sector can hardly be blamed for not implementing these issues earlier. However a general lack of information about environmental effects has led to late advancement in the area as the development of strategies based on research first had to be prepared and after practical applicable models can be developed to meet the future requirements. Further, the Swedish building sector is characterised by its strong fragmentation, dominated by various small and medium sized enterprises, making all-embracing environmental strategies hard to implement.

As a response the *Ecocycle Council for the Building Sector*, which includes developers, property owners, contractors, architects, consultants to the building industry and the building materials industry, was established on a voluntary basis in 1994. One of the endeavours is to limit future environmental problems through action at early stages of product development, planning and project design. This resulted in a plan of actions in 1995 (Ecocycle Council, 1995). More recently an environmental investigation of the building sector's most significant environmental aspects related to buildings, was presented during 2000, Table 1.1.

Table 1.1 The most important environmental aspects (Ecocycle Council, 2001).

Buildings	*Infrastructure*
(1) Energy use	(1) Use of material
(2) Use of material	(2) Use of hazardous substances
(3) Use of hazardous substances	(3) Transports
(4) Indoor air quality	(4) Energy use
(5) Noise conditions in the building	

In the form of a dialogue called Build/Live (Bygga/Bo) between the government, represented by the Environmental Advisory Council, representatives from 20 building and real estate companies and three municipalities a vision, goals and strategies for a sustainable development in the building sector were developed. These are presented below (Build/Live, 2000).

1. No fossil energy sources are to be used for heating or hot water after 2025. Half of the annual energy demand is, by 2015, supplied with renewable sources.
2. Use of delivered energy in the sector has been reduced with at least 30% by 2025 compared to 2000.
3. Information, making it possible to avoid products containing environmental hazardous substances or products which cause known health or environmental risks, should be provided by 2005.
4. All new buildings and 30% of the existing building stock should be examined by declaration and classification with regard to health and environmental impact by 2010.
5. The building sector should no longer use substances and metals included in the Government's guiding principles for use of chemicals (SOU 2000:53) by 2008.
6. At a maximum of 25 % of the building and renovation waste, measured as mass from the year 1994, should be deposited by 2010. By 2025 at most 10 %.
7. Extraction of natural gravel has by 2005 been limited to a few specific purposes and amounts to a maximum of 3 million tons annually by 2020.

These goals can be considered as a high aim but not impossible to fulfil. The first goal involves energy producers more than the building sector itself. The energy producers have to supply renewable energy, as the developers/clients cannot influence the type of energy supplied by the municipal or in the power supply system.

The second goal is relevant for the building sector to build energy efficient, e.g. better insulated and with more efficient installation systems. Since energy use in buildings is effected by the occupants' life-style in which the builder have no control over a separation between energy for HVAC and other energy should be useful if developing sub goals. However, the major problem is not when producing new buildings, it is rather in the existing building stock. Reducing the energy demand in those can prove to be more difficult and costly. For improvements information to tenants about how heat and ventilation systems works and the tuning of such systems can give effective results. Providing stimulus is another way as e.g. by charging energy and water costs directly to the tenant based on use however this requires individual measurements. As reduced energy use is one of the buildings sectors major targets regarding environmental impact this is further examined in the next subsection, 1.2.4.

Guidelines for material declarations have been published by Ecocycle Council (1997) and many producers supply inventories to inform about contents of products. A problem is that the information from different suppliers is not gathered and managed in a database. However some larger real estate clients now develop such a database, MilaB, making inventories and evaluation of products more easily accessible. Declaration of building material will facilitate identification of substances included in the Government's guiding principles for chemical use.

Several organizations and authorities as Build/Live, The National Board of Housing, Building and Planning and countries within the European Union address classification of buildings. In Sweden one recommendation is that the government should integrate a classification system with the tax system where new and existing buildings in the highest environmental classes are being lowered taxed. Today, higher taxes through the taxation value are applied to buildings upgraded to improve their environmental standard giving incorrect signals to both the sector and the customers.

Goals for waste reduction are difficult to follow up since statistical information is not available. Improvement in this area is currently needed.

1.2.4 ENERGY PERFORMANCE FOR BUILDINGS

Goals for energy performance improvements in Swedish homes, residential buildings and offices, are shown in Table 1.2. The goals are an outcome from the dialogue Build/Live in 2001 with high targets both for new buildings and as an average. The reduction has been separated for heat and electricity respectively and is presented for homes, residential buildings and offices.

Table 1.2 Goals for reduced energy use for different types of buildings in kWh/m^2 by 2005 and 2025 (from Build/Live, 2000).

		Houses (120 m^2)		Residential buildings (75m^2/apartment)		Office buildings	
		Electricity	Total	Electricity	Total	Electricity	Total
Today	Average*	35	150-190	40-45	170-245	95-125	140-240
	New buildings	35	105-150	35	175	95	140
Year 2005	Average*	35	160	35	200	90	200
	New buildings	30	90	35	120	80	120
Year 2025	Average*	20	110	40	150	60	100
	New buildings	20	50	30	70	40	70

* The lower values concerns buildings built after 1986 and the higher value buildings built before 1986.

At the moment the European parliament has submitted a proposal for a directive on the energy performance of buildings ENV 636 (2001). The purpose of the directive is to promote the improvement of the energy performance of buildings taking into account climatic and local conditions, as well as indoor climate requirements and cost effectiveness. The directive concerns a general framework methodology for calculation of integrated energy performance of buildings, application of minimum requirements on energy performance of new buildings and large buildings subjected to renovation, energy certification of buildings, etc. The Council's work and the directives given are likely to influence the future approach taken by the Swedish building sector.

The Swedish National Board of Housing, Building and Planning (2001) has on a commission of the government developed a model for calculating reference values describing energy performance of buildings. The reference values are supposed to be used for follow up national and international goals and to be a basis for statistical comparisons between different buildings energy demand and their environmental impact. The supplied amount of energy used for heating, hot water, cooling and operation etc. is measured for each energy type and is divided per square meter (m^2) heated area (BRA). The unit is kWh$_{index}$/m^2 BRA and year where,

kWh$_{index}$/ year	Total amount of annual supplied energy divided on energy type
index	Electricity respectively district heating, oil, gas, coal, peat, pellet or other
m^2	Heated area (BRA) according to Swedish standard SS 021053

1.3 BACKGROUND TO THE PROJECT

As a result of poor productivity development in the Swedish building sector the program ***Competitive building*** was established in 1997 by a decision from the Foundation of Strategic Research (SSF). The project *LCC, LCP and environmental assessment* was initiated within its frame in 1999 and the findings are presented in this thesis. The development of the project is based on the conclusions presented by Sterner (1999) in the licentiate of engineering thesis Environmental requirements on buildings and construction (Miljökrav på byggnader och byggande). One result from the thesis study was an identification of environmental requirements stipulated in procurement documents of building projects. It was found that clients to a varied extent included environmental requirements in procurement documents and that aspects related to environmental impact from operation of the building were exceptional. Improvements were needed to expand the perspective from focusing on aspects related to material, waste and construction to a life-cycle perspective of environment and costs. The implication was to develop a tender evaluation model including those environmental aspects that can be sufficiently considered in monetary terms, used mainly for design and build contracts. Further use of such a model is in the design phase when comparing different alternatives.

Competitive Building promotes internationalisation of their doctoral students. This project was partly carried out at the School of Architecture, University of British Columbia, Canada providing an excellent possibility to study environmental design from the architects' perspective. Also life-cycle cost estimations in relation to environmental design were investigated.

1.4 AIMS

The aim for the work presented in this thesis is to contribute to the understanding of whether costs and environmental impact of a building can be integrated, from the users perspective, in a practical model applied for tender evaluation. The model should also be able to use as a base of evaluating different alternatives effect on life-cycle cost and environmental impact in the design phase. Specifically this means to:

- Increase knowledge about integration of economical and environmental aspects from a life-cycle perspective in relation to buildings
- Provide recommendations for procurement of cost effective and environmentally aware buildings

1.5 OBJECTIVES

The overall objective is to provide a multi attribute approach for evaluation of tender sums integrating life-cycle costs with environmental impact from operational energy use. Other environmental aspects are handled through requirements in tender documents. More specified the objective includes to:

- investigate which environmental requirements clients consider and which are useful to reduce environmental impact without leading to increased costs from a life-cycle perspective.
- investigate to what extent life-cycle costs estimations is used among Swedish clients and identify if constraints prevent clients from adopting the life-cycle cost methodology
- investigate if life-cycle costs estimations are considered useful by clients aiming at green design
- exemplify the costs of green design from a life-cycle perspective based on a case study
- integrate life-cycle cost with environmental impact from operational energy use and present a model which can be applied as one parameter in tender evaluation

1.6 SCOPE AND LIMITATIONS

This thesis primarily deals with the clients' perspective of including environmental requirements, impact assessments and life-cycle costs in procurement and tender evaluation of building projects.

A client is in this thesis defined as the part that initiates a building project. This part is herein considered as *the owner* of the building. In most cases the client orders the building project, obtains the building permit and is responsible for the fulfilment of laws and regulations. The client can be a private or a legal person (company, organisation or public administration).

The environmental aspects examined are limited to environmental impacts from buildings. This includes use of resources, energy, negative effect caused on land, water and air from construction, operation, maintenance and final demolition. Indoor climate concerns people's health and comfort while spending time in the building, and can be affected by, for instance, emissions from materials which is important but in most parts left outside this study.

The environmental impact assessment is strictly related to operational energy use, which today represents a major part of the total environmental impact. However, if efficiency improvements in operational energy use are accomplished this statement should be reconsidered. Another reason to limit the scope of impact assessment is practicality, assuming that a too complex model only will find a limited use in practice. Integrating environmental impact with life-cycle cost adds to its complexity, in regard to parameters included.

For the analysis of environmental impact and life-cycle costs existing input data is looked upon as relevant with respect to the objective of the thesis. The purpose is therefore not to produce new and better technical input data, for example concerning life-cycles and maintenance intervals of material and components.

The tender evaluation model developed integrates the price, the estimation of life-cycle costs and environmental impact. Other parameters possible to weigh together with the price as e.g. technical ability and financial soundness are not examined. The calculation of the initial cost includes many uncertainties but related methods are not investigated herein.

The definition of the building sector in this thesis is used in a wide sense and refers to client organisations, designers, consultant engineers, construction companies, suppliers of material and manufactures.

The investigations made mostly describe the situation in Sweden and to some extent the experiences from the Canadian building sector.

1.7 ORIGINAL FEATURES

The work presented here is an investigation related to how clients stipulate environmental requirements in procurement and to what extent they use life-cycle cost estimations. Drawbacks were found in both areas and a model to assist clients in embracing environmental impact and life-cycle costs tender evaluation was developed. The model can also be used to compare different alternatives in the design phase. The original features of this thesis are, as far as the author knows:

- Identification of which environmental requirements are stipulated in procurement of buildings and recommendations to avoid cost increases in a life-cycle perspective.
- Investigation of to what extent clients use life-cycle cost estimations, which limitations they consider are present and if life-cycle cost analysis are considered useful for environmentally designed construction projects.
- The development of a multi attribute tender evaluation model integrating life-cycle cost with environmental impact from operational energy.

2 METHOD

This chapter provides a description of the research design used in this thesis which includes the selection of method, data collection and methods for analysis. Finally some methodological considerations as the validity and reliability are discussed.

2.1 THE RESEARCH DESIGN

A research method can be defined as processes, principles and procedures that the researcher uses to approach the problem and to find possible solutions. It can be seen as a link between two parts (1) the problem examined, the aim and the theoretical understanding (2) the data collection and the analysis (from Bergström & Lumsden, 1993). Andersson and Borgbrant (1998) have exemplified some types of research designs, Table 2.1, showing different ways to approach a problem through the research process. The marked cells represent the research performed in this thesis.

Table 2.1 Design of a research process (translated from Andersson and Borgbrant, 1998).

	The research process →				
Type of research	The research question	Method	Method for data collection	Analysis and interpretation	Results and presentation
Change of practice	What should be changed and how	Case studies within organisations and working environments	Dialog Open and closed questions	Feedback Deeper data collection	Knowledge about changes in processes. Working material Seminars
Evaluation	Mapping What characterise the object studied	Investigations Examining of different objects	Questionnaire, interview	Descriptions of parts and entirety Causes and effects	Knowledge about the studied phenomenon Internal and public reports
Develop theory or model	Knowledge theory Development of new theories and models	Studies of published material	Empirical studies and original sources	Combination of known and new knowledge	Documentation of developed theories, concepts and models in articles, papers
Verification	What characterise a specific function	Laboratory studies Experiments	Measurements Simulations	Hypothesis trying Model building	Facts about the object studied Scientific publications

2.1.1 RESEARCH DESIGN FOR THIS PROJECT

According to Table 2.1 the research performed in this thesis will be a combination between evaluation and development of theory or model. To support the description of the methods and analysis models used herein the research design is illustrated in Figure 2.1.

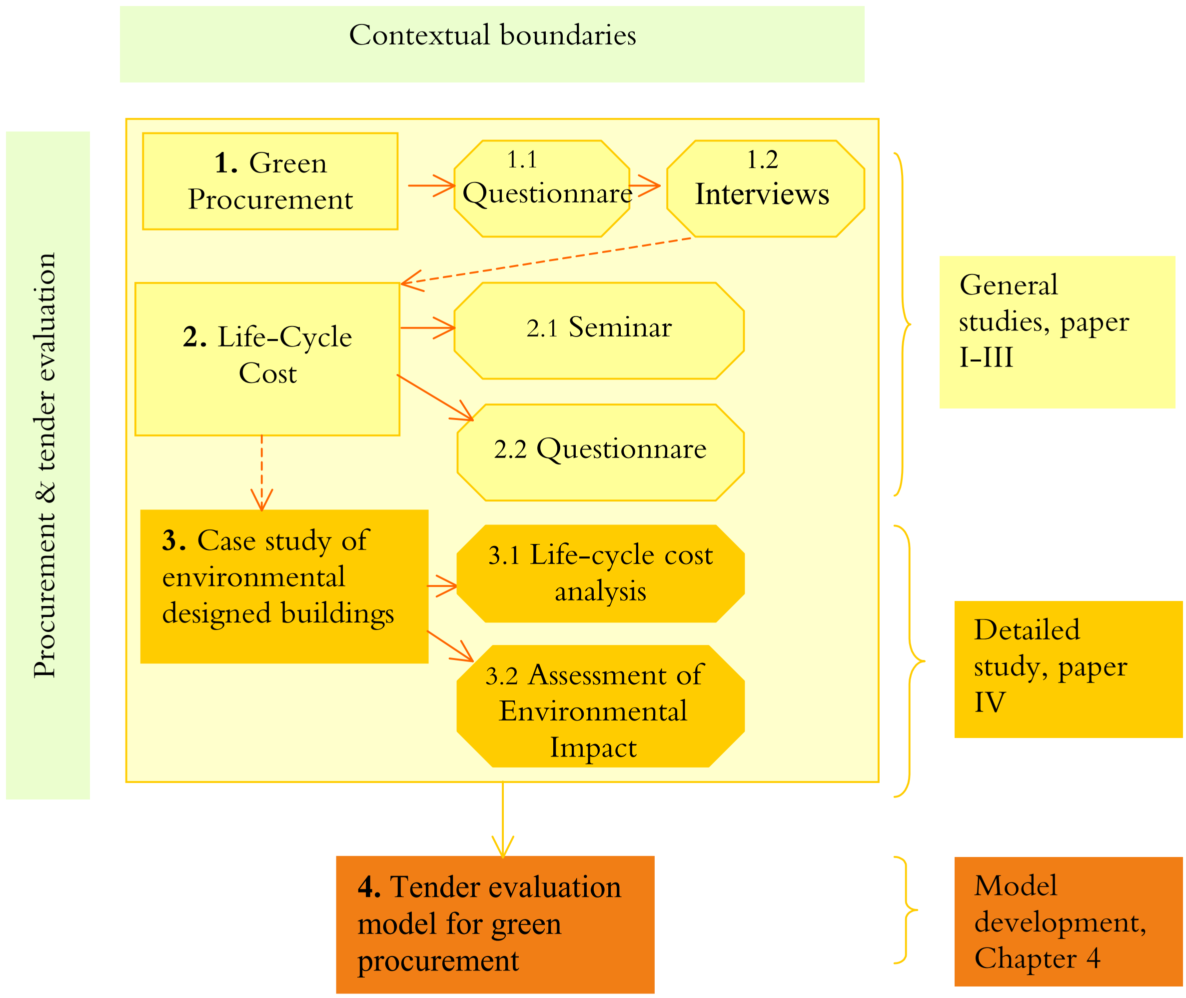

Figure 2.1 Research design used in the thesis.

The overall focus of the thesis is to provide recommendations for procurement of environmentally aware and cost effective buildings based on a life-cycle perspective. Contextual boundaries as legislation, regulations and the sectors' voluntary undertaking in general and the procurement process in specific set the framework.

(1) Green procurement. Information was initially collected from previous literature and by a questionnaire (1.1) to examine to what extent Swedish clients included environmental requirements in procurement documents. The client's performance of environmental strategies in the building process was examined through interviews (1.2). The results are presented in Paper I.

(1.1) Questionnaires. The motive to use a questionnaire is the ability to reach a large target group in a practical and efficient way. Herein the questionnaire concerned environmental requirements stipulated by clients in procurement documents. Both public and private clients were included as differences in their achievements in, and attitudes towards, ecological sustainable construction could be expected. A large number of clients were first identified in five sample groups. Then each group were reduced to together consist of totally 70 clients, Table 2.2. The selection of clients within each group was based on identifying those most likely to have included environmental requirements in procurement documents.

Table 2.2. Sample groups and yielded response to the first questionnaire.

Sample groups	*Group size*	*Clients contacted*	*Clients responding (%)*
Municipals	288	38	28 (74)
SABO	300	11	10 (91)
Government	16	11	9 (83)
Private	83	9	6 (67)
County Councils	21	1	1 (100)
Total	*708*	*70*	*54 (77)*

- Municipals selected were all members of Sekom, an organisation for municipalities with an ecological outlook. There are a total of 288 municipalities in Sweden and members of Sekom is considered to be more likely than others to have included environmental aspects in their procurement.

- SABO, an organisation for clients involved in municipal housing, with 300 members. From a survey performed by SABO, their members were asked questions about how they worked with environmental aspects in general. Four questions from that study related to building activities were identified and used as a selection criterion i.e. the client had to have considered all four questions to be selected for the study presented here.

- Governmental clients selected were all members in the Governmental Network for Quality and Construction, which includes 16 clients, departments and committees. Nine of these were selected. Excluded clients were those not heavily concerned with the procurement of buildings.

- The private clients selected were members of Byggherreföreningen, an assosiation for clients, with 83 member companies were 38 are private clients. The nine largest of these, according to business volume, were selected on the assumption that they have the financial wherewithal to develop and implement environmental strategies.

- The County Councils' Federation, including the 21 county councils in Sweden represented one sample group. At the time of the study building projects performed by county councils were rather concentrated in the Stockholm region, so only the Stockholm county council was included in the study.

The information obtained from the questionnaire was analysed by a categorisation, compare for instance Weber (1990), where the requirements were gathered in six different groups of categories. The categories were analysed to examine their possible influence on costs from a life-cycle perspective.

(1.2) Interviews. The motive to use interviews is the ability to develop a better understanding of the problem area. By interviews it is possible to develop around questions but with a constrain that the interviewer influence the respondents answer. To limit the influence and facilitate the evaluation of the result structured interviews is used, i.e. questions are prepared in advance and applied to all interviews. Some of the questions are structured so that the respondent could choose between clearly defined alternatives, other questions allowed the respondent to develop an open answer (for structured interviews see for instance Patel and Tibelius, 1986). Three clients distinguished from the others as they had, based on the questionnaire (1.1) response, developed the most complete procurement documents with regard to environmental requirements and are selected for interviews. The clients were: Lunds Kommuns Fastighets AB (LKF), Akademiska Hus in Stockholm AB, and Locum AB, Locum Bygg.

The information obtained from the three interviews were analysed by using a cross-case model in accordance with the method described by Miles and Huberman (1994). One aim of studying multiple cases is to increase the chances of generalisation and to develop descriptions. The information obtained from the interviews was initially scanned in a consecutive order using the interview questions as headings. Thereafter a categorisation i.e. themes in the information were identified and a structure was created.

(2) Life-cycle costs. A seminar (2.1) to examine the practical use of life-cycle costing as a method for motivating green design was performed in Canada. A questionnaire (2.2) was performed parallel to examine to what extent life-cycle cost models where used by Swedish clients. The results are presented in Paper II and III.

(2.1) Seminar. The motive to use a seminar was to in a time saving and easy way reach a larger group of respondents. There are though some constrains in the method applied as it might intimidate the respondents to speak freely and interviews may in that case be a better option. The seminar, held in Vancouver, Canada, was used to examine use of life-cycle cost in practice, the barriers existing for a wide uptake and the usefulness of life-cycle costing and full cost accounting in green design. There are many both private and public clients in Vancouver that have worked with environmental design of buildings making their experiences interesting to relate to the work performed herein. For the seminar questions were prepared in advance and circulated to the 20 attendants (facility managers, public and private clients, architects, engineer consultants, contractors and quantitative surveyors). Three of the attendants were invited each to during 30 minutes address the issues raised in the circular, offer personal insights and afterwards in a discussion exchange views with the other seminar participants.

The information obtained from the seminar consisted of notes related to practical uptake of life-cycle cost estimations. The notes were directly after the seminar categorised into following groups: motivation, contextual issues, methodological limitations and access to reliable data. The viewpoints obtained within each category where in some cases supported by aspects discussed by other authors in previous literature. The result is presented in Paper II.

(2.2) Questionnaire. The motive to use questionnaires was again the ability to reach a large target group in a practical and efficient way. This second questionnaire aimed at collecting information about the practical use of life-cycle cost estimations by Swedish clients. It was sent to the 83 clients who all are members of Byggherreföreningen as representing for instance industrial, commercial, and public clients. The clients who had not answered the questionnaire in due time were sent a reminder within a three weeks period. A total of 53 (64 %) clients responded. 12 of these were asked some additional questions specifically targeting the life-cycle cost models used by them. The response rate to the additional questions was 67 %. The result is presented in Paper III

(3) Case study. In a case study the life-cycle cost (3.1) and environmental impact (3.2), from three environmental designed buildings are compared with three conventional buildings. The result is presented in Paper IV.

(3.1) Life-cycle cost. Herein the case study is represented by a building project consisting of three separate buildings. The information collected is of strictly quantitative character and consisted of measures areas and costs related to the construction and first year of operation. The areas (m^2) in the buildings have been established based on drawings preceded by a visual inspection of the buildings. As this is not a conventional project and as a consultant team has developed the environmental design it was necessary to meet with these persons in order to understand the planning and design process used and the development of the project's environmental features. Meetings with the architect, the contractor and the service installation (HVAC) consultants was performed to obtain information about the construction work, the heat and ventilation system, and the initial costs associated.

To establish the maintenance cost and some annual costs, such as cleaning etc., all interior and exterior surfaces are measured from drawings. Future required provision for maintenance are estimated based on intervals given in Repab (Repab, 2000) which also provides recommended values for annual costs. The energy use for the buildings was obtained from consultants, based on the first year of operation. Future energy costs were thereafter forecasted.

The cost related data obtained from the case study is of strictly quantitative character and consisted of measured areas and information of initial cost and the first year of operation costs mainly related to energy and water use. The information was evaluated using a sensitivity approach as described by for instance Flanegan and Norman (1987). The sensitivity approach is used to determine how the value of one parameter is affected by variation in another parameter on which it depends. Herein this approach was used to determine the change in break-even point for the different types of project analysed.

(3.2) Assessment of environmental impact. Assessment of the environmental impact in the case study project was related to operational energy and performed by classifying the emissions into global warming, acidification, and eutrophication potentials using a life-cycle assessment (LCA) approach. The evaluation method to weight the categories together is based on the Swedish Environmental Quality Objectives.

(4) Tender evaluation model. The experiences gathered in step (1) to step (3) forms the basis for development of a tender evaluation model integrating environmental impact from operational energy use with life-cycle costs, presented in Chapter 4. To determine the relevance of the life-cycle cost elements integrated in the model for instance the response from the questionnaire (2.2) and the evaluation of life-cycle cost elements in the case study (3.1) is used.

2.2 METHODOLOGICAL CONSIDERATIONS

The methods applied to meet the objectives herein are a combination of qualitative and quantitative approaches. The two first part of the research (1) and (2) can furthermore be defined as deductive as being based on previous work within the building sector. A deductive approach is characterised by creation of a theory, through for instance literature reviews, from which a number of hypotheses are deducted. The hypothesis is then tested on a number of cases with the aim to verify the formulated theory. By questionnaires and interviews definitions have herein been tested on a sample of cases making this a deductive process. The drawback of a deductive approach is that conclusions always are looked upon as true within itself. The case study (3) is inductive by character as used to generate data after which a model is developed. One risk with inductive approached is that the possibility of generalisation is limited.

The validity of the result is dependent on what is measured and how that is explained when defining the problem to be examined. The aspects measured are reported in: the questionnaire concerning environmental requirements included in Paper I, the interview manual also included in Paper I, the questionnaire concerning life-cycle costing appended in Appendix B, the data used to calculate the life-cycle cost appended in Appendix C and the data used to calculate the environmental impact in Appendix D.

The reliability of the result is determined by how the studies are performed and how the information is analysed. For the questionnaires and interviews the description of the sample selection and the processing of the information are important for the reliability which have been done in this sub section. The reliability of the data used for calculating environmental impact and life cycle costs is described in Chapter 4.

3 OVERVIEW OF CURRENT PRACTICE AND RELATED RESEARCH

This chapter provides a description of four areas related to the work presented in this thesis. At first different procurement systems are described as these set one boundary for how costs and environment can be considered. The second subsection (3.2) is a state of the art review related to life-cycle costing. Subsection (3.3) is related to life-cycle assessment and the tools currently used, subsection (3.4) concern tender evaluation. Finally, a short summary of the provided overview is presented.

3.1 THE PROCUREMENT PROCESS

The procurement system is an organisational system assigning specific responsibilities and authorities to people and organisations, and defines the relationships of the various elements in the construction of a project (Love et al., 1998). The procurement system selected is significant for obtaining a successful construction project, delivered on time, within budget and to the quality required. For a client this initially means to decide if the resources needed to perform the project, (e.g. architects, consultants, engineers, construction workers, etc.) are going to be procured separately or if one contractor should be responsible for the work. The most common procurement systems used in Sweden today are general contract and design and build contract. New forms occurring are the performance based contract and partnering.

General contract, is often seen as the traditional procurement process in where the client hires a consultancy team as architects, designers, and project managers. Thereby one or several designers are involved in the design of the building. After the design phase the client procures the construction contractor separately who in turn is responsible for the procurement of subcontractor work. This form may discourage teamwork as various parties often assume adversarial roles.

Design and build contract, is a method of procurement in which one organisation takes full responsibility for both design and construction. This organisation may be a multi-disciplinary firm with in-house design staff or a consortium involving a contractor, an architect, a structural engineer and a building service engineer (Anumba and Evbumwan, 1997). Design and build contracts have several advantages for the client such as the potential to use single contractual arrangement for the total process which can promote innovative solutions, integration of design and construction expertise, shortened construction time, and lower total cost. The disadvantages may be lack of flexibility to respond to changing client needs, issues of durability, flexibility of systems, future expansion etc. (Palaneeswaran and Kumaraswamy, 2000). However, few construction contracts in Sweden are performed as conventional design and build contracts indicating predetermined technical solutions. This since it is difficult to define a product without specifying its technical solutions. Procurement methods not allowing the contractor to develop the best solutions/methods can increase building costs and prevent productivity development. In a design and build contract the clients' possibility to raise environmental requirements is related to the stipulation of performance requirements and to the evaluation of the contractors submitting tenders.

Performance based contracts of buildings (Lagerqvist, 1996) is an improved form of the design and build contract. Performance based contracts and requirements have been used in different forms by for instance the Swedish National Road Administration see for instance Nylén (2000) for procurement of road operation. The distinctive part is in the client stipulating measurable requirements based on performance and that contractors are not obligated to revile the technical solutions corresponding to stipulated requirements. By providing the possibilities to introduce new technical solutions, methods and systems the performance requirements can also favour competition for environmental development. For liability boundaries between purchaser and seller become clearer where the seller undertakes a greater responsibility as the guarantee time is expanded. Performance based contract will also provide a stimulus for the contractor to develop products with a higher level of industrialisation.

Partnering has proved to be a successful contract form not at least in the UK (Atkin and Gravett, 2000) where significantly reduced costs and production times are achieved. As in Sweden the UK construction industry is characterised by its strong fragmentation. To improve this many of the 'best' clients use partnering or similar agreements to keep project teams together. According to Atkin and Gravett (2000) partnering serves to improve performance through agreeing mutual objectives, devising a way for resolving disputes and committing everyone to continuous improvements. It is however emphasised that this is not an easy option for constructors and suppliers as it can be more demanding than conventional tendering, requiring recognition of interdependence between clients and constructors, open relationships, effective measurement of performance and an ongoing commitment to improvement.

Between these classifications there are a number of variations. The conventional procurement process for contract works (general contract) in Sweden starts with a tender invitation to one or several contractors for performing the work. Contractors who wish to submit a tender must obtain the procurement document in which cost for performing the work is calculated. The procurement documents consist of drawings, descriptions and administrative specifications. The administrative specifications specify administrative and legal requirements normally arranged according to AF AMA and are used for any type of procurement contract. Unlike many other countries Sweden has no particular legislation concerning contract relationships for building projects by private clients. Though in 1908 the Swedish technology association examined contract agreements (Söderberg, 1993) and later in 1954 general conditions (Allmänna Bestämmelser) AB 54 for contracts within building and civil engineering works were developed in co-operation between clients and contractors. These conditions have been revised over time and today AB 96 is accepted practice.

For public procurement more restrictions than for private procurement apply. The principles for public procurement have changed drastically since Sweden's entry in the European Union and from January 1st 1994 the ECs harmonising regulations and the Swedish Public Purchase Act (Swedish Code of Statutes, 1992) apply. Restrictions to consider in public procurement related to the EC regulations is described by for instance Falk (2001). Private procurement can be performed within a wider context and with less complicated regulations. However, this must still be done in such a way that public principles for contracts, purchase laws and laws regarding competition are followed.

3.1.1 GREEN PROCUREMENT

An extensive review of literature by Hatush & Skitmore (1997) shows that there has been a huge increase in the complexity of projects and in the clients' needs together with an associated increase in alternative forms of project delivery system during the last two decades. Environmental requirements are one example of new aspects in project design and construction and implementation of green procurement, i.e. procurement including environmental requirements, has developed in both private and public sector during the most recent years. By stipulation of environmental requirements procurement can provide a significant contribution to ecological sustainable development and it is of major importance that the government, municipalities and country councils do so.

A number of studies on green procurement have been performed in Sweden. The Swedish EPA (1995b) published a report on public procurement with environmental concerns and Gren (1999) for instance examined environmental requirements as a political means in public procurement. Environmental procurement in relation to building and civil engineering works is examined by Faith-Ell (2000) for road maintenance within the Swedish National Road Administration and by Faith-Ell and Sterner (2001) for buildings and road maintenance. To promote green procurement within governmental agencies, local authorities and county councils the Committee for Sustainable Procurement (EKU-delegationen, 2001a) has developed a guide to ecological sustainable procurement. One of the task groups examined stipulated requirements for construction and service within building and facility management (EKU-delegationen, 2001b). It was concluded that the requirements stipulated do not correspond to the requirements on effective and sustainable use of resources and that a change in approach is needed to contemplate environmental impact from a broad perspective. However, procurement can be the means for reaching sustainable goals by using quantitative, preferably measurable requirements, and targets for reduced environmental impact.

3.2 INVESTMENT APPRAISAL TECHNIQUES

Investments in building works focus towards the high initial costs and less attention given to reduction of construction costs. This can result in an economical underrating of the operation phase. Some could argue that the initial construction cost is of such magnitude that operation costs can be ignored. That may well be the case of certain individual products/components. However, if a system approach is applied where costs of operation and maintenance are included these can account to about 55 % of the total cost seen over 40 years (Flanegan et al., 1989). In Figure 3.1 the relation between a few accounting methods are presented.

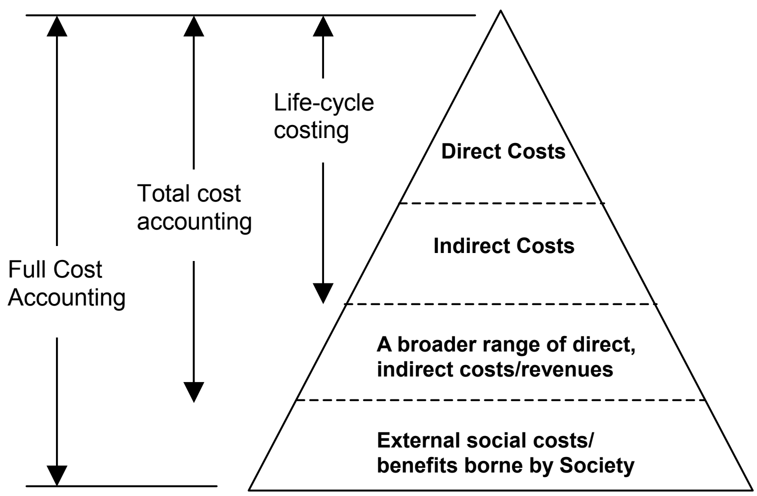

Figure 3.1 Alternative cost accounting methods (adapted from British Columbia Ministry of Environment, Lands and Parks, BCMELP, 1997)

Life-cycle cost embraces the direct (initial) costs for construction and the indirect (future) costs of operation. Total cost accounting can embrace a somewhat broader perspective of costs as for instance the cost of salaries of people working in the building and the influence of occupant productivity. For public assets the investments methods can exceed that perspective. The Swedish National Road

Administration (SNRA), for whom it is relevant to include benefits and external costs for the society, uses such methods in the planning phase of projects and sometimes life-cycle costing in procurement (SNRA, 1999). Still, for many clients such a comprehensive view of costs is not useful in making decisions about alternative building design options. Table 3.1 provides a short description of some accounting concepts, a more extensive overview of accounting tools is found in Gluch (2000).

Table 3.1 Description of some economical investment methods that can be used to account for life-cycle costs or/and benefits.

Concept	***Description***
Cost-Benefit Analysis or Full-Cost Accounting	Cost-Benefit Analysis is an economic tool for supporting decisions on larger investments from a social viewpoint (Moberg et al.,1999). The attempt is to internalise the externalities, such as social costs, so that the company producing the environmental impact brings the costs into the costing system (Epstein, 1996). Future costs and benefits are discounted to take the time horizon of effects into account.
Total-Cost Accounting or Life-Cycle Cost	Total cost accounting, synonymously with whole-life costing and life-cycle cost is an approach where the systematic consideration of all relevant costs and revenues associated with the acquisition of an asset is considered. For construction this is expected to take into account all the relevant costs for capital or procurement during the whole life-cycle (Clift and Bourke, 1999). A standard methodology for whole-life costing is currently being developed by ISO (ISO/TC 59/SC 14N). Moreover the ISO standard for life-cycle costing is ISO 156868 (ISO, 2001).
Life-Cycle Profit	The linkage between investment and income is sometimes expressed as life-cycle profit (LCP). This includes the whole income after all life-cycle costs has been deducted (Bejrum, 1991).

In the next subsections only life-cycle profit and cost are described as the research presented in this thesis do not attempt to embrace other aspects than those given by these methods.

3.2.1 LIFE-CYCLE PROFIT

Life-cycle profit is an expanded perspective of life-cycle cost estimations including the profit. The cost elements are described in 3.2.2 as these are the same in both methods and here only the profit is discussed.

The relevance for clients to include profit in the investment appraisal is to optimise incomes in relation to costs. In general the revenue from facility management at a certain point in time is affected by many factors as the technical performance, the state of the building and its modernity, the use, expectations of future use, the properties location, the facility managements organisation and level of ambition within the institutional boundaries. All these factors act together in a complex pattern which change over time (Bejrum and Lundström, 1995). Although the income side for buildings is relatively passive, as the profit is partly determined by external factors, there are still several opportunities for an investor to increase the revenue. For residential buildings the income is in direct relation to rents where the level is determined by the user evaluation of the apartment character (size, number of rooms, standard of equipment, environmental profile, etc.), benefits in relation to the apartment (shared common spaces, etc.), external factors (location, access to commercial and public services, environment, etc.)

By identifying aspects that tenants find important, and are willing to pay for, the client's possibilities to profit will increase. In Sweden some contractors have specialised on the idea of a healthy, higher quality indoor environment and can probably retain a higher profit per square meter. Other consequences of environmental design can be reduced service installations where the space earlier required for the installations can be used more effectively and generate an income. However aiming for reduced investment and operation costs are more important from an economical perspective.

In the U.S. a standard practice (ASTM E 964, 1993) for measuring benefit to cost ratios (BCR) for buildings or building system have been developed. The equation (3.1) is possible to use when comparing the life-cycle profit for different design alternatives. The BCR provides a numerical ratio that indicates the economic performance of a project by the size of the ratio. A ratio less than 1.0 indicates an uneconomic project and a ratio greater than 1.0 indicates that the project is economic according to

$$BCR = \frac{\sum_{t=0}^{N} (B_t - C_t)/(1+r)^t}{\sum_{t=0}^{N} I_t/(1+r)^t} \quad (3.1)$$

where

BCR	benefit to cost ratio
B_t	benefits in the period *t*, as advantages in revenue or performance
C_t	costs in period *t*, excluding investment costs that are to be placed in the denominator for the building or system
I_t	those investment cost in period *t*, that the investor wishes to maximise the return for, and
r	the discount rate

3.2.2 LIFE-CYCLE COSTING

According to the definition by ISO 156868 part 1, the life-cycle cost method is: *A technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both on terms of initial capital costs and future operational costs.*

The technique is equally applicable to existing buildings or for consideration of an element of a building. The outcome of the analysis is most useful as a comparative figure for the purpose of ranking different design alternatives (Seldon, 1979) but can also enhance the contractors interest in operation and maintenance plans. These are usually a vague and unimportant consideration during the early phases of planning. The early development of life-cycle costing took place in the U.S. where federal and state laws now demand life-cycle costs to mandate or encourage energy conservation. A guide for selecting energy conservation projects based on life-cycle costs for public buildings was presented by the Department of Commerce in 1978 (DOC, 1978) followed by a life-cycle costing manual for the federal energy management program (Ruegg, 1980). American Standard for Testing Material, ASTM E917 (1989), have developed methods for life-cycle costing and the International Standardisation Organisation, ISO 15686 a standard. Countries such as Canada have adopted the ASTM principles and in the UK similar methods based on whole-life cost occur. However, the use of the standard by the UK and Canadian clients has been limited in practice due to among other things scarce input data (Clift and Bourke, 1999; Larsson and Clark, 2000).

To exemplify the use of life-cycle costing in standards, Canada who has a similar climate to Sweden and also have responded to the challenge of climate change, have taken several measures to improve energy performance in buildings (Natural

Resources Canada, 1999). One is the Model National Energy Code for Buildings (MNECB) published in late 1997 by the Canadian Commission on Building and Fire Codes. The code establishes minimum construction standards in areas relating to energy use in commercial, institutional and large residential buildings. Life-cycle cost estimations was used when developing the envelope prescriptive requirements where the envelopes with the lowest life-cycle cost were selected for inclusion in the code (Haysom and Lacroix, 1999). The analysis included the use of different fuel types for heating, current and future energy cost, construction costs and estimated long-term interest costs, discount rate and economic life of the building. The general inflation rate was set to 3 %, real discount rate to 6% and the nominal interest rate to 9 %. The overall heat transmittance of each assembly was calculated and its effect on heating and cooling costs over a 30 year life of a representative building was estimated (Carpenter, 1999). As noticed the discount rate used is high and the life-length for the studies are rather short from a building life perspective. Using too high interest rate undermines the effect of future costs and the importance of performing a life-cycle cost analysis will be reduced. The effect of discounting is further discussed in the next subsection.

3.2.3 LIFE-CYCLE COSTING METHOD

The use of life-cycle cost techniques in building design is discussed by several authors as cost-in-use by Stone (1967); life-cycle costing by Flanegan and Norman (1983), Flanegan et al. (1987); Robinson (1986); Bromilow and Pawsay (1987); Kirk and Dell'Isola (1995). The result of their investigations shows the significance of operation costs, in particular related to energy use. In Sweden Öfverholm (1984) and Bejrum, (1991, 1994) have discussed the method and application for building projects. Further, Westin (1989) developed a model for investment appraisal based on life-cycle costing applicable in the different phases of the building process. When performing a life-cycle cost analysis the present value (PV) method is in most cases applied. In short the PV represents the amount of money that is to be invested today to pay for initial and future costs. Due to inflation the value of money will be less in the future and costs are discounted to a present value, usually when the initial investment is made. One general expression, which can be used to calculate the life-cycle cost is

$$LCC = I_0 + \sum_{t=0}^{N} O \cdot PV_{sum} + \sum_{t=0}^{N} M \cdot PV_{sum} - S \cdot PV \qquad (3.2)$$

where $PV_{sum} = \frac{(1+r)^t - 1}{r(1+r)^t}$; $PV = \frac{1}{(1+r)^t}$

I_0	Initial costs	(including site costs, design fees, construction cost etc.)
O	Operation costs	(annual costs including energy, cleaning, etc.)
M	Maintenance cost	(annual costs and costs for replacement, alteration)
S	Salvage value	(income from sale or cost for demolition)
PV_{sum}	Presentvalue sum	
N	Length of study	(year)
t	Time variable	
r	Discount rate	

The initial cost I_0, includes development costs (design, fees, land, cost of capital etc.) and construction costs. Together these represent the investment cost to obtain a building. The construction costs are a summation of quantities (labour, material, machines etc.) multiplied by rates and constitute the largest part of the initial cost. The operating costs O, are the costs associated with operating the building and include: energy, care taking, cleaning, insurance, rates, security etc. The costs are usually calculated per m^2 annually where future costs are transformed to a present value. The maintenance costs M, are represented by the cost to keep a building in good repair and working condition including: painting, repairs, renewals etc. These costs occur at different time intervals and are strongly dependent on the life-cycle, when the building becomes older these increase. The salvage value/cost S, represents the income from sale or cost for demolition. As environmental issues have become more important the disposal phase is being recognised as a significant and potentially costly aspect at the end of a buildings' life. Abraham and Dickinson (1998) examined disposal costs for environmentally regulated facilities by using the life-cycle cost approach and found them significant for the total cost. However, as discounting is used this have a minor impact on the total cost for conventional buildings.

The discount rate represents the time value of money often established as the actual rate of increase in the value of money over time, i.e. the rate over the general economy inflation rate. Inflation may be considered as a general increase of prices of goods and services over time in the economy as a whole, without a corresponding increase in value. Cost growth is an increase in the price of an individual item with or without a corresponding increase in value. A discount rate, which does not include inflation, can be used for comparative analysis and is based on the assumption that the private industry will seek a certain set rate of return over the general inflation rate no matter what the inflation rate may be (Kirk and Dell'Isola, 1995).

It is normally the prerogative of the owner or policy maker to select the discount rate. The decision can be based on for instance the cost of borrowing money and profit expected or the rate of return from an alternative investment. Choosing a discount rate will depend on the objectives of the client and will in most cases depend on whether the client is financing the project with borrowed money or from capital assets. In the first case the appropriate discount rate should be equivalent to the actual cost of borrowing the money. In the second case the discount rate should be determined by current and future rate of return for that investment, ultimately, by the best alternative use of such funds (Flanegan et al., 1989). In this thesis a discount rate of 4 % is used as an example and is selected to be corresponding to the long-term cost of borrowing money. In Figure 3.2 the change in the repo rate is shown for the last five years and the statistics show that it has been close to 4 % during this period of time.

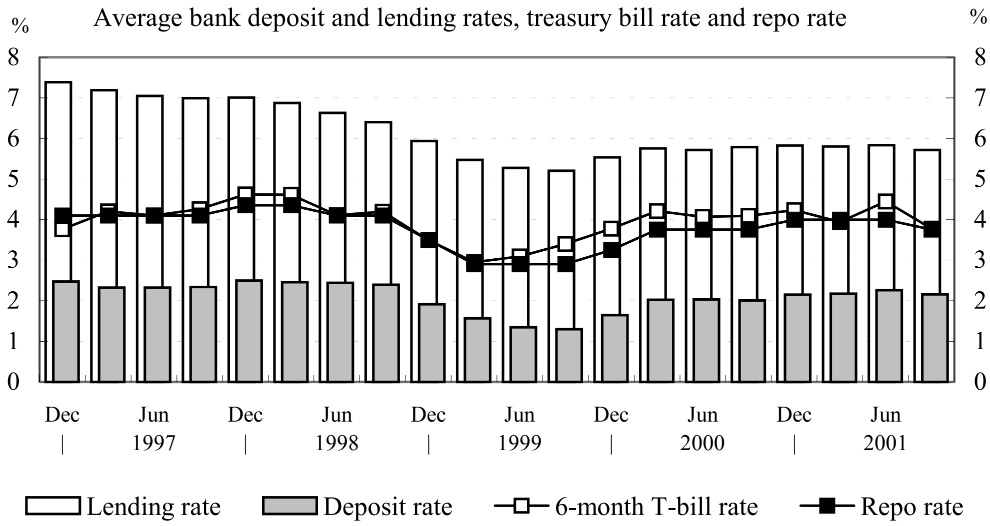

Figure 3.2 The variation of the average bank deposit and lending rates, the treasury bill rate and the repo rate. The repo rate is used to determine the discount rate for the life-cycle cost analysis in this thesis (from Sweden's central bank, the Riksbank).

A low discount rate will bias investment decisions that reduce future operation and maintenance costs. In contrast high rates encourage minimum standards of construction since the resulting operating cost is heavily discounted and has a less impact on the analyse (Stone, 1967). The discount rate is usually one of the critical variables in the life-cycle cost analysis, in that the decision to proceed with a project will be crucially affected by which discount rate is chosen.

The results of a life-cycle cost analysis are always uncertain and mainly related to the discount rate applied and the input data since these are estimates and assumptions about the future based on what is known today. It is important to make an assessment of the effects of these uncertainties as for instance by varying the discount rate. How much the life-cycle cost is affected by changes in these estimates is likely to vary quite markedly, both across the options being compared and with the respect to the estimates made (Flanegan et al., 1989; Kirk and Dell'Isola, 1995). Most of the literature concerning life-cycle costing suggests two different approaches to risk analysis. These are either sensitivity analysis or a probabilistic approach. The sensitivity analyse identifies the impact of a change in a single parameter value within a project and is used in this thesis, whereas the probabilistic simulation is a multivariate approach (Flanegan and Norman, 1989).

3.2.4 INFLATION AND PRICE ESCALATION

The objective of discounting is to produce a value which will relate to current prices. When alternatives are being compared it is common to consider the discount rate, r, as the rate above the general economy inflation, i, where all costs are assumed to increase in price at the same rate as the inflation. It is also to be expected that costs will escalate differently over time and therefore it is being argued that discounting future cash flows should include the effects of inflation. When prices are escalating over the inflation it is commonly referred to as *differential escalation* (Kirk and Dell'Isola, 1995). When for instance the energy price escalation rate is less than the discount rate the differential escalation rate, *d'*, is calculated according to Eq. 3.3 and used in the PV Eq. 3.4. If the energy price escalation rate is higher than the discount rate, PV_{Esc} can be determined according to Eq. 3.5.

$$d' = \frac{1+r}{1+i} - 1 \text{ for } r > i \tag{3.3}$$

$$PV = \frac{1}{(1+d')^t} \tag{3.4}$$

$$PV_{Esc} = \frac{\frac{1+i}{1+r} \cdot \left(\left(\frac{1+i}{1+r} \right)^N - 1 \right)}{\frac{1+i}{1+r} - 1} \text{ for } r < i \tag{3.5}$$

Robinson (1986) suggests two approaches to discounting: the real cost approach and the monetarist approach. The real cost approach uses today's costs for both initial and recurring costs and no allowance for inflation is made. Recurring costs are discounted at a real rate of interest with the inflation component removed. A drawback will be to formulate a real discount rate. The monetarist approach allows for inflation to be used for both initial and recurring costs where recurring costs are compounded at an expected rate of inflation and discounts at the cost of capital. A drawback here is to formulate the expected rate of inflation.

3.3 ASSESSMENT OF ENVIRONMENTAL IMPACT

Several studies related to buildings, Adalberth (2001), and building products, Erlandsson (1995), Jönsson (1998), show the importance of considering environmental aspects from a life-cycle perspective. In this sense the building sector holds a unique position in comparison to several other sectors as the buildings have a considerable longer technical useful life than most other industrial goods. Also for buildings the environmental impact caused by operation e.g. heating, ventilation, maintenance, alteration and waste produced is large and a collected assessment of all the effects is complicated to perform.

3.3.1 LIFE-CYCLE ASSESSMENT

Life-cycle assessment (LCA) is used for analysing and assessing the environmental impact of a material, product or service throughout its life-cycle, usually from the acquisition of raw materials to waste disposal (Jönsson, 1998). LCA can be performed for the purpose of (Consolio et al., 1993): decisions involved in product or process development; decisions on buying; structuring and building up information; eco-labelling; environmental product declarations; and decisions on regulations. Since the early 1990s the international Society of Environmental Toxicology and Chemistry (SETAC) has developed a structure and terminology for the LCA methodology which has contributed to a broader acceptance of the method. ISO has also proceeded far in the development of a formalised structure for LCA including the following four steps (ISO 14040):

1) Goal definition and scope: the goal and scope of the LCA study should be well defined as to what questions are examined and how the results are to be applied and communicated. All system boundaries should be set and assumptions made should be clearly stated and a definition of the functional unit the result is assigned to should be made.

2) Inventory analysis: involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. These inputs and outputs may include the use of resources (input) and releases (output) to air, water and land associated with the system. Interpretations may be drawn from these data, depending on the goal and scope of the LCA. These data also constitute the basis for the impact assessment.

3) Impact assessment: evaluates the impact of various environmental loads using the result of the inventory analysis. This process involves associating inventory data with specific environmental impacts and attempting to

understand these impacts. The level of detail, choice of impacts evaluated and methodologies used depends on the goal and scope of the study.

4) Life-cycle interpretation: in interpretation the findings from the inventory analysis and the impact assessment are combined together, or in the case of life-cycle inventory studies, the findings of the inventory analysis only, in line with the defined goal and scope.

There are several advantages with using life-cycle methods: increasing the perspective from a main focus on manufacturing to involve the whole process, facilitating the identification of the processes or phases causing the largest impact to be able to concentrate improvement measured to those. There are still limitations in the use of the method as defining boundary settings and deciding on what allocation principles to apply. Trinius and Borg (1999) have studied this specific problem and one conclusion is that allocation appears to be of great importance to the LCA result especially for highly recyclable material such as steel. Another current limitation is in obtaining relevant, exact and applicable data, performed in the inventory analysis, step 2. This partly depends on the cradle to grave approach implying that a large amount of data is to be collected e.g. related to resource and energy use from extraction to manufacture and use, the emissions emitted, the waste created, manufacturing processes and transports at all stages. Several manufactures are likely to be involved and their presentation of the environmental impact differs.

The impact assessment, step 3, involves grouping the inventory data (categorisation) and associate this with specific environmental impacts (characterisation). Initially the information is categorised by its potential environmental impact as global warming etc. The emissions are assigned an environmental impact by characterisation factors further described in Chapter 4.

3.3.2 ASSESSMENT TOOLS

Assessment tools based on the LCA perspective and developed specifically for evaluation of impact from buildings are for instance Eco-Quantum (Boonstra and Knapen, 2000) in Netherlands, 'Building Research Establishment Environmental Assessment Method'- BREEAM (Baldwin et al., 1998) in UK, 'Building Environmental Performance Assessment Criteria'- BEPAC (Cole et al.,1993) in Canada, and 'Environmental Priority Strategy'- EPS (Steen and Ryding, 1992) in Sweden. These methods are well developed but results of evaluations should be carefully considered if compared, as these to a large extent are depending on how limitations are set. Jönsson (1998) compared floor materials using three different evaluation systems showing that the assessment methods gave varied results although the same products were examined.

Environmental and economic objectives are sometimes conflicting and the need to include economic parameters to the life-cycle impact assessment tools has been recognised. Chau et al. (2000) reviewed some vital elements of current assessment schemes and concluded that fundamental changes are needed. These changes are needed since most assessment schemes tend to focus on the credibility issue but fail to address the economic concern and values of most developers. The 'Green Building'-GB tool, second generation, has a broader scope as to include cost issues as one criteria in the assessment (Larsson, 1999). Two other assessment models of special interest herein are 'Building for Environmental and Economic Sustainability'- BEES related to material, and Ecoeffect related to buildings as both attempt to combine environmental impact with life-cycle costs.

BEES (Lippiatti, 1999) measures the environmental performance of building products by using the life-cycle assessment approach specified in ISO 14000 standards. All stages in the life of a product are analysed: raw material acquisition, manufacture, transportation, installation, use, recycling and waste management. Economic performance is measured using the ASTM standard life-cycle cost method, which covers the costs of initial investment, replacement, operation, maintenance and repair, and disposal. Environmental and economic performances are combined into an overall performance measure using the ASTM standard for Multi-Attribute Decision Analysis. For the entire BEES analysis, building products are defined and classified according to the ASTM (1989) standard classification for building elements known as UNIFORMAT II.

EcoEffect (Glaumann, 2001) is a method of assessment of buildings total environmental impact described in bar charts. The impact is assessed based on energy use, material use, indoor and outdoor environment, Table 3.2. Assessment of environmental impacts from energy use and material is performed using the LCA methodology with the real estate as a boundary. The total impact from inflow of material and energy and the outlet of waste, drainage, and emissions to air is assessed. The assessment on indoor and outdoor environment is for the most part based on questionnaires, and on some observations and measurements. Also the life-cycle costs is estimated and includes the costs related to investment, heating, electricity, water, and maintenance. Costs not directly related to the buildings environmental impact, as capital costs, are not included in the indicator. The indicator can for instance be used to study the pay-back time of investments under different development in prices. The method uses 0 % or 3 % escalation in prices over the general inflation.

Table 3.2 Environmental effects assessed in EcoEffect (from Glaumann, 2001)

Energy and material	***Indoor environment***	***Outdoor environment***
Discharge:	*Health effects:*	*Health effects:*
[1]GWP	Comfort	Air pollutions
Ozone depletion	Sick Building Syndrome	Land pollutions
Acidification	Allergy	Noise
Eutrophication	Cancer	Shadow
[2]POCP	Infection	Wind
Human toxicity	Segment problems	Smell
Eco toxicity	Specific sensibility	
Dust	Other	
Waste:	*Environmental factors:*	*Eco system:*
Building waste	Air quality	Vegetation
Radioactive waste	Thermal climate	Water
Slag and dust	Sound	Surface water
Hazardous waste	Day lighting	Biological production
Natural resources	Electrical light	Natural land
Fuel	Electricity	Build plantation
Metals	Drinking water	Other
Minerals	Surfaces	Waste separation
Bio mass		Compost
Chemical substances:		

[1]GWP = Global warming potentials, [2]POCP = Photochemical ozone creation potential

Currently the work with Ecoeffect involves making it practical, which must be a rather complex task, and a part of the design and facility management process. A difficulty has been observed in communicating of for instance global warming potentials (GWP) as a measurement of energy use instead of kWh. The merits of using GWP are to display the environmental impact effected by composition of the supplied kWh.

The major source of environmental impact from a building comes from its energy use which is targeted in all assessment models. Energy use and the related environmental impact are further described in the next subsection.

3.3.3 ENERGY USE AND ITS IMPACT

The environmental impact from energy use is dependent on the energy source, the production technique and the heat supply system. The emissions caused will represent a large part of the environmental impact and a variety of technical options are available which could reduce emissions for instance through improved energy efficiency in production, delivery and in buildings, fuel switching, nuclear power, capture and storage of CO_2.

Forms of energy, heat and electricity, should be separated and also a separation between primary and delivered energy can be done. When electricity is produced through a fuel based heat power process only about 40 % of the combustion heat can be transformed to electrical energy. From a thermodynamic point of view this type of electrical energy requires 2.5 times as much energy as that required for producing heat (Elmroth et al., 1987).

Energy forms. Energy use in buildings represents 40 % of the total energy use in Sweden, of which 86% is related to heating and hot water, Figure 3.3. Almost 50 % of the energy use is supplied by electricity where the main primary sources are 55 % hydropower and 39 % nuclear power (SEA, 2001). For electricity produced by hydropower the environmental impact is mainly local or regional and the emissions diminutive. The power plants affect or disturb the agricultural landscape, the biological diversity, cultural assets and fishing and have to be assessed in a different way which is usually somewhat more complicated but can be handled through principles as e.g. examination of willingness to pay. Risks related to production of electricity by hydropower are the possibility of reservoirs failures that can include huge environmental consequences if an accident occurs. For nuclear power, the environmental consequences are mainly related to risks in handling of radioactive waste from production, risks of nuclear reactor breakdown and also risks involved in uranium mining. Oil products, district heating and bio fuels supply the remaining 50 % of the energy used.

Energy use in buildings in Sweden: 145 TWh
Heating and hot water (124 TWh)
Other (21 TWh)

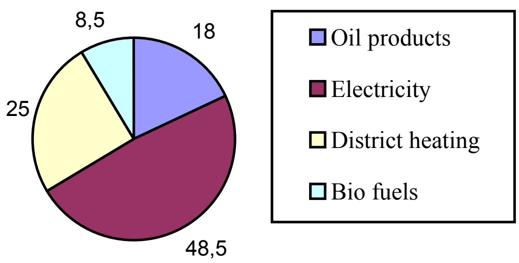

Figure 3.3 Energy use in buildings in Sweden during 2001, in percent (from SEA, 2001).

The trend in Sweden, see Figure 3.4, shows an increase in electricity use, while energy for heat has been reduced. This reduction is a result of improved thermal efficiency as a consequence of the energy crises in the 1970s. The increase in electricity use depends on a change of heat supply from fossil fuels to electricity but also changed living conditions where electricity-demanding equipments such as computers and kitchen appliances are becoming more common. In buildings almost half of the energy use is supplied by electricity. A reason for this can be that the Swedish building regulations were previously somewhat biased towards efficient use of thermal energy, with electricity use not being considered particularly important.

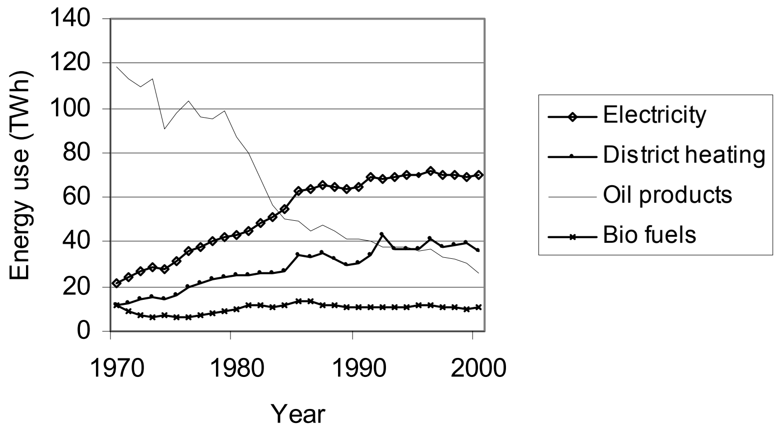

Figure 3.4 Change in supply of energy use in buildings 1970 to 2000 (from SEA, 2001).

Reductions of energy use in Swedish buildings has been investigated and improved since the oil crises in the 1970s. In 1981 the Swedish Government decided on energy reduction goals for housing with the aim to profoundly reduce energy for heating. Demonstration projects where new innovative solutions could be implemented were carried out during this time. In a demonstration project 'the Stockholm-project' six new residential buildings were built and the energy used for heating and hot water could be reduced with 50 % to 70 kWh/m^2 compared to average buildings (Elmroth et al., 1988). This can for instance be compared to the newly built European Housing Expo, Bo01, in Sweden which is a full-scale project of a sustainable residential area. A limit of 105 kWh/m^2 annual was set for the average energy use properties (Nilsson, 2001) which are still being evaluated.

In Canada, for instance, different governmental programs as the Advanced House and the R-2000 standard (Natural Resources Canada, 2001) have been initiated to encourage and improve energy performance in buildings. The typical Canadian house consumes an estimated 160-200 kWh/m^2 annually. The target for the Advanced Houses was 52 kWh/m^2 but the actual monitored energy use was 81 kWh/m^2 annually. This meant a reduction from normal houses of 50 to 60 %. On average Canadian houses are using the same amount of energy as Swedish houses and for the buildings within the Canadian programs profound reductions are made, Figure 3.5.

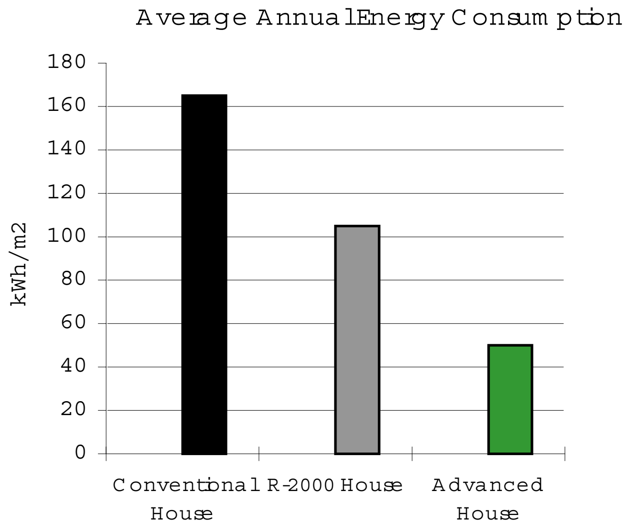

Figure 3.5 Comparison of average annual energy consumption for conventional, R-2000 and Advanced houses in Canada.

Primary and delivered energy. Delivered energy is the energy used by the consumer. The initial energy together with losses (extraction, transportation, production and distribution) is the energy required to supply the delivered energy which varies according to fuel types and the means for production. In Sweden the distribution losses are usually considered to be approximately 6% for both electricity and district heating (Wahlström et al., 2001). Consequently it is argued that the environmental impact from energy use should be measured as the primary energy, i.e. the energy required from nature embodied in the energy consumed by the purchaser (Fay et al., 2000). The Swedish National Board of Housing, Building, and Planning (2001) has been commissioned by the government to investigate and suggest suitable indicators for energy use in buildings. It is suggested that the indicator for supplied energy is measured for each separate type of energy used and then divided per square meter of heated area. When considering environmental impact from the different energy sources it is suggested that production and distribution losses are included. In this discussion though, and in the author's view, the building sector should not be blamed for the environmental impact caused by the type of energy supplied but should provide means to reduce the energy demand. Also the distribution losses should be attributed to the producer as the builder has no possibility to improve those. The following flowchart gives the relationship between primary and delivered energy.

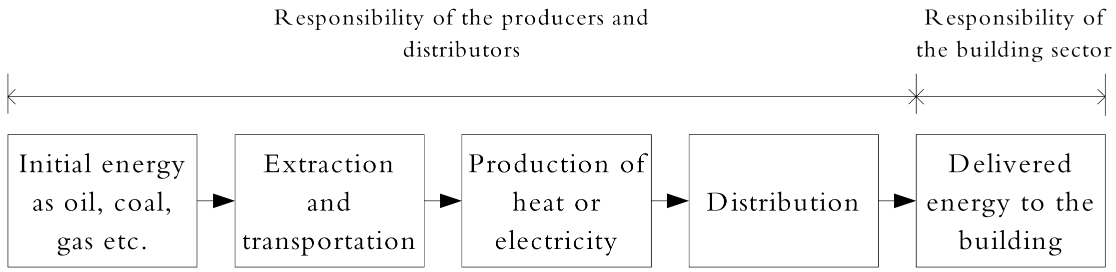

Figure 3.6 Relation between initial and delivered energy.

Heat supply systems. Wahlström et al. (2001) examined environmental impact from different heat supply systems in buildings. The systems examined were district heating, heat pump, electricity, pellets, fire wood, natural gas and oil. The impact was categorised as global warming potentials, acidification, photochemical ozone creation potential, ozone depletion, eutrophication and aerosols. To enlighten the assessment a typical house with an annual energy demand of 25 000 kWh was used. The results show that oil, gas and district heating have the largest impact on global warming potentials while pellets and fire wood have the largest effect on acidification and eutrophication. Electricity, which was based on the Swedish mix during 1999, has in all categories the least impact.

3.4 TENDER EVALUATION

Tenders evaluation consists of the client comparing the obtained tenders and selects the one that from pre-determined parameters is the most advantageous. This requires a sophisticated knowledge and experience to ensure that the selected contractor is capable of performing the project according to the client's requirements. The prequalification approach is used to evaluate the financial and technical capabilities of contractors. The ones qualified are invited to submit tenders. The evaluation criteria for contractors include several aspects such as financial and technical considerations, as well as tender sum evaluation (Alsugari, 1999). Holt et al. (1995) who reviewed the tendering practices in the UK construction industry suggested that the selection approach should integrate pre-qualification with the tender sum to generate a final score and thereby identify the optimum contractor. The recommendation given was that the selection of the contractor should be based on the 'value of money' rather than accepting the lowest tender (bid). Hatush and Skitmore (1997) later identified a common set of five criterias involved in prequalification and tender evaluation of contractors in the UK as: financial soundness, technical ability, managerial capability, safety, and reputation.

At the tender evaluation stage it was however found to be general practice to select the contractor with the lowest tender sum irrespectively of the five criterions. Lately it is though reported by several researchers that the traditional perception of tender evaluation is changing into embracing other aspects. Wong et al. (2000) examined the UK construction clients tender selection process and found that clients base the tender evaluation of contractors on the 'best possible value' by including some project specific criteria (PSC). The study furthermore shows that the tender price still is emphasised as more important than the PSC. In another study by Gibb and Isack (2001), 59 senior personnel from major construction clients were interviewed about clients' drivers for construction projects. The perception of the term 'value for money' was investigated and it was found that, lowest whole-life cost, lowest cost for a given quality, satisfied end users, highest quality for a given cost and consistent quality were preferred definitions. However, Gibb and Isack (2001) found that even if the lowest whole-life cost was the most used definition several respondents admitted that their organisations did not use this measure. One possible reason can be the absence of practical methods to include other aspects than initial costs.

Tender evaluation at the post-tender stage involves the consideration of the tender sum in addition to the contractors' capability. Traditionally, most construction contracts are procured based on 'lowest price' implying that the client selects the tender, which from this limited perspective, is the most advantageous. Selecting contractors based on lowest price may be valid in simple and straightforward situations due to the repetitive nature of works and similarity in working environments. In most situations though awarding a contract based merely on lowest price can be misleading.

3.4.1 EVALUATION PARAMETERS

The tender sum commonly represents the initial price where the lowest price is awarded as the highest value, referred to in the studies shown previously. Methods that advocate the contractor to submit a tender based on life-cycle cost can be of greater use and especially suitable for contracts on heat, ventilation and air-conditioning (HVAC) systems in buildings. The explanation is that operation costs are greater than the initial investment cost for such systems. In Sweden, ENEU 2000 (Swedish Engineering Industry, 2001) represent a guide for clients on how to procure service installation systems based on life-cycle costs. Environmental costs for future disposal are handled as one factor in the tender evaluation. However that factor does not consider the environmental impact and guidelines on how an environmental cost should be accounted for is not yet developed.

When other parameters than the costs are included in an evaluation model, stipulating which parameters and how these are to be evaluated, must be clearly defined. Models based on multi attributes are usually used to combine the price with the pre qualification criterions. However, comparing different criteria's measured on separate scales can encounter difficulties. For example, ways to make such approaches objective are proposed by Ellis and Herbsman (1995). The latter comments on a time/cost approach to determine the winning tender in highway construction contracts by which tender price and contract time is integrated. They reported that tendering on both cost and time has been applied successfully by the American State Highway and that time reductions are achieved in almost every case in which it has been used. For the contract time therefore a unit time value (UTV) is applied, converting this to a cost, and a comparison is then possible on a single criterion. Herbsman et al. (1995) propose the UTV to represent the costs of delays to the owner and made up of both direct costs (e.g. increase use of temporary facilities and increased moving costs) and direct costs (e.g. losses to the business opportunity and reduction of potential profits). The following equation presented assess the contractors' tender price and contract time

$$\mathrm{TCB} = \mathrm{ECC} + (\mathrm{DRUC} \cdot \mathrm{EPD}) \qquad (3.6)$$

where TCB is the total combined bid price, ECC is the estimated construction cost, DRUC is the daily road user cost and EPD estimated project duration. The contractor who submits the lowest TCB is awarded the contract. The DRUC is estimated by the Department of Transportation in various states to represent the economic benefits of the road to the public and local economy. It often includes the public cost arising from absence of the road such as those associated with additional travelling time, travel distance and fuel expenses and is reported to vary between \$1000/day to \$200000/day. For a more general equation of construction contracts (3.7) can be used

$$\mathrm{TCB} = p + (\mathrm{UTV} \cdot t) \qquad (3.7)$$

where p is represented by the price, UTV is the unit time value specified by the client (such as liquidated damages rate given by a constant value) and t is the construction time.

Drew et al. (2002) report that similar approaches are used in the UK and Hong Kong for selection of consultants when combining technical scores with fees. The CIB (1996) recommendation (3.8) suggested for selection of consultants is also tested on a number of cases and evaluated by Drew et al. (2002).

$$C_A = qW_q - 100\ W_f\,(f - f_{\min})/f_{\min}) + 100 \qquad (3.8)$$

where q is the consultant's technical score, W_q is the predetermined weighting for technical score, W_f is the predetermined weighting for fees, f is the consultant's fee, and f_{min} is the lowest fee. The consultant with the highest C_A value wins the contract. The predetermined weightings will differ from client to client and was exemplified by the weighting used by the SAR Government 70/30 and by the Housing Authority 50/50, both in Hong Kong.

In Sweden the evaluation of non monetary parameters as environment is related to the contractors ability of performing the environmental requirements stipulated in procurement documents. In many cases this is accomplished by awarding a value for fulfilling pre-determined factors in a point system either as a per cent of the total tender price or as a per cent of the lowest tender. The total score obtained is converted to a percentage value and weighted together with the tender sum according to a given formula. The Committee for Sustainable Procurement (CSP) (EKU-delegationen, 2001b) gives examples of weight factors that clients have given to environmental aspects, presented in Table 3.3. In the study two evaluation methods were distinguished in the CSP study (EKU-delegationen, 2001b) one relative and one absolute. In the former the tenders are compared among themselves, in the latter the tenders are compared in relation to a predetermined scale.

Table 3.3 Example of different contract forms used by Swedish clients and the weight given to different environmental aspects in tender evaluation (adopted from EKU-delegationen, 2001b).

Client	*Contract form*	*Weight system for environmental aspects*
Governmental authority	General	Environmental aspects are given an additional value in % *of the lowest tender* as: • Consideration, 2 % *of the lowest* tender • ISO/EMAS, 1 % *of the lowest* tender • Random inspection, 1 % *of the lowest* tender which is deducted from the price
Governmental, facility management	All types	None
County council	General	Zero summed tenders: 85 % weight to the price 10 % weight to the environmental aspects 5 % other
County council	Operation & maintenance	Environment is given a weight of 25 % in evaluation of tenders in a point system (250 points of 1000). 0 to 50 points each for: • follow up on installations • green procurement • handling of chemicals • energy efficiency • waste handling
County council	Design & build	Quality and environmental management system is given a weight of 10 % compared to other parameters using a point system (30 points of 300).
Municipal, real estate	Not defined	Zero summed tenders: 85 % weight to the price 9 % weight to the environmental aspects 6 % other
Municipal, real estate	General	The *lowest price* is used as the evaluation criterion and a reduction of the tender price is given for: • ISO/EMAS, reduction with 1400 SEK • diploma, reduction with700 SEK (regional system) • environmental management system, reduction with 350 SEK However it is not mentioned if this is independent of the contract sum
Municipal facility management	Operation & maintenance	70 % weight to the price 8-10 % weight to environmental aspects, controlled by fine 20-22 % other
Municipal, residential housing	Design & build	15 % weight to environmental aspect. 5 % each for: • environmental management system • environmental plan • environmental revision

In addition to the tender sum, environmental aspects are usually evaluated jointly with previous experiences of environmental construction, quality and management/personnel. These parameters can have a determining importance in the overall evaluation. It should be noticed that the percentage value given to the factors in Table 3.4 is not strictly comparable since sometimes provided as per cent of the total tender price and sometimes as per cent of the lowest tender. In general, the environmental aspects are given approximately 10 % of the total value but in some cases up to 25 %.

Warner and Ryall (2001) investigated green purchasing activities within 410 local authorities in England and Wales. It was found that cost remains the principal determinant in the purchase of products or services followed by quality, value for money, performance and environmental aspects. Costs were identified as the main constraint to implement green purchase. One conclusion from this study could be that the total cost of green purchasing actions must be displayed so that even if the initial cost is higher, the reduced costs for operation and maintenance will be demonstrated. Warner and Ryall (2001) further showed that 24 % of the clients include environmental aspects in tender evaluation related to housing however without stating how this is done.

3.5 SUMMARY OF THE LITERATURE REVIEW

Based on this overview of literature and current practice in the building sector the following conclusions are drawn:

Procurement. To promote green procurement in Sweden within governmental agencies, local authorities and county councils the Committee for Ecological Sustainable Procurement has developed a guide to ecological sustainable procurement. For the building sector it was concluded that the requirements stipulated not correspond to the requirements on effective and sustainable use of resources and that a change in approach is needed to contemplate environmental impact from a broad perspective.

Life-cycle cost estimations. There are several life-cycle investment appraisal techniques available. However the scope of the life-cycle cost method seems appropriate also for procurement and tender evaluation of building projects. Uncertainties in the life-cycle cost analysis which are related to estimation of future costs, predicted lives of components and most important to the selection of a discount rate can be reduced by use of sensitivity analysis.

Assessment of environmental impact. Energy use is currently considered to be the largest source of environmental impact from a building. One way to assess the impact is through environmental impact categories. There are however several methods developed intending to be used for assessment of environmental impact from buildings or material, including a broader perspective. These methods are complex and probably not practical for the purpose of procurement. Methodological difficulties are also prevailing related to data and boundary setting.

Tender evaluation. The initial cost is usually the determining factor in tender evaluation of contractors submitting tenders. Parameters related to environmental performance are also evaluated and thereby given a greater importance. In the investigation by the Committee for Ecological Sustainable Procurement it is shown that public clients in Sweden consider environment in procurement. Requirements are stipulated by clients but going beyond that and assessing environmental impact as a parameter in tender evaluation is not done. Systems for that should be developed to better embrace and encourage the development in the area.

Conclusions. When environment is included in tender evaluation it is in most cases related to the contractors ability of fulfilling the stipulated requirements. Awarding contractors that develop designs reducing environmental impact can further promote progress of sustainable construction. However such tender evaluation models are not used. The life-cycle costs perspective seems useful for this purpose as emphasis on efficient energy use is given. In addition the environmental impact from energy use should be considered. Many of the environmental assessment tools developed for estimation of buildings impacts are sophisticated and include a variety of parameters. These have however proved to fail in one area, namely to address costs which are of importance to the client. By integrating life-cycle costs and environmental impact in a tender evaluation model, as developed in Chapter 4, cost effective and environmental aware construction can be promoted.

4 MULTI ATTRIBUTE TENDER EVALUATION MODEL

One way to obtain a more environmentally aware construction process is by stipulation of environmental requirements in tender documents. In addition awarding environmental impact reduction in tender competitions can be useful. This chapter describes an alternative to the traditional evaluation of tender sum to include a multi attribute life-cycle approach. The evaluation model developed here includes a set of life-cycle costs elements integrated with the environmental impact from operational energy. The use of this life-cycle approach allows clients to award some important aspects of sustainable construction and to increase profit by cost reductions.

4.1 MULTI ATTRIBUTES

Multi attribute approaches in tender evaluation combine the evaluation of monetary aspects with other parameters as e.g. technical performance, financial ability and time measured on a different scale. The approach is suitable for projects where innovations or alternatives are being sought and competitiveness is advocated. Clients should further be interested in obtaining a better value for the money spent. Tender evaluation based on lowest price still is practical for small-scale projects that have been clearly defined in terms of design.

The two attributes combined with the tender sum are life-cycle energy cost and its associated environmental impact. The motive for this combination is that consideration of future costs can increase the clients profit and that operational energy use is a major source of environmental impact which the building sector can improve by using energy efficient methods. The total combined tender (TCT) price is a function of the price p, the life-cycle energy cost LCC_E, and the environmental index EI_X.

$$TCT = f\,(\,p,\, LCC_E,\, EI_X\,) \qquad (4.1)$$

The complete TCT gives the possibility to include the environmental impact from energy use as a monetary term in the life-cycle cost estimation. For the client's who not want to exceed the perspective of life-cycle costs the environmental impact index factor EI_X can be disregarded. In the next subsections 4.2 and 4.3 all the parameters included in the model are described and motivated.

4.2 LIFE-CYCLE COST ELEMENTS

A traditional life-cycle cost model consists of the total investment cost (I_0), possibly reduced by the salvage value (S) or increased by a disposal cost, annual operation costs (O) and a annual maintenance cost (M) described in sub section 3.2.3 and generally expressed as:

$$LCC = I_0 - S + \sum_{t=0}^{N} O \cdot PV_{sum} + \sum_{t=0}^{N} M \cdot PV_{sum} \qquad (4.2)$$

where *N* is the time horizon of the analyse and *t* a time variable. By using a present value factor (PV_{sum}) the future costs are discounted to present time. Performing a life-cycle cost estimation by including all components of a building is impractical and quite time demanding as data often is not arranged in a way suitable for such analysis. The maintenance cost for instance is represented by a large amount of items and the need to direct attention to those areas where financial benefits might most easily be achieved has been recognised by several authors as Al-Hajj and Horner (1998), Bromillow and Pawsay (1987). For simplification and generalisation of the model developed herein the cost elements that have the largest relevance for the total cost were identified based on three earlier life-cycle costs analysis and a survey study, Table 4.1.

- Johansson and Öberg (2001) presented a Swedish case study based on four multi family dwellings, completed between 1994 and 1998. Of the operating costs energy represented approximately 23 to 34 % of the total cost using a discount rate of 2.5 % and a life-length of 60 years. Periodical maintenance (13 to 20 %) and care taking (12 to 17 %) represented the second and third highest annual cost.

- Bejrum et al. (1986) presented a study based on empirical data for 21 Swedish residential buildings completed between 1924 and 1972, using a discount rate of 4 % and a length for analysis of 50 years. A mean value for the cost elements from Bejrum et al. (1986) is calculated in this thesis and shows that operation costs represent 25 %, maintenance 10 % and the initial investment the remaining 65 %. The maintenance cost is further related to maintenance in apartments 38 %, service installations 36 % and common spaces and yard 26 %.

- Macsporran and Tucker (1996) examined the operating costs of 116 office buildings based on a survey by BOMA (Building owners and managers association) in Australia. In a median distribution of costs, energy represented roughly 24 %, cleaning 19 %, general fees 10 %, lifts and escalators nearly 9 % and air-conditioning and ventilation 8.5 %. The result is probably not applicable to Swedish conditions as Australia's climate is dissimilar and unit costs probably differ. Although, in spite the differences a similar distribution of the cost elements importance is shown.

- The last column in Table 4.1 shows the main results of a questionnaire aimed at studying Swedish client's general perception about the relevance of different life-cycle cost elements. Detailed descriptions and results are presented in Paper III.

Table 4.1 Ranking of the most significant annual costs based on four separate studies.

Residential[1]	Residential[2]	Commercial[3]	Clients Survey[4]
Energy	Operation	Energy	Energy
Care taking	Maintenance	Cleaning	Maintenance
Maintenance		General fees	Alteration
Water		ACV, lifts, escalators	Cleaning

[1]Johansson and Öberg (2001), [2] Bejrum et al. (1986), [3] Macsporran and Tucker (1996), [4] Sterner (2000)

In addition, the estimated life-cycle costs of three environmentally designed buildings (GZ1-3) completed in the year 2000 were compared with three conventional buildings (Ref 1-3), Table 4.2. The environmentally designed buildings are a part of a demonstration project, Greenzone, in Sweden and the buildings are further described in Paper IV. It is shown that the life-cycle energy cost represents approximately 35 % of the total cost for the conventional buildings and about 30 % of the environmentally designed buildings. A particular feature is the contrast in energy use for the environmentally designed buildings. This, as GZ 1 in Table 4.2, has a heat demand which has been profoundly reduced when compared to the conventional alternative. The other buildings, GZ2 and GZ3, have a very small heat demand as electricity used for other purposes generates heat. The energy cost represents the cost for total energy use (heating and electricity) as it has been difficult to obtain a separation between these for all buildings. A discount rate of 4 % and a life-length of 50 years have been used for the analysis.

Table 4.2 Relevance of costs in % of total life-cycle cost.

Cost elements	Environmental designed buildings				Conventional buildings			
	GZ 1	GZ2	GZ 3	m	Ref 1	Ref 2	Ref 3	m
Initial cost	80	60	58	66	57	57	53	56
Energy	6	29	31	22	35	35	38	36
Operation	12	8	9	10	6	6	7	6
Maintenance	2	3	2	2	2	2	2	2

Although the studies are based on a limited number of buildings some parameters of high importance can be identified. Of the operation costs energy constitutes the largest part as representing up to 38 % of the buildings total cost, as seen in Table 4.2. By including the initial cost and the energy cost 88 % to 92 % of the buildings life-cycle cost are 'captured'. Maintenance costs are often of a rather small magnitude in the overall perspective, especially for the commercial buildings. For the residential buildings periodical maintenance is higher and represent about 10 % of the total cost where maintenance of service installation represent a third (Bejrum et al., 1986).

To simplify the calculation in the tender evaluation only initial cost and operation energy costs are included. If representative data is available the care taking of the service installation systems, maintenance and replacement costs of the heat system can be considered Eq. 4.3.

$$LCC_E = \sum_{t=0}^{N} O_E \cdot PV_{sum} + \sum_{t=0}^{N} M_E \cdot PV_{sum} \qquad (4.3)$$

The second attribute included in the tender evaluation is environmental impact from operational energy use, described in the next subsection 4.3.

4.3 ASSESSMENT OF ENVIRONMENTAL IMPACT

A complete assessment of the environmental effects caused by buildings is a difficult operation as many components and materials are included and the technical life length is long. The assessment of environmental impact itself is further a difficult task much due to the complex cause-effect relationship that is present, Figure 4.1. To exemplify, different *activities* as for instance energy combustion will give emission of different substances. The emissions will increase the concentrate of these substances in the air and the effect on the environment as changed radiation balance is called *primary effects*. Different substances can give the same primary effects. Furthermore, the primary effect causes one or several new effects called *secondary effects*. In principle, the cause-effect chain continues to infinity (Zetterberg and Finnveden, 1997).

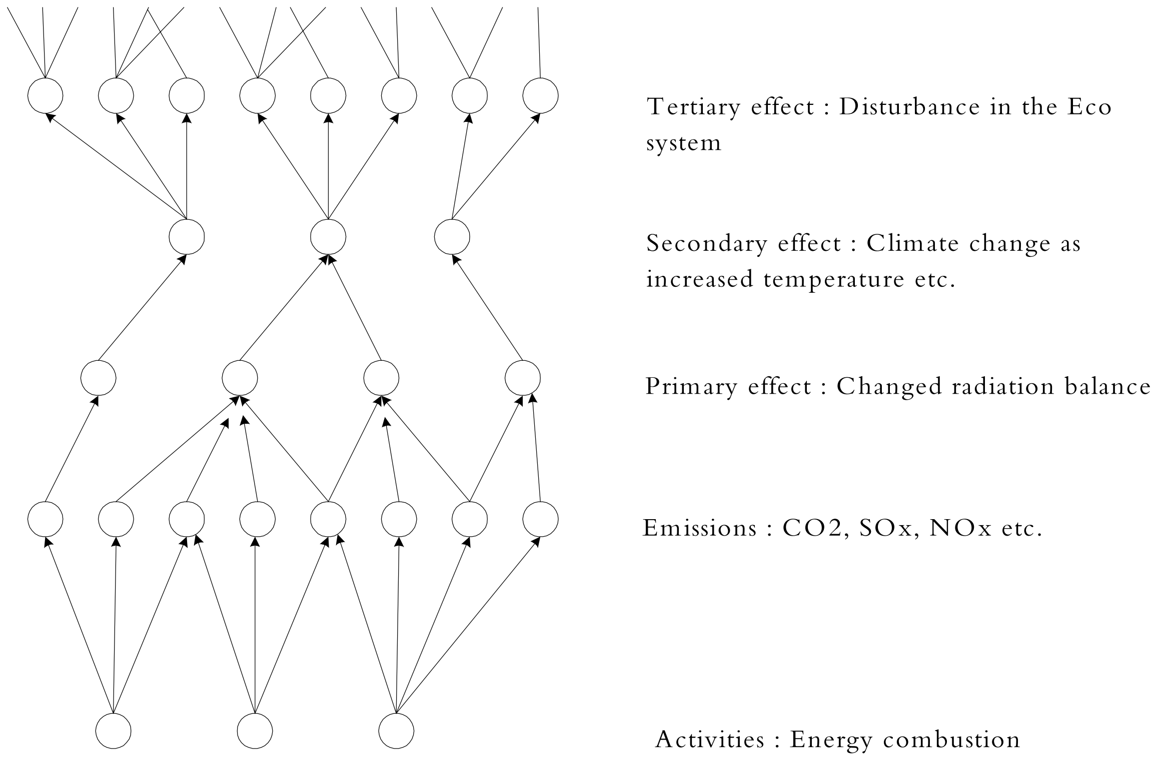

Figure 4.1 A schematically description of the cause-effect chain (from Finnveden et al., 1992)

The evaluation of environmental impact is in this thesis is based the Environmental Quality Objectives described in subsection 1.2.2. From the authors point of view the objectives are integrated and difficult to separate but an attempt to divide them into three primary categories, objectives that aim to protect human health, environmental impact categories and objects that are aimed at protecting the environment or cultural assets is maid. No distinguishing between the levels of relevance for obtaining ecologically sustainable development is made.

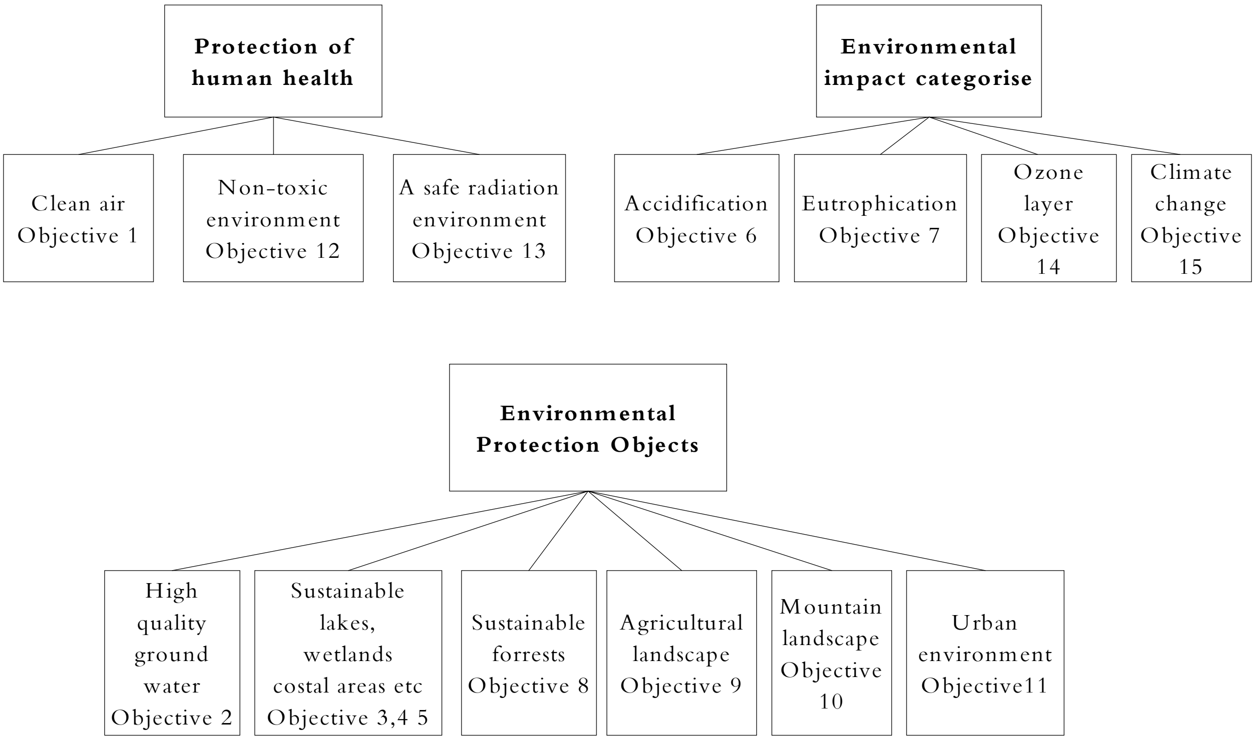

Figure 4.2 Structuring of the environmental quality objectives in protection objectives and environmental impact categories.

The Swedish EPA has suggested an extensive system of over 200 indicators to follow up on these goals (Swedish EPA, 1999). The indicators are recommendations on for instance which emissions to include when assessing the impact on an objective. Herein operational energy use from buildings is targeted for the analysis and by characterisation of emissions it is possible to relate the emissions to different EQOs, described in 4.3.1.

4.3.1 CHARACTERISATION

The characterisation aims at estimate emissions and other substances contribution to different environmental effects by environmental impact categories as global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), ozone depletion potential (ODP) and photochemical ozone creation potential (POCP). The impact categories can be linked to the EQO as:

Objective 1, Clean air : An indicator for clean air is photochemical ozone creation potential (POCP). About 300 individual organic compounds make some contribution to photochemical ozone formation, created in the atmosphere under the influence of sunlight. In the lower atmosphere ozone is formed in reactions between sunlight and gases as carbon monoxide (CO), nitrogen oxides (NO_X) and volatile organic compounds (VOC). In Sweden the discharge of nitrogen oxides and hydrocarbons are mainly related to traffic but combustion plants can also be a dominant source. Derwnet et al. (1998) have developed a reactive scale of organic compounds based on the amount of ozone formed from each compound using a highly detailed representation of the atmospheric chemistry of the polluted boundary layer over northwest Europe, Table 4.4. The Swedish EPA suggests that NO_X and VOC are used as indicators.

Objective 15, Climate change : The contribution different gases have on the climate change can be described in Global Warming Potentials (GWP) by using a method developed by the International Panel of Climatic Change (IPCC, 1994). The IPCC is an intergovernmental scientific and technical body consisting of a small secretariat, a bureau and a global network of about 2,500 scientists and experts. The method by IPCC translates other emissions into carbon dioxide (CO_2) equivalents with the characterisation factors found in IPCC (1996). A characterisation factor indicates how effective one gas is on influencing the climate in relation to the CO_2 emission, usually seen from a one hundred year perspective, Table 4.3. Thus, the effect of reducing CO_2 emissions by a certain amount can be compared with the effect of reducing methane (CH_4) emissions by a different amount. Global warming potentials (GWP) have inherent uncertainties, typically about 35 %, not least because of the range of possible lifetime of the reference gas, CO_2. Other gases contributing to the greenhouse effect are methane (CH_4), nitrous oxide (N_2O) hydroflourcarbones (HFCs) and sulphur hexafluoride (SF_6) where the two last are strong greenhouse gases but are present only in low concentration.

Table 4.3 Examples of Global Warming Potential, referenced to CO_2 (from IPCC, 1996).

Gas	*Global warming potential for various time horizons*		
	20 years	100 years	500 years
CO_2	1	1	1
CH_4	56	21	6,5
N_2O	280	310	170
HFC-23	9100	11700	9800
HFC-32	2100	650	200
SF_6	16300	23900	34900

The Swedish EPA suggests that CO_2, CH_4 and N_2O are used as indicators.

Objective 14, Ozone layer : The gases impacting ozone depletion are mainly forms of CFCs, HCFCs and Hs which is not mainly emitted from energy combustion and is therefore not included here. This is however a simplification as the production of district heating in Sweden includes 15 % heat pumps, which can if including CFCs and other cooling substances leak such emissions. When district heating is produced by heat pumps that involve such substances ODP can be included by using the characterisation factors for different emissions contribution to ozone depletion as published by Solomon and Albritton (1992). The Swedish EPA suggests CFCs and HCFCs to be used as indicators.

Objective 7, Eutrophication : The amount of nutrients in lakes and oceans is increasing as a result of anthropoid discharges of nitrogen and phosphorus whereas the natural balance between production and degradation is disturbed. The characterisation factors for different emissions contribution to eutrophication have been published by Lindfors et al. (1995) and Hauschild (1996). The Swedish EPA suggests that NO_X, and NH_3 are used as indicators.

Objective 6, Acidification : The total contribution to acidification can be estimated using the same procedure as climate change. However, the important emissions are sulphur dioxide (SO_2) and nitrous oxides (NO_X) which when discharged to the air, spread in the atmosphere, oxidise and transforms to acid. The discharge is mainly from energy combustion, different types of industrial activities and traffic. The characterisation factors for different emissions contribution to acidification have been published by Lindfors et al. (1995), and Hauschild (1996) as stoichiometric formation of H^+, Table 4.4. The Swedish EPA suggests that SO_2, NO_X and NH_3 are used as indicators.

Table 4.4 The characterisation factors used herein to calculate the potential environmental impact from energy use in categories.

Impact categories	Characterisation factors	Unit
PI_{GWP}	$1 \cdot CO_2 + 310 \cdot N_2O + 21 \cdot CH_4$	(g CO_2-equivalent)
PI_{AP}	$1 \cdot SO_2 + 0.7 \cdot NO_x + 1.88 \cdot NH_3$	(g SO_2-equivalent)
PI_{EP}	$1.35 \cdot NO_x + 3.64 \cdot NH_3$	(g NO_3^--equivalent)
PI_{POCP}	$0.337 \cdot VOC$	(g C_2H_2-equivalent/g VOC mix)

Furthermore different evaluation methods can be applied to determine the relation between the categories. Methods used often reflect on political aspects and the prevailing considerations in the society. In 4.3.2 the method used herein is described.

4.3.2 WEIGHTING OF ENVIRONMENTAL CATEGORIES

In this thesis the aim is to develop a model that is practical, implying that its usefulness will be prior to the absolute accuracy of the result. There are several quantitative methods that can be used for the purpose of weighting categories together. These are often divided into, quantitative expert panel methods, cost based methods and goal related methods. Several assessment methods uses goals to determine the weight factors as by Heijungs et al. (1992) and Kortman et al. (1994) and Eq. 4.4 shows a simple way used to calculate such factor

$$V_i = \frac{1}{T_i} \qquad (4.4)$$

where V_i is the weight factor and T_i the goal.

The method used here is a goal related method proposed by Erlandsson (2000). It is used to determine the weight factors to be used to interrelate for instance a contribution from global warming to a contribution from acidification. The weigh factors for the environmental impact categories are based on the goals given in the Environmental Quality Objectives (EQO). The EQO are in many cases expressed as maximum discharges allowed for some specific compounds (the believed acceptable environmental impact) in Sweden, which are considered by politicians to be of importance for achieving a long-term acceptable state of the environment. The maximum discharges are determined politically and expresses which environmental load the nature is believed to tolerate in the year 2010, based on scenarios by for instance the Swedish EPA, Table 4.5.

Table 4.5 The goals given in the EQO (from Swedish EPA (1999) reports, 4995, 4999, 5000, 5002, 5003)

Goal	Mtonnes/year
CO_2	55 400
CH_4	284
N_2O	26
NO_X	152
SO_X	67
NH_3	52
VOC	241

Assuming that all quality objectives are equally important a weighting between the categories is established by,

1) A characterisation (Table 4.4) of the allowed annual discharge (Table 4.5) into environmental impact categories.
2) A normalisation of the categories in regards to the number of persons in the system (8.7 millions in Sweden by 2010).

The weight of the emissions contribution to different impact categories is determined by the characterisation and normalisation which provides the maximum impact each individual is 'allowed' within a category. The politically determined importance of each category is now specified by a factor, the *normalisation factor*, Table 4.6.

Table 4.6 Normalised values used to weight the potential environmental impact categories together.

Environmental impact category	Normalisation factor	Unit
Global warming	7980	kg CO_2 eqv/person
Accidification	31	kg SO_2 eqv/person
Euthropichation	45	kg NO_3 eqv/person
Photochemical ozone creation	9.34	kg C_2H_2 eqv/person

Using the calculated normalised valued, Table 4.6, demonstrates that 1 kg CO_2 equivalents equals 31/7980 kg SO_2 equivalents implying that the acidification potential limit is 254 times lower than the limit for global warming potential. If the political goals change the weights must be accordingly revised.

Summing up the categories and normalising each with the corresponding normalised value from Table 4.6 give the weighted environmental impact, WI, according to Eq. 4.5.

$$WI = \sum_i PI \cdot wf = \frac{PI_{GWP}}{7980} + \frac{PI_{AP}}{31} + \frac{PI_{EP}}{45} + \frac{PI_{POCP}}{9.33} \qquad (4.5)$$

where

WI weighted environmental impact
PI potential contribution from the impact category
wf weight factor for the impact category

Thus Eq. (4.5) is simplified to:

$$WI = PI_{GWP} + PI_{AP} \cdot 257 + PI_{EP} \cdot 177 + PI_{POCP} \cdot 854 \qquad (4.6)$$

4.3.3 INVENTORY OF DATA.

Using the data published by Uppenberg et al. (2001) the impact from electricity production, (hydro, nuclear, wind, and the Swedish mix) and from energy for heat production has been estimated. The inventory is presented as emissions per MJ useful energy which has been converted to emissions per kWh. The data presented by Uppenberg et al. (2001) is, as far as the author knows, one of the most extensive inventories of emissions from energy sources in Sweden. The inventory includes manufacturing of material and construction of power plants for hydro, wind and nuclear power as these causes the largest impact. Risks have not been assessed herein and are consequently not included in the evaluation of environmental impact.

The impact from the production of electricity in Sweden is here referred to as the Swedish mix which to large extent consist of hydro and nuclear power (SEA 2001). For district heating a Swedish mix, Figure 4.3, is used as an example to calculate the environmental impact. However, for district heating it is more relevant to use the local district heating supply when a specific building is examined.

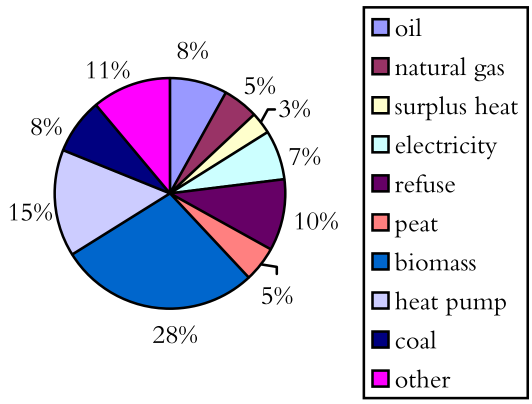

Figure 4.3 The mix in the Swedish district heating net during 2001 which is used to exemplify the estimated environmental impact (from Fjärrvärmeföreningen, 2001).

Based on E.q 4.6 WI has been calculated for different types of energy as presented in Table 4.7. A more detailed calculation is presented in Appendix A. Use of oil has the largest impact while electricity produced by hydropower has the least impact. Uppenberg et al. (2001) also emphasises that comparison between different energy sources should be done with caution, as there are differences in the studies used to generate the inventory data, sometimes making an analysis not completely comparable.

Table 4.7 Normalised potential environmental impact from different energy sources in g/kWh energy for each category and as a weighted index, WI according to Eq. (4.6).

	Electricity				Energy for heat				
	Hydro power	Nuclear power	Wind power	Swedish electricity	Natural gas	District heat	Fire wood	Pellet	Oil
GWP	5.1	3.4	6.6	32.7	224.8	122.0	29.5	25.2	343.1
AP	0.006	0.016	0.028	0.086	0.090	0.458	0.661	0.704	0.447
EP	0.009	0.013	0.024	0.076	0.151	0.402	0.908	0.983	0.536
POCP	0.005	0.0007	0.0018	0.0043	0.0055	0.014	1.95	1.95	0.0314
WI	*8.7*	*10.5*	*19.6*	*71.9*	*279.0*	*341.0*	*2024.6*	*2044.7*	*579.8*

4.3.4 THE ENVIRONMENTAL IMPACT INDEX

The weighted environmental impact index WI in Table 4.7 is used to determine the environmental impact index, EI_X used in the tender evaluation model. The index EI_X accounts for the environmental impact of operational energy use, which for a building, depends on:

- The amount of energy used
- The type of energy used to supply heat and electricity in the building
- The type of heating system used and its efficiency

In the model a distinction is made between energy for heat and electricity as these have diverse impacts (compare with suggestions from the Swedish National Board of Housing, Building and Planning in 1.2.4). Each energy source is then multiplied by the weighted environmental impact factor, WI, in Table 4.7. For heating, the heat supply systems efficiency factor must be included. Thereafter a division per square meter [m^2] usable building area, *A,* is performed. The usable building area is defined in accordance with the Swedish standard SS 02 10 53, as the usable area of the building enclosed by its inside, by the building elements or other enclosing areas relevant for the measure. The above procedure provides the environmental impact index, $EI_{(X)}$ as:

$$EI_{(x)} = \frac{\left(\frac{WI_H}{\eta} \cdot E_H\right)}{A} + \frac{\left(WI_{El} \cdot E_{El}\right)}{A} \quad (\text{kWh}_{\text{index}}/\text{m}^2\ \text{BRA, year}) \qquad (4.7)$$

where

$EI_{(x)}$	environmental impact index from operational energy use
WI	weighted environmental impact index from use of electricity, district heating, oil, gas etc.
η	the selected heat supply systems efficiency factor
A	building area (m^2)
E_H	energy use for heating (kWh/year)
E_{El}	electricity use, except heating (kWh/year) related to the building

4.3.5 GOAL FACTOR

Furthermore it is suggested that the environmental impact from energy use is related to some energy goals E_G (kWh/m^2, year) determined by the client. For instance can the goals presented in the dialogue Build/Live (see 1.2.4) be used.

$$\varphi = \left(\frac{(E_H + E_{EL}) - E_G}{E_G} \right) \tag{4.7}$$

If the energy use is higher than the set goal, the environmental index will add a cost to the tender evaluation sum. If the energy use is lower, the environmental index will accordingly deduct the cost. The EI_X translate the impact into a monetary term by specifying a conversion coefficient *a*, representing the impact from energy use.

4.3.6 DETERMINING THE COEFFICIENT *a*

The environmental impact is converted to a cost, here seen as a factor to promote improvements for further energy reductions, and by doing so a comparison on a single monetary criterion is possible in the tender evaluation. The client will have to specify the coefficient *a* in SEK/kWh and the higher the value used is the greater the importance a reduction of environmental impact from energy use is given. Since the weighted environmental impact, WI, is reflecting the energy sources relative impact, the same coefficient *a* can be applied for all types of energy use. A discussion about possible ways to decide the magnitude of *a* is given below.

It is argued that the external costs of energy use, as e.g. climate change is not fully reflected by the market prices. Deciding the external costs may be one way to select the coefficient, *a*. This raises various theoretical and complex issues from a methodological point of view. Another possibility is to use environmental taxes, e.g. on energy, assuming these reflect some of the cost of the external impact.

Taxes on energy have existed in Sweden since the 1950s initially to finance the public sector and later to direct the use and production to different political energy and environmental goals. Application of environmental taxes has increased in recent years. The reasoning underlying this is that manufactures and consumers should pay for the damage, originating from different types of activities. The taxes applied on energy are energy, electricity, carbon dioxide, sulphur and nitric oxide taxes. For example is carbon dioxide tax paid per kg-emitted emission and applied to most fuel types with the exception of bio fuel and peat. Fuel used for electricity production is not imposed with the carbon dioxide tax while fuel for heat production is imposed. Assuming that the magnitude the taxes are given is in proportion to the environmental impact caused the weight of the coefficient *a* can be determined.

The environmental and energy taxes applied varies with for instance fuel type and for oil is between 0.215 to 0.234 SEK/kWh, natural gas 0.141 SEK/kWh, peat 0.015 SEK/kWh, pine pitch oil 0.221 SEK/kWh and for electricity between 0.125 to 0.181 SEK/kWh (SEA, 2001). Based on the taxes a variation of *a* from 0.015 to 0.234 can be a possible range of values where higher values gives more importance to the environmental impact. The taxes are however already accounted for in the LCC_E and application of EI_X within the suggested range provides a double taxation.

4.3.7 UNCERTAINTIES IN DATA

When examining environmental impacts the selected level of aggregation of data depends on the purpose of the analysis, i.e. what the results are to be used for and by whom. A more aggregated analysis will be easier to grasp but will have larger uncertainties as the information tends to go from scientifically based information to information based on appraisals. Here the aim is to create a practical model and a more aggregated analysis is used. A designer or client that wants to use aggregated results but without renounce its accuracy can use the potential environmental impact categories without weighting them together. The result from the inventory, from the characterisation and from the evaluation will then be used separately. Further the EI_X will most likely not be used for comparison of different energy sources environmental impact as the form of energy supply is determined by the client or restricted by for instance the municipal. The EI_X will then promote energy reduction in the tender evaluation and the uncertainty in data will be equal to the competitors.

4.4 TENDER EVALUATION MODEL

Based on the definitions given in sections 4.1 to 4.3 the tender evaluation model developed for total combined tender (TCT) price is summarised as:

$$TCT = p + LCC_E + \varphi \cdot EI_X \cdot a \tag{4.9}$$

To facilitate the use of the model the notations as well as the equations are listed below.

$$LCC_E = \sum_{t=0}^{N} O_E \cdot PV_{sum} + \sum_{t=0}^{N} M_E \cdot PV_{sum} \; ; \qquad \varphi = \left(\frac{(E_H + E_{EL}) - E_G}{E_G} \right)$$

$$WI = PI_{GWP} + PI_{AP} \cdot 257 + PI_{EP} \cdot 177 + PI_{POCP} \cdot 854$$

$$EI_{(x)} = \frac{\left(\frac{WI_H}{\eta} \cdot E_H \right)}{A} + \frac{(WI_{El} \cdot E_{El})}{A} \quad [\text{kWh}_{\text{index}}/\text{m}^2 \text{ BRA, year}]$$

p	submitted tender sum [SEK/m^2]
LCC_E	life-cycle cost for energy use [SEK/m^2]
O_E	annual operational energy cost [SEK/m^2]
M_E	annual maintenance cost [SEK/m^2]
PV_{sum}	present value sum
φ	goal factor
E_H	energy use for heating [kWh/m^2, year]
E_{El}	electricity use, except heating [kWh/m^2, year] related to the building
E_G	goal for energy use in buildings [kWh/m^2, year]
WI	weighted environmental impact index from use of electricity, district heating, oil, gas etc., presented in Table 4.7
EI_X	environmental impact index from operational energy use
η	the selected heat supply systems efficiency factor
A	building area [m^2]
PI_{GWP}	potential environmental impact related to global warming potential
PI_{AP}	potential environmental impact related to acidification
PI_{EP}	potential environmental impact related to eutrophication
a	conversion factor decided by the client [SEK/EI_X]

4.5 EXEMPLIFICATION OF VARIABLE DIFFERENCE

To exemplify the use of the model, according to Eq. 4.9, and the difference in the result by varying predetermined coefficients and by removing the environmental index factor EI_X the case study buildings as reported in Paper IV is used. The project data in Table 4.8 presents the initial cost and the total energy use.

Consider a case where two contractors are competing in three different projects 1, 2 and 3. The first contractor (A) suggests an environmental design with a higher initial cost and focus on energy reduction. The second contractor (B) suggests conventional solutions with traditional energy consumption. The difference in each of these projects gives a good representation of three possible cases. In case 1 there is a large difference in the tender sum and also the difference in energy use is high. In case 2 the difference in price is somewhat less and so is also the difference in energy use. In case 3 the difference in price is again high but the difference in energy use is not as high as in the first project. A discount rate of 4 % and a length of analysis of 30 years are applied. A shorter length is here chosen to obtain a greater variation in the ranking result. The costs applied for the electricity is 0.464 SEK/kWh and for district heating 0.52 SEK/kWh.

Table 4.8 is used for defining a possible range for the goal factor. For office buildings today the factor is 0.71, in the year 2005 it is 0.67 and in the year 2025 it is 0.43. To exemplify *a* is varied using 0.015 an 0.243 SEK/EI_X as is the same as the taxes magnitude, the median 0.1245 SEK/EI_X is also used.

For the first comparison the total combined tender price is determined *without* the converted environmental impact index and goal factor ($\varphi \cdot EI_X \cdot a$). The tender sum, p, is represented by the initial cost and LCC_E only includes the present value of the life-cycle energy cost. For a better accuracy the maintenance cost should be included.

Table 4.8 Some basic project data used to exemplify the use of the tender evaluation model Eq. 4.10.

	Building 1		Building 2		Building 3	
	A1	B1	A2	B2	A3	B3
Total energy demand						
Electricity [kWh/m^2]	79	104	838	1017	1139	1452
District heating [kWh/m^2]		141				
Tender sum, p [kr/m^2]	10053	8355	17592	16180	22903	17176

Competition 1 (With and without EI_X, Swedish electricity mix for both A and B, *a* = 0.1245 SEK/kWh impact and φ = 0.71)

	p [kr/m²]	LCC_E [kr/m²]	φ·a·EI_x [kr/m²]	p+LCC_E [kr/m²]	Rank	p [kr/m²]	LCC_E [kr/m²]	φ·a·EI_x [kr/m²]	TCT [kr/m²]	Rank
A1	10053	634	-	10687	2	10053	634	502	11189	1
B1	8355	2102	-	10457	1	8355	2102	4774	15231	2
A2	17592	6723	-	24315	1	17592	6723	5326	29641	1
B2	16880	8159	-	25039	2	16880	8159	6464	31503	2
A3	22903	9137	-	32040	2	22903	9137	7239	39279	1
B3	20 000	11648	-	31648	1	20000	11648	9228	40876	2

Competition 2 (With and without EI_X, electricity for A based on wind power, electricity for B Swedish mix, *a* = 0.1245 SEK/kWh impact and φ = 0.71.)

	p [kr/m²]	LCC_E [kr/m²]	φ·a·EI_x [kr/m²]	p+LCC_E [kr/m²]	Rank	p [kr/m²]	LCC_E [kr/m²]	φ·a·EI_x [kr/m²]	TCT [kr/m²]	Rank
A1	10053	634	–	10687	2	10053	634	134	10821	1
B1	8355	2102	–	10457	1	8355	2102	4774	15231	2
A2	17592	6723	–	24315	1	17592	6724	1422	25737	1
B2	16880	8159	–	25039	2	16880	8159	6464	31503	2
A3	22903	9137	–	32040	2	22903	9137	1933	33973	1
B3	20000	11648	–	31648	1	20000	12648	9228	40976	2

Competition 3 (Swedish electricity mix for both A and B, *a* = 0.015 SEK/kWh impact and φ = 0.43 and 0.67.)

	p [kr/m²]	LCC_E [kr/m²]	φ·a·EI_x [kr/m²]	TCT [kr/m²]	Rank	p [kr/m²]	LCC_E [kr/m²]	φ·a·EI_x [kr/m²]	TCT [kr/m²]	Rank
A1	10053	634	37	10724	1	10053	634	57	10744	1
B1	8355	2102	348	10805	2	8355	2102	543	11000	2
A2	17592	6723	389	24704	1	17592	6723	606	24921	1
B2	16880	8159	472	25466	2	16880	8159	735	25774	2
A3	22903	9137	528	32568	2	22903	9137	823	33391	2
B3	20000	11648	673	32321	1	20000	11648	1049	33370	1

Competition 4 (Swedish electricity mix for both A and B, *a* = 0.015 and 0.234 SEK/kWh impact and φ = 0.71.)

	p [kr/m²]	LCC_E [kr/m²]	φ·a·EI_x [kr/m²]	TCT [kr/m²]	Rank	p [kr/m²]	LCC_E [kr/m²]	φ·a·EI_x [kr/m²]	TCT [kr/m²]	Rank
A1	10053	634	60	10747	1	10053	634	944	11631	1
B1	8355	2102	575	11032	2	8355	2102	8973	19430	2
A2	17592	6723	642	24957	1	17592	6723	10010	34325	1
B2	16880	8159	779	25818	2	16880	8159	12149	37188	2
A3	22903	9137	872	32912	2	22903	9137	13606	45646	1
B3	20000	11648	1112	32760	1	20000	11648	17345	48993	2

In the first comparison it is showed that just by including the life-cycle cost the ranking of project 2 changes but not for project 1 and 3. This since the difference in initial costs for building 1 is 17 % higher and for building 3 13 % than the conventional case and the energy cost reduction is not enough to equal the tenders. Inclusion of the environmental impact index changes the ranking of all three projects.

In the second competition, once again comparing the ranking without EI_X but this time with different energy sources shows that contractor A easily wins the competition. This as wind power electricity has a much lower impact than the Swedish electricity mix. This suggests that if different types of energy is used this will have a great effect on the result and this particularly competition is very dominated by the use of different energy sources.

In the two first comparisons the factor φ has been set to 0.71. Setting a goal that is difficult to meet increase the importance of the environmental impact index. Here it is assuming that the building sector will perform energy efficient improvements and the factor will be lower, here set to 0.43 and 0.67. In competition 3 a low value for *a* is further applied an as shown the environmental impact index will have a minor influence on the result, though enough to change the ranking for project 1 and 3 when the higher goal factor is used.

In the last comparison *a* is varied and when using the higher value for *a* the ranking in all competitions change. Conclusively is the variation of *a* shoving a larger influence on the result then when varying of the goal factor φ.

In Figure 4.4 the variation of *a* is plotted against the weight of the tender sum in relation to TCT. As shown contractor B will be more effected by the inclusion of the environmental impact index, the higher the value given to *a* is the greater the importance in relation to the price is.

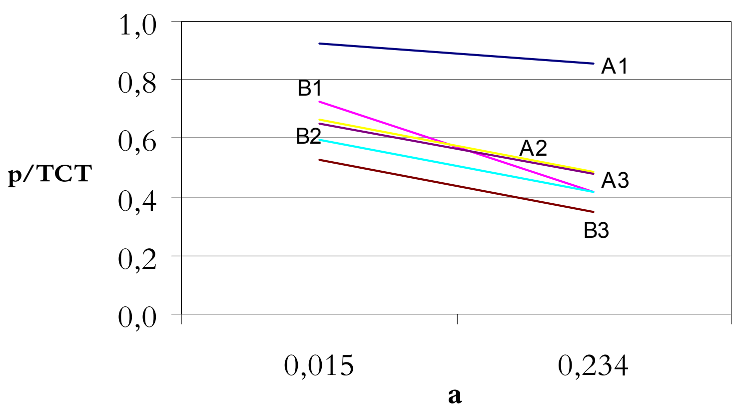

Figure 4.4 The relation between the tender sum and the TCT with variation in *a*.

4.6 APPLICATION AND RECOMMENDATION

Environmental aspects are today, if considered in tender evaluation, mostly related to the contractors' capability of performing environmental projects based on their environmental management system (ISO or EMAS), earlier described in subsection 3.4. The contractors environmental management system has little to do with the environmental merits of a specific building project. The clients competence in how to stipulate and follow up relevant requirements will be of significant importance. In Paper I it is shown that the stipulation of requirements in many cases are not sufficient as to cover the aspects of sustainable construction, failing especially to include operational energy.

In addition to stipulating environmental requirements the complete TCT gives the possibility to include the environmental impact from energy use as a monetary term in the life-cycle cost estimation. By using TCT energy reductions leading to reduced environmental impact is encouraged, assumed that clients are willing to take a responsible attitude towards these questions and that contractors take the opportunity to develop new methods. By the life-cycle cost perspective the design of the building, the energy performance with use of passive heat and daylight will have an influence on the result. By using this perspective it is hereby possible for the contractor/designer to spend somewhat more on initial costs to obtain a low overall score. With some modification the suggested model can also be used when developing systems for energy classification of buildings.

4.7 LIMITATIONS

Environmental work is about continuous improvements. Aspects considered as important to meet sustainability today may embrace different aspects and criteria in the future. Therefore it is necessary to regularly update the normalisation factors and inventories used to determine the environmental impact. Today environmental impact from operation is considered important but when efficiency improvements are accomplished other aspects may become more important. It is also possible that the Swedish Environmental Quality Objectives are revised and then the normalisation factors must follow.

The weight method applied to develop the environmental impact index includes uncertainties on different levels. The major uncertainty however is likely to be in the development of the normalisation factors combining the impact categories into one value as these are merely based on goals and in the characterisation factors applied. For GWP the uncertainty in the characterisations factors is about 35 %. The inventory data used also includes some uncertainties but is based on measurements or calculations, which can be determined with better accuracy. One possible way for clients that want to use more detailed and accurate results is to compare each environmental impact category individually and exclude the use of the weight model. Moreover, the estimation of environmental impact is further limited to emissions. For instance are the risks with radioactivity, the assessment of cultural values and destroyed natural areas not assessed and can be misleading in the use of the result.

Most of the mathematical model to calculate EI_X is developed based on data from Sweden. These results can be extrapolated for a more general international proposal using targets for the Scandinavian countries or Europe.

Another limitation of the model is related to the calculation of energy use which is one parameter in the evaluation. Different energy simulation programs present different results on buildings energy performance and even the same program can arrive at different results depending on how the user of the program interpret different factors. The client should therefore suggest which type of simulation program to use in order to make the tender evaluation as fair as possible.

4.8 ADDITIONAL NOTES

Since the submission of Paper IV the model have been improved to include the goal factor which have been edited into Paper IV. Further, improved energy data have been obtained for building Ref 1. which also have been included in the paper.

5 CONCLUDING REMARKS AND SUMMARY OF PAPERS

This chapter summarises the appended **Papers I-IV**. In the first part of this work, referred to in **Paper I,** requirements stipulated by Swedish clients in procurement documents were investigated through a questionnaire. It was found that operational aspects as energy use were vaguely considered. An incentive for efficient energy use could be provided by the client if evaluating tenders based on life-cycle costs. The development of a model integrating life-cycle cost and environmental impact was thereby suggested. The second part of this work, referred to in **Paper II-IV,** the use of life-cycle cost estimations in design are investigated and a tender evaluation model is proposed. **Paper II** describes some general aspects of life-cycle cost estimation, its methodology and application in relation to environmental design. An identification of use of life-cycle cost methods by Swedish clients are presented in **Paper III.** Finally a life-cycle cost analysis was performed in a case study of three environmentally designed buildings, presented in **Paper IV.** The results from the life-cycle cost analysis were compared to three similar conventional buildings and the empirical data generated were used to verify the multi attribute tender evaluation model developed (described in Chapter 4).

5.1 GREEN PROCUREMENT OF BUILDINGS A STUDY OF SWEDISH CLIENTS CONSIDERATIONS

The principal aim of **Paper I** was to investigate environmental requirements stipulated by clients in procurement documents based on a questionnaire performed during 1998/99. By stipulating requirements clients can encourage the development of alternatives (materials, methods, buildings etc.) from an environmental point of view. An identification of the requirements gives an idea of which environmental aspects clients consider important to improve. Most requirements concerned construction waste, the contractors' environmental work, aspects related to the selection of material and construction methods. It was further concluded that requirements related to selection of material should aim at avoiding hazardous substances otherwise competition can be limited and costs will increase, Appendix A. Few clients stipulate requirements related to operation of building as for example energy use, which is currently considered to be the most important environmental aspect. The requirements were further examined in relation to the Ecocycle Councils' prioritised areas which reflected that the Ecocycle Councils' work has been effective when focusing on the areas of material and waste.

The requirements were also evaluated in relation to their possibility of improving environmental construction without increasing construction costs seen from a life-cycle perspective, Appendix D. Furthermore the aim of the study was to examine how the environmental requirements were followed up in the building process. The complete study is found in Sterner (1999).

In general, government and private clients had addressed more environmental aspects than most municipal clients. The latter should make substantial efforts to properly address environmental construction. Further it was found that requirements stipulated occasionally were too vague when expressions such as 'limited environmental impacts' were used. Stipulated environmental requirements are minimum measures that the contractor has to fulfil and by not using distinct expressions the effectiveness of the requirements is questionable as the possibilities of verification are limited.

The interview study herein was performed with three of the clients participating in the questionnaire. The selection was based on the identification of the clients having developed the most complete procurement documents covering aspects of environmental construction. Some difficulties were experienced in relation to evaluation of environmental impact from materials due to lack of practical models and standardised procedures. The assessment methods used were based on LCA procedures but were considered to be rather complex and the results quite uncertain as different impact categories were difficult to compare.

One way for clients to promote environmental construction is by including environmental parameters in tender evaluation. Furthermore a tender evaluation including environmental impact assessment makes it possible to award contractors that exceeds the established standard in the procurement document. By an integration of life-cycle costs estimates and environmental impact assessment it would be possible for clients to emphasise efficient energy use in buildings. The result will in the long run be reduced environmental impact from buildings. The first step in order to develop a practical model was to examine the methodology of life-cycle cost estimations and use in design of environmental building projects, described in Paper II.

5.2 RECONCILING THEORY AND PRACTICE OF LIFE-CYCLE COSTING

Paper II was aimed at identifying and discuss some of the implications between the theory and practice of life-cycle cost estimations by categorising some key aspects of use in current practice. The implication of the methodology for environmentally designed buildings was investigated.

A qualitative approach was used to examine the use of life-cycle cost estimations and the existing barriers for a wider recognition in use. The collected information was based on a seminar held in Vancouver, Canada. In North America life-cycle costs estimations are used by governments to promote energy conservation in building projects and is one reason to perform the study in Canada. Environmental building projects had further been developed in the Vancouver area and clients, designers and contractors invited to the seminar had that experience. A set of questions was prepared in advance of the seminar and circulated to a total of 20 attendants (facility managers, public and private clients, architects, engineer consultants, contractors and quantitative surveyors). Three of the attendants were invited and each were given 30 minutes, to address the issues raised in the circular, they then offer personal insights and afterwards in a discussion exchanged views with the rest of the participants. The seminar was intended to explore the practical use of full-cost accounting and life-cycle cost methods in green building design by addressing the following questions:

- What are the most significant benefits in using full-cost accounting and life-cycle cost in green design?
- Can green building be promoted through full-cost accounting and life-cycle cost, and how?
- What are the constraints of doing so (time, cost, how the input data is gathered or generated etc., and embedded in owner/developer agendas)?
- When are full-cost accounting and life-cycle cost methods most appropriately performed (design, tendering etc.)?
- Is there a resistance among clients to using full-cost accounting and life-cycle cost?
- How rigorous are the full-cost accounting and life-cycle cost methodologies currently being used in practice (how detailed, which parameters are included/excluded etc.)?
- What is the scope of life-cycle cost assessments (whole buildings, building components, HVAC systems, etc.)?
- How can a widespread use of full-cost accounting and life-cycle cost be encouraged?

Notes were made through out the seminar and afterwards the text was compiled into the following groups: motivation, contextual issues, methodological limitations, and access to reliable data. Aspects discussed in pertinent literature additionally supported the point of views obtained within each category.

This paper illustrated that the limited direct use of life-cycle costing in building design is mainly related to constraints in data accuracy and in current design practice. The absence of a formalised life-cycle cost approach were a further constraint and capital costs were used as the primary basis to compare alternatives. In the context of environmental design, life-cycle cost approaches was found particularly important as it is then possible to examine if the adoption of green materials, systems and strategies will indeed give significant benefits as reduced operating cost, etc. associated with that choice.

5.3 LIFE-CYCLE COSTING AND ITS USE IN THE SWEDISH BUILDING SECTOR

Paper III presents an investigation of to what extent Swedish clients use life-cycle costs estimations by emphasising limitations and benefits in the procedures and models used.

The study was based on a questionnaire, Appendix 2 and performed in 1999/2000. The questioner was mailed to 83 public and private clients. The survey probed aspects in the use of life-cycle cost estimations and the perceived difficulties of its use. The response rate was 64 %. This was expanded up on by asking some additional questions to 12 of the clients concerning the life-cycle cost models used by them.

In summary, nearly 66 % of the responding clients consider life-cycle cost mainly in design (57 %) and to a limited extent (26 %) in procurement. In general the cost elements considered are investment, energy and, maintenance costs. Some clients include costs related to disposal and the environmental disturbance this causes. All clients assumed they would use life-cycle cost as a parameter in tender evaluation if a simple model was available and some clients already included life-cycle cost in tender evaluation. As in Paper II similar constrains for practical use of the life-cycle cost technique are identified due to lack of relevant input data but also due to a limited experience in use of the method.

Two types of models used for life-cycle cost estimations were identified. A rather advanced model was primarily used to evaluate different installation systems (HVAC) where the only commercial program found in use was ENEU 94 (2000). Own programs were developed by the clients who did not use ENEU 94 which included sensitivity analysis and usually the following parameters:

acquisition, energy, operation, maintenance, environmental costs, salvage value. In the narrower models sensitivity analysis were sometimes performed but only related to the discount rate. The more advanced models also varied energy prices and studied life lengths.

Papers I-III emphasised that the application of a practical tender evaluation model may lead to a wider acceptance of aspects related to assessment of environmental impact and life-cycle cost estimations.

5.4 COMBINING LIFE-CYCLE COST AND ENVIRONMENTAL IMPACT: A CASE STUDY AND MODEL FOR TENDER EVALUATION

Paper IV demonstrates the use of life-cycle costing in the context of three environmental designed commercial buildings built in a project called Greenzone. This is done in order to display the merits of using a life-cycle perspective in green building design and thereby providing confidence to clients in the application of environmental approaches. Also the relevance of the cost elements was identified to reduce the range of items included in the life-cycle cost calculation. Finally, the generated empirics were used in the development of a general multi attribute tender evaluation model, in Chapter 4.

In particular the study addressed the effects of initial cost increases, possible operational cost savings and environmental impact reduction from operational energy use. The reasons for selecting Greenzone for the case study are the following:

- the high level of environmental strategies implemented which have been prior to consideration of initial cost making this represent an extreme case of environmental design
- costs of reference projects without explicit environmental design are available
- the follow-up on water, energy and electricity use by installation of gauges in the buildings facilitates the estimation of future costs

Future required provisions for maintenance were estimated based on intervals given in Repab (2000), in which recommended values also are provided for annual costs. The energy use is obtained from consultants, based on the first year of operation and the future energy costs are thereafter forecasted to be at the same annual magnitude through the life length of the study. A sensitivity analysis was used to examine the effects on the result from variation in the discount rate, the life-length and the energy price escalation rate. For the comparison and identification of break-even points, information on initial and operation costs for three equally sized buildings without environmental design was obtained from the investor and the tenants.

The sensitivity analysis focuses on energy use as being of significant importance to the life-cycle cost and environmental impact. In Figure 5.1 the discount rate has been varied within a range of zero to four per cent applied to the electricity price. As the difference is in the amount of electricity used and not in energy price, the variation of the discount rate for the Greenzone buildings will have less effect on the present value compared to the conventional building. Conclusively, it can be argued that analyses of energy efficient buildings are less sensitive to variations in the discount rate and that the corresponding life-cycle cost analysis can be performed with more accuracy than for traditional buildings. Adding the escalation in price over the general inflation rate to the analysis of the total life-cycle cost proves under which conditions the environmental design is advantageous over the conventional design as seen in Figure 5.2.

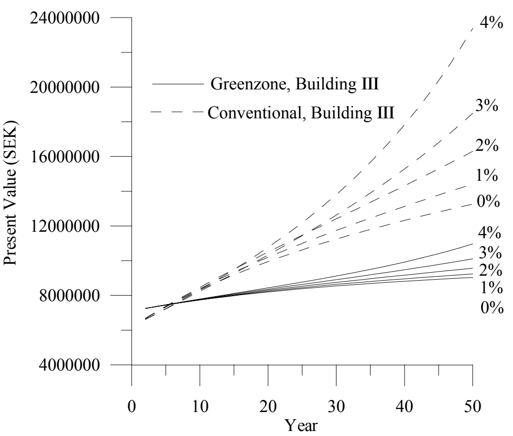

Figure 5.1 The influence of variation in discount rate on the present value of the electricity cost.

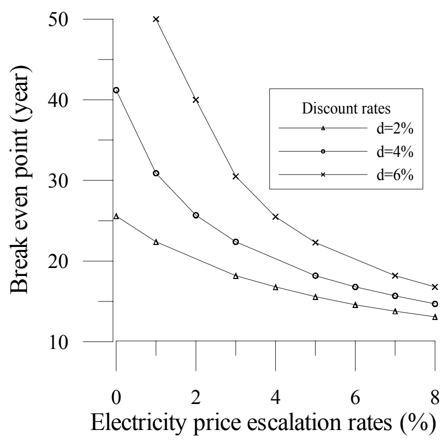

Figure 5.2 Example of the variation in break-even points (in years).

In the comparison of the total life-cycle cost, applying a discount rate of 4% and a life of 50 years (Figure 5.2), the environmentally designed buildings are in the same cost range as the conventional buildings although these have significantly lower initial costs. The fact that the environmental designed buildings are economically advantageous is an interesting aspect, as the Greenzone project has been developed to meet high environmental targets and is the first of its type for the client, consultants and contractor involved. For standard procedures, the occupants of two of the buildings, use standardised buildings and construction methods which have been repeated numerous times and conclusively the cost optimisation have been possible. In general environmental designed projects have often a higher quality than conventional buildings, which is difficult to evaluate in monetary terms. For the interested client a broader perspective of the life-cycle cost analysis can be an aim.

The life-cycle cost analysis showed that the maintenance cost has a relatively small impact on the total cost result (roughly 2 %). The calculation of maintenance costs was found time demanding and better procedures for arranging data are still needed. To disregard the maintenance cost can simplify the analysis for this type of buildings, but this decision is highly dependent on the aim of comparison. Initial costs proved to have a large impact on the result (56 %) and the impact of energy costs (electricity) was also of high magnitude (22 %).

The environmental impact of energy use, related to emissions, was calculated as global warming potential, acidification potential, eutrophication potential and photochemical ozone creation potential. A significant reduction of the environmental impact from the Greenzone buildings was found, as energy use is considerably low and the electricity is produced by means of wind power. The type of energy, efficiency of the heating system and total use of electricity for daily activities are all of major importance when reducing the environmental impact for commercial buildings.

A combination of environmental impact categories to an environmental impact index using a method proposed by Erlandsson (2000) provided a practical way of comparing environmental impact from operational energy use between buildings. Moreover, the environmental impact index was integrated with the life-cycle cost from operational energy use and the initial price in a tender evaluation model. Operational energy use is, however, only one of the potential parameters that can be emphasised in a cost evaluation. As energy use is currently seen as the most prevailing problem, awarding reduced environmental impact in tendering competitions can be an incentive for the development of environmental cost effective construction.

Clients that include life-cycle costs estimates in tender evaluation will have the possibility to reduce the total cost and reduce environmental impact as energy efficiency is promoted. For clients with higher ambitions for environmental impact reductions the use of the tender evaluation integrating life-cycle cost estimations with environmental impact assessment can be used to award contractors that exceed the established standards in the procurement document. Both procedures will in the long run result in reduced environmental impact from buildings.

6 DISCUSSION

This thesis work takes as starting-point the politically determined goals for environmental improvements namely the Environmental Quality Objectives (EQO) decided by the Swedish parliament. These objectives aim at providing feasible solutions to the major environmental problems within one generation. Due to the slowness of the ecosystem were environmental effects remain long after corrective measures are taken this can be considered rather naive. As the author views it there are a number of significant problem to solve such as:

- How to the follow up of the goals. The goals are very general but the development of more detailed sub goals are progressing. Indicators developed to show how different sectors are effecting the environment are one example but do not cover all aspects of environmental problems as described in the EQO.

- How to calculate environmental impact. Even though extensive amounts of data are available through agencies such as the Swedish EPA, Swedish Energy Agency and Statistics Sweden this is not enough to give a complete description of the environmental problems. Of the 15 environmental objectives only four have been included here. For the other 11 it is concluded that the lack of data as well as mathematical models makes it very difficult to consider them. There are further differences in the interpretation of which characterisation factors to use, thereby the calculation of potential environmental impact in categories will differ between reports. Many give recommendations but a more unified position has to be taken in the future. Reports for instance by Environmental Management Market in Sweden on how this should be performed according to ISO are good examples.

- How information is presented. For the reliability of reports in this area it is important that the data used, simplifications made and equations applied are explained and presented.

The tender evaluation model developed includes uncertainties related to the estimation of life-cycle costs and environmental impact. The prediction of the energy use will influence the result and the calculation program used will therefore have an effect to the result. As there are differences in results depending on the program used the development towards a more unite system for instance can be useful. Further the life-cycle cost estimation is influenced by estimation of future costs, the increases in prices and the discount rate selected. These uncertainties can be handled through sensitivity analysis. The environmental impact index further includes other uncertainties related to the goal based method used to add environmental impacts together. Another possible procedure, instead of using goals, could be to establish a price for the impact based on its damage and thereby determine their relative weight. However that is a very complex exercise still involving subjective assessments and the uncertainties are several.

Some results in this thesis can be compared to goals presented by Build/Live, see sub-section 1.2.3, and especially to goal (2) which concern the use of delivered energy to the sector. It is shown that the use of delivered energy to the sector can be reduced by at least 30 % for new buildings without influencing the life-cycle cost negatively. According to goal (4) all new buildings and 30 % of the existing building stock should be examined by declaration or be classified by the year 2010. The environmental impact index developed herein for use in the tender evaluation can, with some modification, be a contribution to such development.

It is in the authors' point of view that the Swedish building sector has progressed far in its investigations, probably much in gratitude of the organised voluntary work. The accomplishments in practice are less examined once again as follow up is a difficult task. The work presented herein gives some indication on the status. When the Swedish EPA examined the building sectors progress (in relation to EQO 11) the tone was pessimistic. This can partly be dependent on that an allocation between the occupants of buildings and the building sector is not well defined, especially in relation to energy use. The building sector should not be blamed for the energy used by the consumers as this to a large extent is in the control of the occupant. Providing energy efficient designs and HVAC systems is though more relevant.

The client has several possibilities to provide incentives for ecological sustainable development. One is by using life-cycle cost estimations for tender evaluation as investigated herein. Moreover the procurement system decided by the clients is relevant for the development of ecological sustainable construction. Conventional procurement methods as general contracts where technical solutions are determined can prevent the development of new and more environmental conscious products and methods. The possibilities given by performance-based contracts can therefore be advantageous.

The costs of building today are high due to for instance low productivity, reduced subsidies and high taxes. It is therefore important that environmental requirements do not further increase cost from a life-cycle perspective. The initial investment cost is often the determining factor for design and construction, and the use of a life-cycle perspective with consideration to the environment is limited in use. Making environmental improvements profitable for clients under the current practice should require a changed structure for financing, loans and revenues and then clients can to a larger extent base their investment decisions on economical estimations from a life-cycle perspective. Conflicting interests regarding pay-offs within the clients company or within an authority should also be replaced with long termed strategies. Moreover, prevailing systems with rates for example water and sewage do not provide incentives for ecological sustainable development and can be a constraint. For instance, in the case of the Greenzone project analysed herein all wastewater is treated on site, but no savings is recorded since all buildings must be connected to the municipal sewage system and a rate is paid regardless if used or not. This system undermines the incentives for ecological investments.

Another limitation of today's financial structure is that higher taxation values that are applied to environmentally upgraded buildings, making such investments not economically beneficial. Conclusively both the financial and tax structure of building related investments should be reconsidered in order to obtain ecological sustainable development within the sector.

7 CONCLUSIONS

This thesis mainly deals with implementation of environmental aspects and life-cycle costs in the procurement and tender evaluation process. It features the establishment of the environmental requirements clients have stipulate in procurement documents and those most useful for reducing environmental impact without preventing more cost effective construction processes are identified. A state of the art review of life-cycle cost estimations, methodologies and application in relation to environmental design is presented. Limitations for a wider acceptance and an identification of the life-cycle cost methods used by Swedish clients offered. A life-cycle cost analysis and environmental impact assessment in a case study of three environmentally designed buildings is further presented**.** Life-cycle cost estimation and environmental impact were combined in a tender evaluation model. Verification of the model was based on empirical data generated from a case study.

The following conclusions are recommendations to clients to obtain an environmentally aware and cost effective building through the procurement.

- Clients that use green procurement have the possibility to influence and encourage the development of sustainable construction. When the aim is to reduce environmental impact without preventing more cost effective construction processes following requirements can be used: prefabrication and customised materials, reduced amount of wrapping and co-ordinated transports. Requirements concerning selection of materials should be limited to not include use of hazardous substances/components for instance by using the Chemical Inspectorates lists.

- Stipulating environmental requirements in a general manner reduces the effectiveness of the requirement since the possibilities of verification are limited. Preferably, clearly stipulated and measurable requirements should be used.

- In the planning and design stages of building projects, sustainable construction can be achieved by applying the principles, procedures and methods of life-cycle assessment (LCA). However, clients consider the LCA methods available rather complex and the results difficult to interpret and compare. LCA, moreover, accounts for the measurable aspects while other environmental considerations should be handled through requirements.

- To motivate reductions in energy and operating costs, it is strongly recommended that clients evaluate tenders based on life-cycle cost estimations.

- For clients with a higher level of ambition additional emphasise can be given to environmental impact from energy use by the multi attribute tender evaluation model as summarised in subsection 4.4. It is then possible to award the contractors exceeding the established standard in the procurement document.

- Life-cycle cost estimations in procurement and tender evaluation is currently considered to a limited extent where the lack of reliable and consistent data is one major obstacle. Further, the inclusion of too many components makes the analysis impractical. To direct attention to those areas where financial benefits most easily is achieved a preliminary analysis indicates that about 70 to 90 % of the total cost is captured by including the initial cost and the life-cycle operation energy cost.

- The application of life-cycle cost estimations in design and in tender evaluation can give clients better possibilities to increase profits by reducing operation and maintenance costs. Somewhat increased initial costs for environmental designs can be justified by displaying reduced operation costs.

- Clients that search for innovations or alternatives of designs are recommended to use design and build or performance procurement systems. When the client offers such system it is a driving force for the contractor to increase research and development but the working methods applied must be modified.

7.1 FUTURE RESEARCH

Building procurement: A main focus in the development of the tender evaluation model has been the procurement of buildings to be constructed. In the author's opinion, building research and practice in Sweden is focused toward new production, which however is very limited while less attention is devoted to the already existing building stock. Due to its magnitude, it should also be managed in a sustainable way which requires further research and implementation. If energy use has to be reduced in existing building stock a substantial challenge waits which can be costly. The development of procurement systems allowing innovations to refurbishment of existing buildings is an interesting aspect for future research.

Life-cycle cost estimations: To perform a life-cycle cost analysis is relatively time consuming and tools must be developed to facilitate this. An attempt was made herein to identify of the cost elements having the greatest relevance to the total cost. However only a limited set of data was available and this can be improved by including more case studies. Also to establish the relevance of cost elements over the life-cycle future research could include a verification by mathematical modelling. In Sweden there exists already well established systems that can be used to classify a buildings in different levels as components, materials, and elements such as BSAB 96. This system provides a sheet to calculate the initial cost for material and work. Future development could include integration of provision intervals multiplied with a present value factor for the chosen analysis horizon and discount rate. This would considerably improve and facilitate the practical use of life-cycle cost calculation in Sweden.

Assessment of environmental impact: The assessment of environmental impact in the developed model was limited to operational energy use as it constitutes a major part of most buildings environmental impact seen from a life-cycle perspective. However the comparison between different types of energy is based herein only on emissions and just includes three environmental impact categories. Also large uncertainties remain in the relation between various effects and the consequences on the environment which limits the reliability of the method. Future research can address the inclusion of supplementary aspects reflecting on the environmental quality objectives offering greater reliability to the weighting method.

Energy use and modelling: The tender evaluation model developed prerequisites that the energy demand in buildings can be predicted with a relatively good accuracy. According to other studies and current development the predictions often underestimates the actual energy use. The occupants further influence energy use in buildings. The development of robust systems that can monitor the users behaviour and adjust accordingly is an interesting area of development.

Other areas of application: The evaluation of environmental impact performed can with some modification be applied in the development of energy classification systems of buildings.

8 REFERENCES

Adalberth, K. (2001). Energy use and environmental impact of new residential buildings. PhD thesis, report TVBH-1012, Lund Institute of Technology, Lund, Sweden.

AB 96, Allmänna bestämmelser för byggnads -,anläggnings- och installationsentreprenader (General conditions for building, civil engineering and service installation contracts works). Byggandets kontraktskommitté. In Swedish.

Abraham, D. M., Dickinson, R. (1998). Disposal costs for environmentally regulated facilities: LCC approach. Journal of construction engineering and management, March/April, 146-154.

AF AMA. Gemensamma allmänna administrativa föreskrifter, (Administrative specifications) Svensk byggtjänst, Stockholm, Sweden. In Swedish.

Andersson, N., Borgbrandt, J. (1998). Byggforskning, processer och vetenskaplighet (Construction research, processes and science). Report 1998:11, Luleå University of Technology, Luleå, Sweden. In Swedish.

Al-Hajj, A., Horner, A. (1998). Modelling the running costs of buildings. Construction management and economics, 16, 459-470.

Alsugair, A.M. (1999). Framework for evaluating bids of construction contractors. Journal of management in engineering, 15 (2), 72-79.

Anumba, C.J., Evbumwan,N.F.O. (1997). Concurrent engineering in design and build projects. Construction management and economics, 15 (3), 271-281.

Arditi, D., Messiha, H. (1996). Life cycle costing in municipal projects. Journal of infrastructure systems. ASCE 2 (1), 5-14.

Arditi, D., Nawakorawit, M. (1999). Designing buildings for maintenance, designers perspective. Journal of architectural engineering. ASCE 5 (4), 107-116.

ASTM E917-89. Standard practice for measuring life-cycle costs of buildings and building systems. American Society for Testing Material (ASTM), Washington D.C., U.S.

ASTM E964-93. Standard practice for measuring benefit to cost and savings to investment ratios for buildings and building systems. American Society for Testing Material (ASTM), re-approved 1998, Washington D.C, U.S.

Atkin, B., Gravett, J. (2000). Vändpunkt 2000, Innovation in the function of developers: Lessons from the UK. Royal Institute of Technology, Stockholm, Sweden.

Aye, L., et al. (2000). Environmentally sustainable development: a life-cycle costing approach for a commercial office building in Melbourne, Australia. Construction management and economics, 18, 927-934.

Baldwin, R. et al. (1998). BREEAM 98 for offices. Building Research Establsihment, Watford, UK.

BC MELP. (1997). Total Cost Assessment Guidelines: Assessing the Business Case of Environmental Investments, BC Ministry of Environment, Lands & Parks, Canada.

Bejrum, H., Lundström, S., Söderberg, B. (1986). Hyresfastighetens ekonomi i långtidsperspektiv, analys av empiriska data (The economics of real estates in a long-term perspective, analysis of empirical data). Report 5:23, Institutionen för fastigheter och byggande, avdelningen för Bygg- och fastighetsekonomi. Royal Institute of Technology, Stockholm, Sweden. In Swedish.

Bejrum, H. (1991). Livscykelekonomiska kalkyler för byggnader och fastigheter (Life-cycle economic appraisal for buildings and real estates). Institutionen för fastigheter och byggande, avdelningen för Bygg- och fastighetsekonomi. Royal Institute of Technology, Stockholm, Sweden. In Swedish.

Bejrum, H. (1994). Livscykelekonomi för byggnader (Life-cycle economy for buildings). Swedish Council of Building Research. Sweden. In Swedish.

Bejrum, H., Lundström S. (1995). Fastighets ekonomi, hyresfastigheter. Diagnos, prognos värdering (Real estate economics, residential buildings. Diagnose, prediction, evaluation). 4th ed. Catella och författarna, Sweden. In Swedish.

Bergström, I., Lumsden, M. (1993). Ekonomistyrning i mindre företag (Financial control in smaller enterprices). PhD thesis. Luleå University of Technology, Luleå, Sweden. In Swedish.

Boonstra, C., Knapen, M. (2000). Knowledge infrastructure for sustainable building in the Netherlands. Construction management and economics, 18, 885-892.

Bordass, W. (2000). Cost and Value: fact and fiction. Building Research and Information, 28 (5/6), 338-352.

Bowen, B., Charette, R., and Marshall, H. (1992). UNIFORMAT II – A Recommended Classification for Building Elements and Related Sitework. NIST Special Publication 841, Gaithersburg, VA: National Institute of Standards and Technology. U.S.

Bromilow, F.J., Pawsay, M.R. (1987). Life cycle cost of university buildings. Construction management and economics, 5, 3-22.

Brunskog, E. (1983). Kostnadsinformation regler för gruppering och registrering av byggprojekts kostnader (Information about costs, criterion for grouping and registration of costs in a building project), Sweden. In Swedish.

Build/Live (2000). Tänk Nytt, tänk hållbart!-att bygga och förvalta för framtiden. (Think new, think sustainable!-to build and manage for the future). Ministry of the Environment, Stockholm, Sweden. In Swedish.

Carpenter, A. (1999). *Early experience with the Model National Energy Code for buildings.* Advanced buildings newsletter. 1 (23/24), October 1999. Royal Architectural Institute of Canada. Ottawa, Canada.

CIB (1996). Selecting consultants for the team. Balancing quality and price. Construction Industry Board, Thomas Telford, London, UK.

Chau, C.K., et al. (2000). Towards a successful voluntary building environmental assessment scheme. Construction management and economics, 18, 959-968.

Clift, M., Bourke, K. (1999). Study on Whole Life Costing. Report prepared for DETR, February 1999, Report Number CR 366/98. UK.

Cole, R.J., Rousseau, D., Theaker, G.T. (1993). Building environmental performance assessment criteria (BRPAC), BEPAC Foundation, Vancouver, Canada.

Cole, R.J., Kernan, P.C. (1996). Life-cycle energy use in office buildings. Building and Environment, 31(4), 307-317.

Cole, R.J. (1999). Building environmental assessment methods: clarifying intentions. Building research and information, 27 (4/5), 230-246.

Consolio, F., et al. Vigon, B. (Eds). (1993). Guidelines for life-cycle assessment; a code of practice. SETAC, Brussels, Belgium.

Derwnet, R.G., et al. (1998). Photochemical ozone creation potentials for organic compounds in northwest Europe calculated with master chemical mechanism. Atmospheric Environment, 32 (14/15), 2429-2441.

DOC. (1978). Life-cycle costing, a guide for selecting energy conservation projects for public buildings. U.S. Department of Commerce, National bureau of standards, Washington, D.C.

Drew, D., Skitmore, M. (1997). The effect of contract type and size on competitiveness in bidding. Construction management and economics, 15, 469-489.

Drew, D.S., Tang, S.L., Lo, H.P. (2002). Developing a tendering strategy in two-envelope fee tendering based on technical score-fee variability. Construction management and economics, 20, 67-81.

Ecocycle Council (1995). Handlingsplan: miljöansvar för byggvaror inom ett kretsloppstänkande, ett utvidgat producentansvar (Plan of action: Environmental responsibility for building products within a closed loop thinking, an expanded producers responsibility). Ecocycle Council, Stockholm, Sweden.

Ecocycle Council (1997). Byggvarudeklarationer (Labelling of building products). Ecocycle Council, Stockholm, Sweden.

Ecocycle Council (2001). Byggesktorns betydende miljöaspekter (The environmental aspects of importance to the building sectors). Ecocycle Council, Stockholm, Sweden.

EKU-Delegationen (2001a) Report 2001-09-12. (Title is currently missing in its publication). The committee on ecological sustainable procurement.

EKU-Delegationen (2001b) Miljökrav vid entreprenader och tjänster inom byggande och förvaltning. (Environmental requirements of services within construction and facility management). The committee on ecological sustainable procurement, Report 2001-05-17.

Elmroth, A., et al. (1987). Energisvar, frågor och svar om energihushållning i byggnader (Energy answers, questions and answers about energy performance in buildings). The Swedish Council for building research, Stockholm, G17:1987. In Swedish.

Elmroth, A., et al. (1988). Sex unika hus. Energisnåla flerbostadshus. Teknik och erfarenheter från Stockholmsprojektet. Swedish Council of Building Research, report G2:1988. In Swedish.

ENV 636 (2001). Proposal for a Directive of the European parliament and of the Council on the energy performance of buildings. Council of the European Union, 2001-12-05, Brussels, Belgium.

Erlandsson, M. (1995). Environmental Assessment of building components. Licentiate of Engineering thesis, Department of Building Sciences, Royal Institute of Technology, Stockholm, Sweden.

Erlandsson, M. (2000). Viktning av olika miljöpåverkanskategorier baserat på en vision om det framtida hållbara folkhemmet: de svenska miljökvalitetsmålen (Weighting of different environmental impact categories based on a vision of the future sustainable home: the Swedish Environmental Quality Objectives). Swedish environmental research institute (IVL), B1385, Stockholm, Sweden. In Swedish

Epstein, M. J., (1996). Measuring corporate environmental performance. Irwin Professional Publishing, Chicago, U.S.

Faith-Ell, C. (2000). Environmental management of road maintenance- with emphasis on 'green procurement'. Licentiate of Engineering thesis, Department of Civil and Environmental engineering. Royal Institute of Technology, Stockholm, Sweden.

Faith-Ell, C., Sterner, E. (2001). The use of green procurement in the Swedish building and road maintenance sectors. 2nd Nordic conference on construction economics and organisation, Gothenburg 24-25 April, 2001, pp 63-72, Sweden.

Falk, J.-E. (2001). Övergripande regler som skall betraktas vid offentlig upphandling. In: Miljöanpassad upphandling - offentlig och privat. Stockholm, Sweden, Jure CLN AB. In Swedish.

Fay, R., Treloar, G., Usha, I-R. (2000). Life-cycle energy analysis of buildings: a case study. Building research and information, 28 (1), 31-41.

Ferry, D.J.O., Flanegan, R. (1991). Life-cycle costing – a radical approach, CIRIA Report 122, Construction Industry Research and Information Association, London, UK.

Finnveden, G., Lindfors, L-G. (1992). LCA in different applications- demands and expectations. In Anonymous (1992), 105-131.

Fjärrvärmeföreningen (2001). Fjärrvärme och kraftvärme i sammandrag (District heating and heat power in summary). Fjärrvärmeföreningen -http://www.fvf.se.

Flanegan, R., Norman, G. (1983). Life cycle costing for construction, Quantity Surveyors Division of The Royal Institution of Chartered Surveyors, London, UK.

Flanegan, R., et al. (1987). Life cycle costing and risk management. Construction management and economics, 5, 53-71.

Flanegan, R., et al. (1989). Life cycle costing, theory and practice. BSP Professional books, Oxford, London, UK.

Gibb, A., Isack, F. (2001). Clients drivers for construction projects: implications for standardization. Journal of engineering, construction and architectural management, 8 (1), 46-58.

Glauman, M. (2001). EcoEffect metoden, sammanfattning (EcoEffect, summary) Gävle, Sweden, 2001 08 29. In Swedish.

Gluch, P. (2000). Managerial environmental accounting in construction projects, discussions on its usability and role in decision making. Licentiate of Engineering thesis, Chalmers University of Technology, Gothenburg, Sweden.

Government Bill (1997). Swedish Environmental Quality Objectives. 1997/98:145. Stockholm, Sweden.

Government Bill (2001). Svenska miljömål-delmål och åtgärdsstrategier (Swedish Environmental Objectives-sub goals and measures). 2000/01:130, Stockholm, Sweden. In Swedish.

Gren, I.-M., (1999). Miljökrav vid offentlig upphandling som miljöpolitiskt styrmedel: En ekonomisk analys. In: Swedish Agency for Administrative Development (Editor), Miljökrav vid offentlig upphandling - samhällsekonomiska konsekvenser. Stockholm, Sweden.

HAPM, Component Life Manual and Guide to Defect Avoidance (1992) (CD ROM 1999). Housing Association Property Mutual Ltd, London, UK.

Hatush, Z., Skitmore, M. (1997). Criteria for contractor selection. Construction management and economics, 15, 19-38.

Hauschild, M. (1996). Baggrund for miljøvurdering af produkter. UMPI, Danmarks Tekniske Universitet. Denmark. In Danish.

Haysom, J., Lacroix, M. (1999). Background and main features of Canada's new model national energy codes for buildings and for houses. Institute for research in construction, National Research council of Canada. Ottawa, Canada.

Heerwagen, J. (2000). Green Buildings: A Strategic Perspective. Building research and information, 28 (5/6), 353-367.

Heijungs, R., et al. (1992). Environmental Life-Cycle Assessment of products: guide and backgrounds. CML, Leiden University, Leiden, The Netherlands.

Herbsman, Z.J., Chen, W.T., Epstein, W.C. (1995). Time is money: innovative contracting methods in highway construction. Journal of construction engineering and management, 121 (13), 273-281.

Hill, R.C., Bowen, P. (1997). Sustainable construction: Principles and a framework for attainment. Construction management and economics, 15, 223-239.

Holt, G.D., Olomolaiye, P.O., Harris, F.C. (1995). A review of contractor selection practice in the U.K. construction industry. Building and environment, 30 (4), 553-561.

IPCC (1994). Radiative Forcing of Climate Change- The 1994 Report of the Scientific Assessment Group of IPCC; Intergovernmental Panel of Climatic Change, London, UK.

IPCC (1996). Climate change 1995 - the science of climate change, summary for policymakers and technical summary of the working group I report. Cambridge University Press, Cambridge, UK.

ISO 15686-1:2000. Building and constructed assets, service life planning, part 1-general principles. International Standard Organization, 2000.

ISO 15686-2:2001. Building and constructed assets, service life planning, part 2-life prediction procedures. International Standard Organization, 2001.

ISO/TC 59/SC 14N. (2001). Building and constructed assets, service life planning, part 5- whole Life costing. Preliminary version. International Standard Organization, 2001.

ISO 14040 (1997). Environmental management – life cycle assessment- principles and framework. International Standard Organization, 1997.

Johansson, B. (1997). Vi behöver en bättre byggprocess. En förstudie och förslag till förändring (We need a better building process, a preliminary study and suggestion for change). Luleå University of Technology, Luleå, Sweden. In Swedish.

Johansson, C., Öberg, M. (2001). Life cycle cost and affordability perspective for multi dwelling buildings in Sweden. 2nd Nordic conference on construction economics and organisation, Gothenburg 24-25 April, 2001, pp 287-297, Sweden.

Jönsson, Å. (1998). Life cycle assessment of building products, case studies and methodology. PhD thesis. Chalmers University of Technology, School of Environmental Sciences, Gothenburg, Sweden.

Kilbert, C.J. (1994). In First International conference of CIB TG 16 on Sustainable construction, Tampa, FL 6-9 November, Final Session, pp 3-12.

Kirk, S.J., Dell'Isola, A.J. (1995). Life cycle costing for design professionals. McGraw-Hill, Inc. New York, U.S.

Kortman, J.M.G., et al. (1994). Towards a single indicator for emissions-an exercise in aggregating environmental effects. Interfaculty Department of Environmental Sciences, University of Amsterdam, Amsterdam, The Netherlands.

Lagerqvist, O. (1996). Funktionsentrepenad, en model för upphandling av husbyggnader (Performance based contracts: a model for procurement of buildings) Forskningsrapport TULEA 1996:26, Luleå University of Technology, Luleå, Sweden. In Swedish.

Larsson, N.K (1999). Development of a building performance rating and labeling system in Canada. Building research and information, 27 (4/5), 332-3341.

Larsson, N.K, Clark, J. (2000). Incremental costs within the design process for energy efficient buildings. Building research and information, 28 (5/6), 413-418.

Leaman, A., Bordass, W. (1999). Productivity in buildings: the 'killer' variables, Building research and information, 27 (1), 4-19.

Lindfors, L-G., et al. (1995). Nordic guidelines on LCA. Report Nord 1995:20, Nordic council of Ministers, Copenhagen, Denmark.

Lipiatti, B. (1999). Selecting cost effective-green building products: BEES approach. Journal of construction engineering and management, 125 (6), 448-455.

Love, P.E.D., Skitmore, M., Earl, G. (1998). Selecting a suitable procurement method for a building project. Construction management and economics, 16, 221-233.

Macsporran, C., Tucker, S.N. (1996). Target budget levels for building operating costs. Construction management and economics, 14, 103-119.

McDonald, B., Smithers, M. (1998). Implementing a waste management plan during the construction phase of a project: a case study. Construction management and economics, 16, 71-78.

Miles, M., Huberman, A.M. (1994). Quantitative data analysis, an expanded sourcebook, 2nd ed. Thousand Oaks, Sage Publications, Inc., California, U.S.

Moberg, Å., et al. (1999). Miljöstystemanalytiska verktyg, en introduction till beslutssituationer (System analytical environmental tools, an introduction to decision making context). Report 251, Swedish EPA, Stockholm, Sweden. In Swedish.

National Board for Industrial and Technical Development (1997). Climate Report 1997. Report R1997:29, Stockholm, Sweden.

National Board of Housing, Building, and Planning (2001a). Byggsektorns miljömål [The building sectors environmental goals], Stockholm, Sweden. In Swedish.

National Board of Housing, Building, and Planning (2001b). Nyckeltal för energianvändning i byggnader (Indicators for energy use in buildings) Regeringsuppdrag M2001/2226/Hs. Karlskrona, Sweden. In Swedish.

Natural Resources Canada (1999). Improving Energy Performance in Canada. Report to Parliament under the Energy Efficiency Act. Minister of Natural Resources Government of Canada, Ottawa, Canada.

Natural Resources Canada (2001). R-2000 Standard. Office of Energy Efficiency, Minister of Natural Resources Government of Canada, Ottawa, Canada.

Nilsson, A. (2001). Analysis of energy efficient and sustainable buildings at Bo01-first study. 2nd Nordic conference on construction economics and organisation, Gothenburg April 24-25, 2001, pp 91-97, Sweden.

Nylén, A. (2000). Business relationships in road operation procurement: Five case studies. Licentiate of Engineering thesis. Division of Construction Management and Economics, Royal Institute of Technology, Stockholm Sweden.

Palaneeswaran, E., Kumaraswamy, M.M. (2000). Contractor selection for design/build projects. Journal of construction engineering and management, Sep/Oct, 331-339.

Patel, R., Tibelius, U. (1987). Grundbok i forskningsmetodik (The basis of research methodology). Studentlitteratur, Lund, Sweden. In Swedish.

Ramsey, R.G. (1973). Here you have it: Life Cycle Costing. AIA Journal, 60 (1), 11-17.

Repab (2000). Årskostnader 2000: nyckeltal för kostnader och förbrukningar (Annual costs 2000:indicators for costs and consumption) REPAB, Sweden.

Robinson, J.R.W. (1986). Life cycle costing in buildings: a practical approach. Australian Institute of building papers, 1, 13-28.

Ruegg, R.T. (1980). Life-cycle costing manual for the federal energy management program. U.S. Department of Commerce, National bureau of standards, Washington, D.C., U.S.

SEA (2001). Energiläget 2001 (Energy in Sweden 2001). Swedish Energy Administration, Stockholm, Sweden.

Seldon. R., (1979). Life cycle costing: A better method of Government procurement. Westview press, Inc., Colorado, U.S.

SNRA (1999). LCC modeller (bro), förstudierapport, Vägverket, Avdelningen för bro och tunnel, Borlänge 1999, Sweden.

SOU 2000:53 Vissa miljöfrågor (Certain environmental questions). The committee on Environmental and agricultural, SOU 2000:53, Sweden.

Solomon and Albritton. (1992). In Nordic Guidelines on Life-Cycle Assessment, Nordic Council of Ministers, Copenhagen, Denmark.

Spiegel, T.J. (1999). Accurate Cost Estimates, Paper Presented to the Cost and Value in Building Green Symposium, Vancouver, November 18-19, 1999, British Columbia, Canada.

Steen, B., Ryding, S-O. (1992). The EPS Enviro-Accounting method. An application of environmental accounting principles for evaluation and valuation of environmental impact in product design. Swedish Environmental Research Institute (IVL) report B 1080, Gothenburg, Sweden.

Sterner, E. (1999). Miljökrav på byggnader och byggande [Environmental requirements on building and construction]. Licentiate of Engineering thesis, Division of Steel Structures, report 1999:03, Luleå University of Technology, Luleå, Sweden. In Swedish.

Stockholm City (2002). Teknikupphandling av energiberäkningsmodell för energieffektiva sunda flerbostadshus (MEBY) (Procurement of an energy prediction model for energy efficient and sound residential buildings). Stockholms stad, LIP-kansliet. Sweden. In Swedish.

Stone, A. (1967). Building design evaluation. The Chaucer Press Ltd., Suffolk, UK.

Swedish Energy authorities (2000). Energiläget 2000. Stockholm, Sweden.

Swedish code of statues (1992). Lag om offentlig upphandling (Public procurement act). Stockholm, Sweden. In Swedish.

Swedish Engineering Industry (2001). ENEU 2000, systemval, värdering och upphandling baserat på LCC (ENEU 2000, choice of installation systems, evaluation and procurement based on LCC). Förhandskopia 2001-04-04. Bengt Dahlgren AB, VI, Sveriges verkstadsindustrier och Industrilitteratur AB, Sweden. In Swedish.

Swedish EPA (1995a). Jordens klimat förändras, en analys av hotbild och globala åtgärdsstrategier. (The climate is changing, an analysis of the threatening pictures and global actions). The Climate Committee, Swedish Environmental Protection Agency, report 4457.

Swedish EPA (1995b). Offentlig upphandling med miljöhänsyn (Public procurement with environmental consideration) Swedish Environmental Protection Agency, report 4507.

Swedish EPA (1999). System med indikatorer för nationell uppföljning av miljökvalitetsmålen (System with indicators for follow up on the Environmental Quality Objectives) Swedish Environmental Protection Agency, report 5006.

Swedish EPA (1999). Frisk luft: Miljökvalitetsmål 1 (Clean air: Environmental quality objective 1) Swedish Environmental Protection Agency, report 4995.

Swedish EPA (1999). Ingen övergödning: Miljökvalitetsmål 6 (No eutrophication: Environmental quality objective 6). Swedish Environmental Protection Agency, report 4999.

Swedish EPA (1999). Bara naturlig försurning: Miljökvalitetsmål 7 (Natural acidification only: Environmental quality objective 7) Swedish Environmental Protection Agency, report 5000.

Swedish EPA (1999). Skyddande ozonskikt: Miljökvalitetsmål 14 (A protective ozone layer: Environmental quality objective 14) Swedish Environmental Protection Agency, report 5002.

Swedish EPA (1999). Begränsad klimatpåverkan: Miljökvalitetsmål 15 (Limited influence on climatic change: Environmental quality objective 15) Swedish Environmental Protection Agency, report 5003.

Swedish EPA (2000). Naturmiljön i siffror 2000. (The environment in figures 2000) Swedish Environmental Protection Agency and Statistics.

Söderberg, J. (1993). Att upphandla byggprojekt (The procurement of building projects). Studentlitteratur, Lund, Sweden. In Swedish.

The Swedish Construction Federation (2002). Fakta om byggnadet 2001 (Facts about construction 2001). The Swedish Construction Federation CA tryck/Stockholm Offset AB, Stockholm, Sweden. In Swedish.

Trinius, W., Borg, M. (1999). Influence of allocation and valuation on LCA results. International Journal of low energy and sustainable buildings, 1. ISSN 1403-2147.

Treloar, G., Love, P., Holt, G. (2001). Using national input-output data for embodied energy analysis of individual residential buildings. Construction management and economics, 19, 49-61.

Uppenberg, S., et al. (2001). Miljöfaktabok för bränslen, resursförbrukning och emissioner från hela livscykeln (Environmental facts of fuels, resource use and emissions from the total life cycle). 2nd ed, Swedish Environmental Research Institute (IVL), Report B1334A-2, Stockholm. In Swedish.

Warner, K.E., Ryall, C. (2001). Greener purchasing activities within UK local authorities. Journal of Eco-Management and Auditing, 8, 36-45.

Weber, R.P. (1990). Basic Content Analysis. Quantitative Applications in the Social Sciences. Sage Publications, Inc., California, U.S.

Westin, T. (1989). Kostnadskalkylering med LCC-modell, tillämpning för byggprocessens olika skeden (Cost apprasial with LCC model, applied in the different phases of a building project). PhD thesis. Institutionen för byggnadsekonomi och byggnadsorganisation, Royal Institute of Technology, Stockholm, Sweden. In Swedish.

Wahlström, Å., Olsson-Jonsson, A., Ekberg, L. (2001). Miljöpåverkan från byggnaders uppvärmningssystem [Environmental impact from buildings heating systems]. SP Sveriges provnings och forskningsinstitut, EFFEKTIV report nr 2000:01, Borås, Sweden. In Swedish.

Wineman, J. (1985). New Developments in Office Setting Research. In Proceedings: The Architectural Research Centers Consortium Workshop on the Impact of the Work Environment on Productivity held at Washington, D.C. April 17-19, 1985. Dolden, M. E. et al (eds). Washington D C: Architectural Research Centers Consortium, Inc. U.S.

Wong, C,H., Holt, G.D., Cooper, P, A. (2000). Lowest price or value? Investigation of UK construction clients' tender evaluation process. Construction management and economics 18, 767-774.

World Commission on Environment and Development (1987). Our common future. Oxford, UK.

Yin, R.K. (1994). Case Study Research. Design and Methods. 2nd Ed. Applied Social Research Methods Series, 5. Sage Publications, Inc. U.S.

Zetterberg, L., Finnveden, G. (1997). Värderingsmetoder för bedömning av den totala miljöpåverkan från produkter och tjänster, en översikt [Evaluation methods for assessment of the total impact from products and services, an overview]. Swedish environmental research institute (IVL), report B1262, Stockholm, Sweden. In Swedish

Öfverholm, I. (1984). Livscykelkostnader för byggnader (Life cycle costs for buildings). Statens råd för byggnadsforskning, Stockholm, Sweden. In Swedish.

9 APPENDICES

APPENDIX A

ENVIRONMENTAL REQUIREMENTS

Categories	**Concepts / requirements**	**Influence on construction costs**			**Influence on environmental impact reduction**		
		Unchanged	**Reduced**	**Increased**	**Unchanged**	**Less**	**Worse**
Building and demolition waste	• Waste separation	X		X		X	
	• Fractions of waste	X		X		X	
	• Routines	X				X	
	• Waste management						
	• The priority ladder	X		X		X	
	• Prohibition of deposition	X		X		X	
Materials	• Product declaration	X				X	
	• Selection of materials according to the priority ladder	X	(X)	(X)		X	
	• Locally produced materials			X	X	X	X
	• List of Restricted Chemical Substances and Observation List	X		(X)		X	
	• Decomposition time	(X)		X	(X)		X
	• Renewable materials	(X)		X	X	X	X
	• Materials to avoid	X		(X)		X	
	• Recycled materials	X	(X)			X	
	• Materials with a long life length	X	X			X	
	• Eco-labelled materials	(X)		X	X	X	X
Ecological aspects	• Possibilities for waste separation in the finished house	X				X	
	• Water flow control for sanitary	X				X	
	• Separate sanitary line from toilets to collect urine			X	X		
Construc-tion	• Measures in order to prevent generation of waste		X			X	
	• Wrapping	(X)	X			X	
	• Facilitate future recycling			X		X	
Misc.	• Documentation	X				X	
	• Energy sources		X			X	
	• Transports		X			X	
	• Environmentally classified fuels	X				X	

The notations in the table are:

X assessed as the most probable outcome
(x) alternative outcome, less probable than X

One concern when developing and implementing environmental strategies in the building process is cost increases. However, in an initial stage, there are likely to be increases for planning and design of projects and for development of new working methods and alternative materials. When routines are established and if competition within the material industry is present these costs will remain initial. To examine the stipulated environmental requirements possible effect on preventing more cost effective construction processes and on environmental impact reduction following definitions were used:

Environmental impact arise when,
- resources are used
- air, water or land are exposed to hazardous substances or emissions

a reduction is in both cases aimed

More cost effective methods includes a change in the process which

- gives the same result with a reduced use of inputs
- gives a better result with the same amount of inputs or

a combination of these two

In general terms the result is expressed in a physical unit (for example m^2) and the inputs are labour, equipment, materials, construction methods and site management expressed in monetary terms.

The assessment of the environmental requirements effect on efficiency improvements and possibility of reducing environmental impact is based on a discussion of the possible outcome of stipulation in procurement. This assesses the environmental requirements in relation to their expected influence on construction costs and their possibility of reducing environmental impact from a life-cycle perspective.

Environmental requirements that reduces environmental impact and construction costs:
- Measures in order to prevent generation of waste (prefabrication, customised materials)
- Reduced amount of wrapping
- Coordinated transports

The first three requirements reduce non-value changes in construction and are likely to give cost reductions. Prefabrication for instance reduces labour costs on site, customised material and less wrapping reduces waste and therefore also transports.

Environmental requirements that reduces environmental impact and do not effect construction costs:
- Flexible energy systems
- Selection of materials according to the priority ladder
- List of Restricted Chemical Substances and Observation List
- Product declaration
- Recycled materials
- Durable materials
- Documentation of materials used
- Environmentally classified fuels
- Waste separation on site
- Routines for waste treatment on site
- Materials to avoid usually considered to be hazardous
- Water flow control for sanitary

Other requirements will have a negative effect either on costs or on possibilities of reducing environmental impact.

Many requirements concern the selection of materials. The most important aspect should be to avoid use of materials that include hazardous substances/components. The environmental impacts are difficult to estimate if not using LCA methods and even if LCA is used results between different tools applied varies. To avoid restricting the development of improved materials and not to limit the competition between manufactures requirements concerning selection of material should only include avoiding hazardous substances.

APPENDIX B

LULEÅ
TEKNISKA
UNIVERSITET

Division of Steel structures
Eva Sterner

1999-06-01

Life-cycle cost in the building sector

This survey is sent to you with the anticipation that you will able to contribute with some of your experiences and thoughts about the use of life-cycle costs as basis for investment decisions.

The survey is one part of a thesis project preformed at Luleå University of Technology. Earlier environmental requirements stipulated by clients have been identified, analysed and presented in a Licentiate in Engineering Thesis. The project focuses on environmental aspects and life-cycle costs in procurement. One aim is to develop a model integrating environmental impact and costs to be used in tender evaluation. This is an area of great immediate interest where practical knowledge to large extent still is missing and your experiences can be of great importance for the continuation of the research.

The survey is sent to all clients' part of the clients organisation, Byggherreföreningen

Yours sincerely,

Eva Sterner

LULEÅ TEKNISKA UNIVERSITET

Survey about consideration of life-cycle costs in procurement of buildings

Buildings are expensive to develop and construct and new efficient methods reducing costs should be aimed for. One approach is to base investment decisions on a life-cycle approach which also is of great importance when future environmental problems caused by construction, operation, maintenance and demolition are to be limited.

Practical models on how to consider life-cycle costs in procurement and tender evaluation are assumed to be limited in use. This survey attempt to assemble client's practical experiences and thoughts about life-cycle cost estimations.

Responses are preferably received before **1999 - 06 – 16**

Company : ………………………………………………………………………………………....
Name : ……………………………………………………………………………....
Phone : ………………………………………………………………………………………...
Fax : ……………………………………………………………………………………...

Question 1 Are you using any type of LCC assessment model to evaluate investment decisions?

Yes ☐

No ☐

If no, why?

If no, continue to question nr **6**

Question 2 In which phase of a project is LCC assessments made?

Idé phase	☐	Design phase	☐
Planning	☐	Procurement	☐

Question 3 Which cost elements are included in the LCC assessment?

Investment cost	☐	Alteration costs	☐
Energy cost	☐	Cleaning	☐
Maintenance cost	☐		

Other cost elements?

Question 4 Which cost elements do you consider most significant in an LCC evaluation if an entire building is studied?

Question 5 Specify if there are costs of importance which are not possible to include in a calculation, if that is the case what is the reason for not including them?

Question 6 Which are the constrains when calculating LCC?

The models are too complex	☐
The models focus on incorrect cost elements	☐
Input data to perform the calculations are missing	☐
	☐

Other constraints?

Question 7 Do you have any experience in how precise the LCC estimation result is?

Correct ☐

Mainly correct ☐

In some ways correct ☐

Not correct ☐

Question 8 Is it possible for you to base tendering on LCC?

Yes ☐ No ☐

If no, why?

Question 9 If a sufficient enough LCC model were available would you use LCC as a parameter in tendering?

Yes ☐ No ☐

If no, why?

Question 10 Which parameters do you consider important for the development of a LCC model for procurement, place in order of precedence, 1=most important 5=least important?

Investment cost ☐ Alteration ☐

Energy use ☐ Cleaning ☐

Maintenance ☐

Other parameters?

Additional questions to the survey about consideration of life-cycle costs in procurement of buildings

A while ago you answered a survey concerning LCC. The result has now been evaluated and 12 clients are selected to answer some additional questions concerning the calculation models used.

Question 1 Do you use LCC analysis models to calculate the LCC for an entire project or for building materials/elements or installation systems?

Question 2 How advanced is the model? For example which parameters are included is the calculations computer based or performed manually, is increases in price considered?

Question 3 From where is future cost data for maintenance, operation etc. collected?

Question 4 Are sensitivity analysis used to simulate uncertainties in the different parameters, if so, which parameters are varied?

Question 5 When LCC is used for procurement, which parameters are included?

Question 6 Who perform the LCC calculation in the design phase and what type of model is used?

Table B 1 Response to questionnaire, questions 1-3

Company	Question 1		Question 2				Question 3					
	Yes	No	Idea	Planning	Design	Procurement	Investment	Energy	Maintenance	Alteration	Cleaning	Other
1	X			X	X		X	X	X		X	
2	X			X			X	X	X	X		
3	X				X		X	X	X	X		
4	X		X	X	X	X	X	X	X	X		
5	X				X	X	X	X	X			
6	X				X		X	X	X			
7	X				X		X	X	X			
8	X		X	X	X	X	X	X	X	X		
9	X			X	X	X	X	X	X		X	
10												
11		X										
12	X		X	X		X	X	X	X	X		X
13		X										
14	X			X	X	X	X	X	X		X	
15	X				X		X	X			X	
16												
17	X		X	X	X		X	X	X			X
18	X		X	X	X	X	X	X	X	X		X
19	X		X		X	X	X	X	X			X
20		X										
21		X										
22		X										
23	X				X		X	X	X			
24	X		X	X	X	X	X	X	X			
25	X		X	X	X		X	X	X	X	X	
26		X										
27	X				X		X	X	X	X		

Table B1 (*continued*)

Company	Question 1		Question 2				Question 3					
	Yes	No	Idea	Planning	Design	Procurement	Investment	Energy	Maintenance	Alteration	Cleaning	Other
28	X		X		X		X	X		X		
29		X										
30	X			X	X		X	X	X			
31	X		X	X	X		X		X	X		
32	X				X	X		X	X	X		
33		X										
34	X			X	X	X	X	X	X	X		
35		X										
36	X				X		X	X	X			
37	X				X	X	X	X	X			
38		X										
39		X										
40	X					X	X	X	X	X		
41	X		X	X			X	X	X	X		
42	X		X		X		X	X	X	X		
43		X										
44	X		X		X		X	X	X			
45	X			X	X		X	X	X	X		
46	X			X	X		X	X	X	X		X
47		X										
48		X										
49	X		X	X			X	X	X	X		
50	X			X	X	X	X	X	X	X	X	X
51	X			X	X		X	X	X		X	
52												
53												
	35	***14***	***14***	***20***	***30***	***14***	***34***	***34***	***33***	***19***	***7***	***5***

Table B 1 Continuation of response to questionnaire survey, questions 4-7

Company	Question 4	Question 5	Question 6				Question 7			
			Too complex	Inaccurate	Input data	Experience	Correct	Mainly	Somewhat	Not correct
1	M		X					X		
2	I,E					X				
3	Montering					X		X		
4	I,M,O	Productivity			X	X			X	
5	I,E,O	Reorganisations							X	
6	E				X			X		
7										
8			X		X					
9	E,I	Interruptions				X				X
10						X		X	X	
11						X				
12	M		X					X		
13			X		X	X				
14	E,M,C				X					
15	E							X		
16										
17	I,M,O	Customer			X	X				
18	E,M	Clearing work			X	X		X		
19	I,O,M,Ke	Maintenance								
20						X				
21										
22			X		X	X				
23	I	Environment			X					
24			X			X			X	
25	A	Astethics, functions								
26					X				X	
27	O, M									

Table B1 (*continued*)

	Question 4	Question 5	Question 6			Question 7				
Company			Complex	Inaccurate	Input data	Experience	Correct	Mainly	Somewhat	Not correct
28	I,O	Time							X	
29						1				X
30	M, E,I					X		X		
31	M,					X		X		
32	I,E				X	X			X	
33			X							
34	I,E,M	Salvage value			X		X			
35						X				X
36	I,E,M		X					X		
37	I,E,M	Interruptions			X	X			X	
38						X				
39			X			X				
40	I,O				X					X
41	I,O,M	Environment, Governmental regulations	X					X		
42	E	Work environment	X		X	X			X	
43					X	X				X
44	E,M	Alteration	X		X	X				
45	O,M,A,C				X	X			X	
46		Salvage value			X					X
47										
48						X			X	
49					X	X		X	X	
50	I				X			X		
51					X	X			X	
52										
53										
										0

Table B 1 Continuation of response to questionnaire survey, questions 8-10

	Question 8		Question 9		Question 10				
Company	Yes	No	Yes	No	Investment	Energy	Maintenance	Alteration	Cleaning
1	X		X		3	2	1	5	4
2	X		X		1	2	5	4	3
3	X		X		3	4	2	1	5
4	X		X		1	5	5	5	5
5	X		X		1	2	3	4	5
6	X		X		2	1	3	5	5
7	X		X						
8	X		X		1	2	3	4	5
9		X	X		1	2	3	5	4
10	X		X		2	3	1	4	5
11	X		X		1	3	2	5	5
12	X		X		2	3	1	4	5
13	X		X		3	1	5	2	4
14	X		X		1	2	3	5	4
15	X		X		2	1	3	5	4
16	X		X		1	4	2	3	5
17	X		X		3	1	2	4	5
18	X		X						
19		X	X		1	2	3	4	5
20	X		X						
21	X		X		4	1	2	3	5
22	X		X		1	3	2	5	4
23	X		X		1	2	3	4	5
24	X		X		2	4	3	1	5
25		X	X		1	2	3	4	5
26	X				3	1	2	4	5
27	X		X		3	2	1	4	1
28	X		X		1	3	2	5	4
29	X		X		4	2	1	3	5
30	X		X		1	3	2	4	5
31	X		X		3	4	1	2	5

Table B1 (*continued*)

Company	Question 8		Question 9		Question 10				
	Yes	No	Yes	No	Investment	Energy	Maintenance	Alteration	Cleaning
32	X		X		1	2	3	4	5
33	X		X		1	2	2	5	2
34	X		X		3	1	2	4	5
35	X		X		1	3	2	4	5
36	X		X		1	3	2	4	5
37	X		X		3	2	1	4	5
38	X		X		3	1	1	3	1
39	X		X		5	4	2	1	3
40	X		X		3	1	2	4	5
41	X		X		1	3	2	4	5
42	X		X		1	3	2	4	5
43	X		X		3	2	1	4	5
44	X		X		3	1	1	3	1
45	X		X		5	4	2	1	3
46	X		X		1	2	3	5	5
47	X		X		1	2	3	4	5
48	X		X		2	1	3	4	5
49	X		X		1	2	3	4	5
50	X		X		3	1	2	4	5
51	X		X						
52	X		X		5	3	4	4	
53	X		X		1	2	3	4	5
	50	***3***	***52***		***101***	***112***	***115***	***186***	***212***

Table C 1 Operation costs for Greenzone buildings

			GZ 1		GZ 2		GZ 3	
	unit	Cost per unit	m^2	SEK/m^2	m^2	SEK/m^2	m^2	SEK/m^2
Administration	SEK/m^2	15	2430	36450	445	6675	251	3765
Insurance	SEK/m^2	7.2	2430	17496	445	3204	251	1807
Care-taking incl. repairs								
Building	SEK/m^2	3,5	2430	8505	445	1558	251	879
Installations	SEK/m^2	12	2430	29160	445	5340	251	3012
Land	SEK/m^2	7.5	2430	18225	445	3338	251	1883
Total				55890		9836		5773
Refuse disposal	SEK/m^2	5.2	2430	12636	445	2314		16500*
Cleaning								
Joint areas	SEK/m^2	20	2153	43060	222	4440	49	980
Offices	SEK/m^2	165	169	27885	232	38280	3	495
Staff areas	SEK/m^2	368	108	39744	24	8832	21	7728
Restaurant	SEK/m^2	165					178	29370
Total				110689		51552		38573
Water	m^3	14.5	600*	8700	300*	4350	1200*	17400
Electricity	kWh	0.464	263771	122390*	494317	229363*	353083	163831*
Sum (SEK/year)				364251		297458		241876
SEK/m^2, year				109		504		780
PV (SEK/m^2)		21.482		2340		10830		16760

* Values obtained from the clients, others are unit values from Repab (2001).

Table C 2 Maintenance Cost, GZ1

	Maint. cost (unit rate)	Proportion replaced	Quantity (m^2)	Tot. cost (SEK)	Replacement interval (year)	PV (SEK)	t	Present value factor $PV_f=(1+0,04)^{-t}$								
							t	12	15	20	24	30	36	40	45	48
							PV_f	0,6246	0,5553	0,4564	0,3901	0,3083	0,2437	0,2083	0,1712	0,1522
Interior																
f:clinker re-joint	151	100%	177	26652	15	27579			14800			8217			4563	
f:pine rub, 3 layer	129	100%	252	32508	15	33639			18052			10022			5565	
f:exposed concrete	0	100%	2796	0		0										
f:plastic carpet	195	100%	230	44850	30	13827						13827				
w:paint gypsum	37	100%	247	9139	12	12891		5708			3565		2227			1391
w:tiles re-joint	146	100%	21	3066	15	3173			1703			945			525	
w:paint plaster	37	100%	1647	60939	12	85961		38062			23772		14851			9275
w:paint wood panel	37	100%	172	6364	12	8977		3975			2483		1551			969
c:paint gypsum	170	100%	102	17340	12	25433		10831			6764		4226			3612
c:paint wood wool	85	100%	2798	237788	12	335423		148522			92761		57949			36191
c:exposed concrete	0		225	0		0										
w&d:wood w oil	104	100%	92	9568	15	6951			5313						1638	
w&d:wood w change	1600	100%	92	147200	30	45382						45382				
w&d:paint steel	540	100%	7	3780	10	2513				1725				787		
w&d:dbl glas	11090	100%	4		60	0										
w&d:steel frame	7760	100%	7	54320	60	0										
w&d:wood door	2500	100%	27	67500	40	14060								14060		
w&d:entrance	6490	100%	3		60	0						0				
Saintary equipment	6030	100%	7	42210	30	13013						13013				
Exterior																
w: wood panel	70	100%	937	65590	12	66935		40968					15984			9983
r:green roof	0	100%	1720	0	50	0										
r:detalis, 15%	75	15%	1720	19350	30	5966						5966				
r:latern light (18 lights)	37863	100%	19	719397	50	0										
Heating																
pump, boiler etc					25	99134										
Total Maintenance						800857										
SEK /m^2						239										

Table C 3 Maintenance Cost, GZ2

	Maint.cost	Proportion	Quantity	Tot.cost	Interval	PV	t	Present value factor PVf=$(1+0,04)^{-t}$									
								10	12	15	20	24	30	36	40	45	48
	(unit rate)	replaced	(m^2)	(SEK)	(year)	(SEK)	PV_f	0,6756	0,6246	0,5553	0,4564	0,3901	0,3083	0,2437	0,2083	0,1712	0,1522
Interior																	
f:marble/granite rub	495	100%	439	217305	40	45265									45265		
f:exposed concrete	0	0	66,3	0	0	0											
w:Painting/gypsum	37	100%	375	13875	12	19572			8666			5413		3381			2112
w:Tiles re-joint	146	100%	27	3942	15	4079				2189			1215			675	
w:marble/granite rub	495	100%	17	8415	40	1753									1753		
w:cold storage elem.	9480	100%	12	113760	20	75616					51920				23696		
w:change	1370	0%	65	0	0	0											
c:Painting/gypsum	170	100%	283	48110	12	67864			30050			18768		11724			7322
c:acoustic panels	56	5%	192	537,6	12	758			336			210		131			82
w&d:wood wind oil	104	100%	11	1144	12	1614			715			446		279			174
w&d:entrance door	6490	100%		0	60	0											
w&d:paint 2 layers	540	100%	7,2	3888	10	6266		2627			1774		1199			666	
w&d:single steel doors	4180	100%	7	29260	60	0											
w&d:wood doors	2500	100%	11	27500	30	0											
Sanitary equipment.	6030	100	2	12060	30	3718								3718,098			
Exterior																	
w:wood panel	70	100%	569	39830	12	56184			24878			15538		9707			6062
r:green roof	0	100%	604	0	50	0											
r:roof detalis, 15%	75	15%	590	6637,5	30	2046							2046				
r:latern skylight	37836	100%	4	151344	50												
Heating																	
pump,boiler etc.						31707											
Total Maintenance						316442											
SEK/m²						536											

Table C 4 Maintenance Cost, GZ3

	Maint. Cost (unit rate)	Proportion replaced	Quantity (m^2)	Tot. cost (SEK)	Interval (year)	PV (SEK)	n / PV_f	12 / 0,6246	15 / 0,5553	24 / 0,3901	30 / 0,3083	36 / 0,2437	40 / 0,2083	45 / 0,1712	48 / 0,1522
Interior															
f:ceramic tiles	495		298	147510	40	30726							30726		
f: exposed concrete	0		0	0	0	0									
w:Painting gypsum	37	100%	174	6438	12	9081		4021		2511		1569			980
w:tile re-joint	146	100%	232	33872	15	35051			18809		10443			5799	
w:cold storage elem.															
Change	1370	100%	10	33872											
c:Gypsum board spec.	170	100%	284	48280	12	68104		30156		18834		11766			7348
c:acoustic ceiling panels			17												
c:cold storage			8,8												
c:metal strip ceiling															
w&d:wood window change	1600	100%	12	19200	30	5919					5919				
w&d:wood window oil	104	100%	12	1248	12	1760		780		487		304			190
w&d:entrance door	6490	100%	2		60	0									
w&d:paint 2 layers	540	100%	2	1080	12	1523		675		421		263			164
w&d:wood doors, interior	2500	100%	14	35000	40	7291							7291		
Sanitary equipment	4	100	6030	24120	30	7436					7436				
Exterior															
w:wood panel	70	100%	187	13090	12	18713		8176		5106		3190			2241
r:green roof	0	100%	340	50	0	0									
r: roof detalis, 15%	75	15%	310	3487,5	30	1075					1075				
r:latern skylights	38736	100%	2	77472											
Heating															
pump*,boiler etc						23578									
Total Maintenance						210257									
SEK/m²						678									

Present value factor $PV_f=(1+0,04)^{-n}$

f:floor w: wall c:celing w&d: windows and doors r:roof

Table C 4 Maintenance Cost, ventilation and heat supply system

	Quantity	Maint. cost.	Proport.	Interval	PV t	0,8219 5	0,6756 10	0,5553 15	0,4564 20	0,3751 25	0,3083 30	0,2534 35	0,2083 40	0,171 45	0,1407 50
Heat generating system															
Primary pump (2 compressors)*															
compressor*	2	30 000	1	25	15474					11253					4221
Boiler, electricity	1	65 000	1	20	43206				29666				13540		
Total					**58680**				50204				22913		
Solar panel	1	110 000	1	20	**73117**										
Ventilation equipment															
Heat exchanger															
Renovation fan unit	1	28000	1	20	18612				12779				5832		
Renovation fan motor	3	3020	1	20	2007				1378				629		
Heat batteries	3	6500	1	30	2004						2004				
Total					**22623**										

Allocation of the heat systems maintenance cost:
Cost for the solar panel is allocated to GZ1
Other costs (58680+22623) are allocated with the energy consumption as a base

	Energy (kWh)	PV maintenance	Solar panel	Sum
GZ1	88596	26017	73117	99134
GZ2	108507	31708	0	31707
GZ3	79221	23578	0	23578

APPENDIX D

- EMISSIONS FROM DIFFERENT ENERGY SOURCES, mg/kWh

	Hydro power[1]	Wind power[1]	Nuclear pow.	Sw. mix[2]	Oil[3]	Natural gas[3]	Firewood[4]	Pellet[5]
NO_x	6,48	18	9,7	54	396	111,6	648	691,2
SO_x	1,368	15,12	9,4	46,8	169,2	12,24	190,8	194,4
CO	6,84	50,4	2,3	64,8	136,8	36	9000	9720
NMVOC	1,26	4,32	1,6	10,44	75,6	13,32	4680	4680
CO_2	5040	6480	3100	28231	342000	223200	13680	5760
N_2O	0,023	0,029	0,033	2,556	2,3	2,196	4,68	9
CH_4	5,58	6,48	12	176,4	18,7	43,2	684	792
NH_3	0,0083	0,007	0,069	0,792	0,432	n.a	9	13,68

The inventory data, here converted to mg/kWh, are from Uppenberg et al. (2001) based on:
[1] Data from Sydkraft (2000)
[2] Total environmental impact for electricity in the Swedish net during 1999, calculated by Uppenberg et al. (2000)
[3] Total environmental impact per produced kWh in a domestic boiler based on data from Sydkraft (2000) and Boström et al. (1998)
[4] Total environmental impact per produced kWh in a domestic boiler based on data from Vattenfall (1996) and Boström et al. (1998)
[5] Total environmental impact per produced kWh in a domestic boiler based on data from Edholm (1996) and Boström et al. (1998)

- ENVIRONMENTAL IMPACT CATEGORIES (g/kWh) AND WEIGHTED IMPACT, WI

	Hydro power	Wind power	Nuclear power	Sw. electricity	Oil	Natural gas	Firewood	Pellet	District heat
GWP	5,164	6,625	3,362	32,728	343,106	224,788	29,495	25,182	134,93
AP	0,006	0,028	0,016	0,086	0,447	0,090	0,661	0,704	0,47
EP	0,009	0,024	0,013	0,076	0,536	0,151	0,908	0,983	0,412
[1]POCP	0,0005	0,0018	0,0007	0,0043	0,0314	0,0055	1,9469	1,9469	0,0140
WI	8,69	19,59	10,49	71,98	579,83	279,41	2024,67	2044,66	340,85

[1] POCP = 0,416*NMVOC (Heijungs et al., 1992)

- ENVIRONMENTAL IMPACT FROM DISTRICT HEATING

Energy source	%	
Oil	11	Emission data from Sydkraft (2000) and Boström et al. (1998)
Coal	8	Emission data from ExternE (1997) and Boström et al. (1998)
Forest fuel	28	Emission data from Vattenfall (1996) and Boström et al. (1998)
Pine oil	3	Emission data from Åhman (1999) and Boström et al. (1998)
Peat	4	Emission data from Mälkki et al. (1997) and Boström et al. (1998)
Waste	10	Emission data from Finnveden et al. (1994)
Industrial waste heat	7	No environmental impact (100% allocated to the producing industry)
Electricity to boilers	3	Emission data based on IVL (1999)
Heat pumps	13	The efficiency factor for heat pumps is set to 3,0
Natural gas	8	Emission data from Boström et al. (1998)
Other sources	8	Represent an average value.

Per cent distribution given by FVF (Fjärrvärmeföreningen)

- EMISSIONS * (mg/kWh)

	Oil	Coal	Forrest fuel	Wood oil	Peat	Waste	Electricity	Natural gas
NO_x	486	281	334,8	1620	298,8	201	54	176
SO_x	756	284	144	1440	518,4	201	46,8	2,1
CO	68,4	166	1080	79,2	338,4	101	64,8	36
NMVOC	46,8	8,3	82,8	50,4	33,84	5,4	10,44	4
CO_2	324000	381600	10080	86400	352800	82800	28231	202680
N_2O	2,16	46,8	16,92	2,088	33,48	13,68	2,556	1,8
CH_4	15,48	4320	16,92	25,92	612	0	176,4	7,6
NH_3	2,376	6,8	8,64	4,32	3,96	4,32	0,792	0

* Based on an inventory by Uppenberg et al. (2001) and represent the impact from resource extraction to combustion in a heat power plant.

- ENVIRONMENTAL IMPACT CATEGORIES (g/kWh) AND WEIGHTED IMPACT, WI FOR DISTRICT HEATING

	0il	Coal	Forrest fuel	Pine oil	Peat	Waste	Industrial w.h	El. to boiler	Heat pumps	Natural gas	Other	Total
% /100	0,110	0,080	0,280	0,030	0,040	0,100	0,070	0,030	0,130	0,070	0,08	1,0
GWP	324,995	486,828	15,681	87,592	376,031	87,041	0,000	32,728	32,728	203,398	124,93	134,928
AP	1,101	0,493	0,395	2,582	0,735	0,350	0,000	0,086	0,086	0,125	0,44	0,470
EP	0,665	0,404	0,483	2,203	0,418	0,287	0,000	0,076	0,076	0,238	0,38	0,412
POCP	0,019	0,003	0,034	0,021	0,014	0,002	0,000	0,004	0,004	0,002		0,014
											WI	340,850

- ENVIRONMENTAL IMPACT CATEGORIES (g/kWh) AND WEIGHTED IMPACT, WI FOR DIFFERENT ENERGY TYPES

	Hydro power	Wind power	Sw. electricity	Oil	Natural gas	Firewood	Pellet	District heat
GWP	5,164	6,625	32,728	343,106	224,788	29,495	25,182	122
AP	0,006	0,028	0,086	0,447	0,090	0,661	0,704	0,458
EP	0,01	0,02	0,08	0,54	0,15	0,91	0,98	0,40
POCP	0,001	0,002	0,004	0,003	0,006	1,947	1,947	0,014
WI	8,688	19,595	71,979	579,831	279,415	2024,600	2044,657	340,850

- ENVIRONMENTAL IMPACT IN CATEGORIES FOR THE CASE STUDY BUILDINGS

		GZ1	GZ2	GZ3	Ref 1 (El)[1]	Ref 1 (DH)[2]	Ref 2	Ref 3
Energy use	kWh/m^2	79	838	1139	104	141	1017	1452
LC energy use	kWh/m^2	3950	41900	56950	5200	7050	50850	72600
GWP	kg/m^2	26,17	277,59	1836	170,18	860,10	1664,21	2376,04
AP	kg/m^2	0,11	1,16	1,58	0,45	3,23	4,38	6,25
EP	kg/m^2	0,10	1,02	1,39	0,39	2,83	3,85	5,50
POCP	kg/m^2	0,01	0,08	0,10	0,02	0,10	0,22	0,32
WI	kg/m^2	77,37	820,76	2602,12	374,28	2275,95	3660,02	5225,52

[1] El: Electricity; [2] DH: District Heating

PAPER I

GREEN PROCUREMENT OF BUILDINGS: A STUDY OF SWEDISH CLIENTS' CONSIDERATIONS

Sterner, E. (2002) Published in Construction management and economics, Vol 20, 2002, page 21-30

Construction Management and Economics (2002) **20**, 21–30

'Green procurement' of buildings: a study of Swedish clients' considerations

EVA STERNER*

Division of Steel Structures, Luleå University of Technology, 97187 Luleå, Sweden

Received 12 October 2000; accepted 17 August 2001

The results of a survey show that both public and private building clients in Sweden, to varying extents, include environmental requirements in their procurement documents. The requirements identified have been classified into six categories primarily related to building and demolition waste, building material, contractors' environmental work, ecological aspects, construction work and other. One conclusion is that requirements regarding the separation of waste and a contractor's environmental policy are considered important, since they are stipulated in the majority of projects. Another finding is that requirements related to operation and especially to energy use are not considered sufficiently. Structured interviews were conducted with three of the clients who at that time of the survey had developed the most complete procurement documents with regard to environmental requirements. The aim of the interviews was to investigate how the stipulation of requirements, the evaluation of environmental aspects and the verification of environmental requirements were carried out. The conclusion drawn is that Swedish clients find the stipulation of requirements relatively uncomplicated, but find the evaluation of environmental impact, mainly related to selection of materials, problematic due to inadequate evaluation models.

Keywords: Construction, environmental requirement, sustainable construction, procurement

Introduction

The environmental agenda has become increasingly important for the Government in Sweden, and is reflected in growing legislation to counter negative impacts on the environment. One of the primary targets is the building sector, where there is believed to be considerable scope for improvement. Environmental concern has broadened to include fundamental questions about sustainability, and so the concept of sustainable construction has evolved to cover ecological, economic, social and cultural responsibilities. Ecological sustainable construction implies a process that starts in the planning stage and continues after the construction team has left the site (Hill and Bowen, 1997). Responsibilities include managing the serviceability of a building during its lifetime, its possible deconstruction and the recycling of resources to reduce the waste stream associated with demolition. Choice of material, technical solutions, construction methods, and types of services installation also affect total environmental impact, which is to be minimized. Clients and developers have a responsibility for the development of environmentally aware processes by stipulating the requirements under which projects are designed. The client's proficiency in formulating, evaluating and verifying relevant environmental requirements to include these aspects is crucial to this development. The requirements must be stipulated in a way that enables them to be fulfilled by the contractor and verified by the client. Environmental considerations inevitably require clients to modify their project management practices.

This paper reviews a recent study and its results in the area of the environmental requirements for reducing environmental impact from building projects. The objective of the study, via a questionnaire survey, was to identify the environmental requirements that clients have stipulated in their procurement of building projects, and to examine some of those clients' experiences

*e-mail: eva.sterner@ce.luth.se

Construction Management and Economics
ISSN 0144–6193 print/ISSN 1466-433X online © 2002 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/01446190110093560

of green procurement, i.e. procurement including environmental requirements.

Overview of environmental improvements by the Swedish building sector

The building sector in Sweden suffered a recession throughout much of the 1990s. During that period the government vigorously pursued the environmental agenda and prepared a new code in which 15 environmental objectives were identified (Ministry of the Environment, 1998). The built environment in general and the construction sector in particular were seen to be in need of fundamental change aimed at improving environmental load, because of their impact on several of the environmental objectives. To stimulate investment in the environmental improvement of buildings the Swedish state will, over the 5-year period from 1997, have invested ε109 million. The funds are used to subsidize job-creating investments in the ecological sustainable renovation of buildings and plant, and to stimulate investments in waste management, renovation, demolition, water supply and sewerage. However, compared with the annual cost of maintenance and repair of buildings, which in 1999 was estimated to be ε5.8 billion (Swedish Building Industry, 2000), the investment programme is rather modest.

The Ecocycle Commission, appointed by the Swedish government in 1993, has examined producer responsibility for products. The Commission's remit was to develop a strategy for adapting the goods used in the community to the needs of a closed-loop system. This was done to determine the responsibility that should be borne by producers of different goods, namely those who produce, import or sell a product or item of packaging. Producers also include those whose work generates waste requiring special measures for disposal.

In response to the Ecocycle Commission's work, the Ecocycle Council for the Building Sector, which includes developers, property owners, architects, consultants to the building industry and the building materials industry, was established in 1994. One of its undertakings is to limit future environmental problems through taking action at the early stages of product development, planning and project design. The Ecocycle Commission's goals primarily included products/materials and waste streams, whereas little attention was devoted to problems associated with energy used for heating, ventilation or maintenance of buildings. This influenced the construction sector's approach to addressing the environmental agenda, focusing effort on waste streams and materials. As the environmental work has progressed, additional priority areas have been included and both the Ecocycle Commission and the Ecocycle Council have had a significant bearing on the progress of environmentally aware construction in Sweden. The Ecocycle Council (2000) has ranked the most significant environmental aspects related to external impact from buildings, based on lifecycle assessment (LCA) analysis, as follows.

1. Energy use for space heating
2. Material use, including waste and transport
3. Hazardous substances

Energy use for heating

In the reports from the Ecocycle Council (2000) and from the Ministry of the Environment (2000), energy use for heating, including domestic electricity, is targeted as the primary source of environmental impact by the construction sector. The building sector uses 155 TWh annually, representing 39% of the total energy use. In another study, Adalbert (2000) examined the total energy use during the lifecycle of a building from manufacture of constituent materials through to demolition, based on Swedish conditions. One conclusion is that 70–90% of the environmental impact arises from the occupation phase, if this phase is assumed to last for 50 years and today's techniques are used. Airborne emissions, like CO_2, originate from the use of fossil fuels and are to be reduced on a national level. One approach is to replace the use of non-renewable resources, such as coal and oil products, by renewable energy sources like water, wind, sun power and biofuels. Even if the use of renewable energy is increased heavily it will not be enough to cover the total energy needs (Swedish Environmental Protection Agency, 1998). It is important, therefore, to reduce the use of primary energy. Producing buildings that are energy efficient is of primary importance.

Materials, waste and transport

The environmental impact of materials, transport and construction work is minor in relation to the impact of energy use. Nevertheless, the construction sector is responsible for a considerable part of transport and materials usage. Forty-four percent or 75 Mtonnes of the total amount of material used is related to construction, making this an obvious target (Ecocycle Council, 2000). Choice of materials and construction methods has a significant and complex impact on the environment. The long term perspective involved and the large quantity of materials and components make the total impact on the environment difficult to assess. Heavy emphasis has been placed on research into the environmental impact of building materials and assembly methods through the use of lifecycle assessment (LCA) models. LCA is a technique for analysing and assessing the environmental impact of a material, product or service throughout its lifecycle, usually from the acquisition of raw materials to waste disposal (Jönsson, 1998). It is used for the purposes of comparing the impact of different products or assessing the dominant environmental problems related to the production of goods (Tukker, 2000). The method has emerged as a legitimate means for evaluating the performance of buildings across a broad range of environmental considerations (Cole, 1999). Nevertheless, LCA has not been particularly successful in practice in the construction sector, principally because of problems concerning the availability of input data and the complexity of LCA analysis in its present form. So far, LCA has mainly been used on products (see e.g. Erlandsson, 1995; Björklund and Tillman, 1997; Gunter and Langowski, 1997). Currently there are over 40 000 products on the market, and it will take a considerable time before even a small percentage of these are assessed. Moreover, there is a need to develop instruments relevant to whole buildings for use in procurement.

Building and demolition in Sweden generate some 4–6 Mtonnes of waste annually, which represents roughly 5% of the total amount of waste generated by all sectors. During 1990 approximately 90% of the waste from building activities was deposited. Five percent was used for energy extraction and the remaining 5% was reused, mainly for landfill. The quantity of construction and demolition waste creates numerous problems (Peng *et al.*, 1997): it consumes valuable space, especially in larger cities; it generates traffic; and it might be a source of harmful leakage and other contamination. Demands from regulatory bodies, municipalities and the public have placed waste recycling operations under scrutiny, leading to pledges from Sweden's construction sector to reduce the amount of waste to municipal landfill sites by 50% between 1995 and 2000. Many construction and demolition materials have a high potential for recovery and reuse. To support this, most contractors in Sweden now separate waste. Also local markets have been established to sell secondary materials, but it is necessary that clients accept the reuse of materials and that guarantees can be given to make reuse successful. However, long term improvement is likely only if the problem can be tackled at source. In other words, waste elimination should be considered during the planning and design of new projects.

The primary arguments for clients and contractors reducing and recycling construction and demolition waste in most cases have been economic. Municipalities have increased tipping fees and applied stricter regulations regarding the kinds of waste that may be deposited, stimulating efforts to recycle. In Australia similar conditions are prevailing. McDonald and Smithers (1998) have investigated the economical aspects of waste management, and shown that implementing a waste management plan during the construction phase of a project reduces waste generated on site by 15%, with 43% less waste going to landfill because of recycling. Also, cost savings of 50% on waste handling were generated. Nevertheless the waste strategies implemented by municipalities in Sweden or Australia are not exceptional since several of EU member countries have adopted similar approaches.

The general perception of cost savings can differ between countries. In a study of the on-site sorting of construction waste in Hong Kong (Poon *et al.*, 2001) it was found that contractors had considerable reservations about adopting this approach. Their reasons, among others, were that the sorting interfered with normal construction activities, was labour intensive and, consequently, more costly. It was believed that only contract terms could set the bounds for the contractors in building waste management.

Hazardous substances

Current information about the health and environmental effects caused by chemical substances is inadequate, and clearly the risks today are more complex and difficult to assess than ever. This complicates the identification of substances that are hazardous, confuses awareness of the risks involved with manufacturing and usage, and makes the actions needed to prevent or limit their impact more difficult to identify. Annually, the building sector uses 3.5 Mtonnes of material, including hazardous substances, representing 5% of the total use by all sectors. These occur in several of our commonly used building products as cast, cement, electrical materials, adhesives, etc. The National Chemicals Inspectorate has examined the presumed effects of some chemicals on health and the environment. Inventories of chemicals considered to involve risk in use are published and updated regularly (NCI, 1996, 1998). The purpose of these inventories is to identify hazardous substances in materials like asbestos, lead, mercury and formaldehyde, thereby restricting their use.

The study

The study consisted of two parts: first, a questionnaire survey was undertaken to examine which environmental aspects clients have considered when procuring buildings; and second, an interview study to examine the clients' experience of 'green procurement'.

Questionnaire survey

A questionnaire survey was devised to determine which environmental requirements Swedish building clients consider when procuring buildings. The following questions were asked. Has your company considered environmental aspects in the procurement of construction projects? For what project size have environmental requirements been stated? Which environmental requirements do you usually consider? Are you, in the near future, planning to procure construction projects where environmental aspects will be considered? The clients were also requested to submit a procurement document for a construction project of their choice to confirm that such requirements had, in fact, been stipulated.

Table 1 Sample groups and responses to the questionnaire

Sample groups	Group size	Clients contacted	Clients responding
Municipals	288	38	28 (74%)
SABO	300	11	10 (91%)
Government	16	11	9 (83%)
Private	83	9	6 (67%)
County councils	21	1	1 (100%)
Total	708	70	54 (77%)

Sample design

Laws and regulations control clients to varied extents, depending on whether they operate as private concerns or are within the public sector. Therefore both public and private clients were included in the study, since differences in their achievements in, and attitudes towards, ecological sustainable construction was expected. In order to reach a large target group, a representative sample of 70 clients (Table 1) was selected, based on lists of private and public organizations supplied by the following.

- Sekom, an organization for municipalities with an ecological outlook. There are 288 municipalities in Sweden, and those who are members of Sekom were considered to be more likely than others to have included environmental aspects in their procurement.
- SABO, an organization for clients involved in municipal housing, with 300 members. In a survey performed by SABO, their members were asked questions about how they worked with environmental aspects in general. Four questions from that study that related to building activities were identified, and used as selection criteria, i.e. the client had to have considered all four questions to be selected for the study presented here.
- The Governmental Network for Quality and Construction, which includes 16 clients, departments and committees. Nine of these were selected. Excluded organizations were those committees not heavily concerned with the procurement of buildings.
- Byggherreföreningen, an organization for clients, with 83 member companies. The nine largest, according to business volume, were selected on the assumption that they have the financial wherewithal to develop and implement environmental strategies.
- The County Councils Federation, including the 21 county councils in Sweden. At the time of the study, building projects performed by county councils were rather concentrated in the Stockholm region, so only the Stockholm county council was included.

Results from the questionnaire survey

From the responses to the questionnaire it was established that 46 of the 54 clients had included environmental requirements in their procurement documents. However, some of these clients did not indicate which requirements they had considered, or offered a very limited presentation of requirements. Therefore, an evaluation of the clients' answers had to be undertaken. Clients who had included at least four environmental requirements were included, and altogether 23 clients were identified. If less than four requirements were considered then it was suspected that environmental aspects were not to any great extent considered in procurement. Figure 1 shows the percentage of clients in each group, who have included environmental

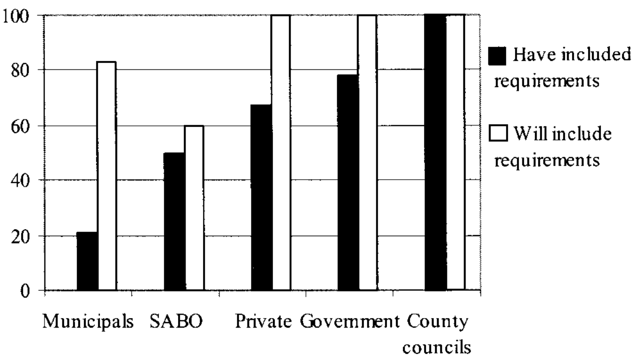

Figure 1 Clients who have stipulated environmental requirements (after evaluation) and whether in the future they will stipulate requirements (in %)

aspects. Also shown is the number of these clients who, in the near future, expect to include environmental aspects as part of their procurement. Few clients (21%) within municipals stipulated environmental requirements as part of their procurement. A study of their documentation revealed a difference: governmental and private clients had developed much more rigorous conditions addressing environmental aspects than most of the municipal and SABO clients. Figure 1 indicates that most of the clients in the study who already have included environmental aspects in a project will do so again in the near future.

The information received in the procurement documents from the 23 clients who had considered environmental requirements was compiled, and the requirements with similar characteristics were classified into six categories:

- building and demolition waste;
- material;
- contractor's environmental work;
- construction;
- ecological aspects; and
- other requirements.

Figures 2–7 show the numbers of clients that considered each concept of the requirements, in terms of a percentage value. The two most commonly stipulated

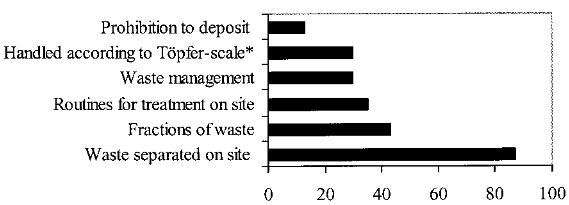

Figure 2 Requirements on waste handling (in %). Note that the Topfer-scale can be used as one basis for selecting building materials from an environmental perspective. The scale includes the following seven steps, all with the purpose of reducing waste: 1, prevent waste occurring; 2, reuse; 3, recycle; 4, reuse for other purposes than the original; 5, extract energy; 6, handle in other ways than deposit; and 7, deposit.

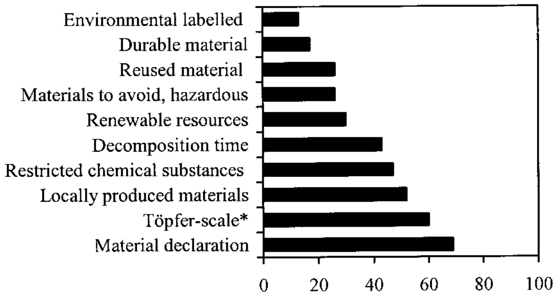

Figure 3 Requirements on material selection (in %)

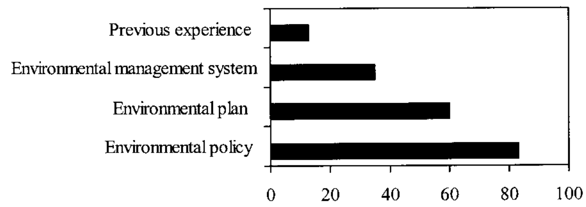

Figure 4 Requirements on the contractors' environmental work (in %)

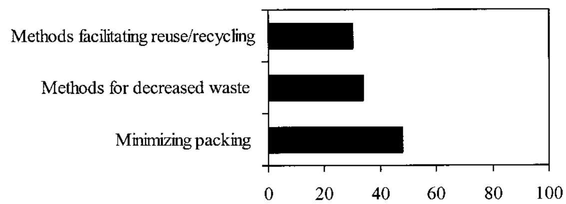

Figure 5 Requirements on construction work (in %)

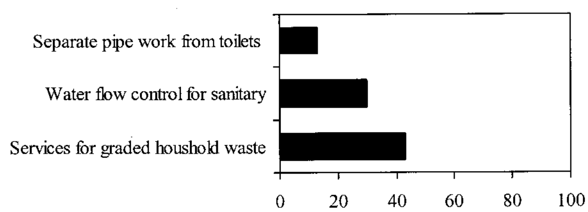

Figure 6 Requirements related to ecological housing aspects (in %)

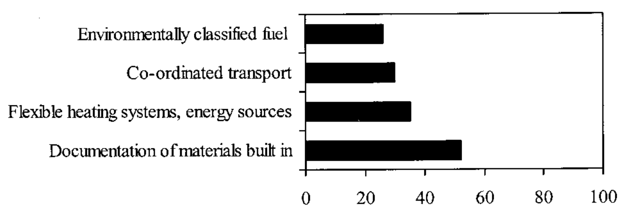

Figure 7 Other requirements (in %)

requirements are separation of waste, stated in 87% of the projects and contractor's environmental policy, stated in 83% of the projects. Reasons can be: (a) that waste separation can be economically beneficial, is easy to follow up and is relatively simple for the contractor to carry out (also public opinion may be a driving force); and (b) that the contractor's environmental policies show his general goals for environmental work, providing an indication to the client as to how the contractor himself considers environmental aspects.

The least common stipulated requirements are: previous experience of environmental projects (13%); prohibition to deposit specific types of waste (13%); and separate pipe works from toilets to collect urine (13%). Reasons can be: (i) that the building sector has faced a recession and few new projects have been carried out (several, especially small, contractors had not had the chance to participate in environmentally profiled projects); (ii) uncertainty about legislation (prohibition on the deposition of waste means simply that the contractor is not able to deposit hazardous waste; however, this is already included in legislation in Sweden and therefore makes the requirement redundant); and (iii) that installation costs for separate pipeworks are high.

Additionally the concepts of requirements have been compiled according to the Ecocycle Council's prioritized areas (Table 2), to examine whether the clients cover those areas. From a long term perspective, most requirements have positive effects on reducing environmental impact. However, some requirements are targeting routines of environmental work, and do not have a direct effect on either of these areas; therefore these are not included in the table. Also the requirements in Figure 6, ecological aspects, target the occupation phase, taking them outside the area of Table 2.

Few requirements are related to energy use for heating. When stipulated in procurement documents, in most cases it concerns the use of flexible heating systems allowing a significant part of the supplied energy from renewable sources. However, there are several other requirements that may be stated within this area, e.g. system solutions providing energy savings, co-ordinated climate systems, increased insulation thickness, passive solar use, etc.

Reduced material use and amount of waste to tipping are better covered by several requirements, as are hazardous substances. This reflects that the Ecocycle Council's work has been effective in focusing on these areas. However, there is a danger that requirements intended to reduce environmental impact in one area could adversely affect another area. The requirement for locally produced material is an example where the aim is to reduce transport but where e.g. the effects of the manufacturing process could be neglected.

Interviews

To examine 'green procurement' at the practical experience level, structured interviews with three clients were undertaken. Structured interviews, i.e. questions prepared in advance and applied to all interviews, are often used when the intention is to compare and generalize the results (Patel and Tibelius, 1986). Some of the questions were structured to seek answers from the respondent only to clearly defined alternatives, while other questions allowed the respondent to answer freely (see Appendix).

Sample

The three clients that, at that time of the questionnaire study, had developed the most complete procurement documents with regard to environmental requirements were selected for interviews.

- Lunds Kommuns Fastighets AB (LKF), which is a municipally owned residential client mainly targeting construction and facility management of residential housing in the city of Lund.
- Akademiska Hus in Stockholm AB, which consists of the parent company Akademiska Hus AB and eight subsidiary companies targeting construction and management of university facilities.

Table 2 Requirements related to the Ecocycle Council's prioritized areas

Energy use for heating	Material and waste	Transport	Hazardous substances
• Flexible heating systems	• Material selected according to Töpfer-scale	• Locally produced material	• Chemical Inspectorate's lists
	• Reuse material	• Co-ordinated transport	• Materials to avoid
	• Durable material	• Environmentally classified fuel	• Prohibition to deposit materials
	• Waste separated on site/ fractions specified		• Environmentally labelled material
	• Waste handled according to Töpfer-scale		
	• Prefabrication of material and customized material		
	• Minimized packing		
	• Construction methods facilitating reuse/recycling		

- Locum AB with Locum Bygg is the Stockholm County Council's facility management co-operation, targeting public health care facilities. Locum Bygg acts as a consultant within the company Locum AB.

The interviews were treated as cases. A case is a phenomenon of some sort occurring in a bounded context, and is the unit of analysis in this study. The cases are the three clients in the context of the environmental work they perform. Two aims in studying multiple cases are to increase the chances of generalization and to develop descriptors. A cross-case analysis has been performed, in accordance with the method advocated by Miles and Huberman (1994). Initially, the information obtained from the interviews was scanned in consecutive order using the interview questions as headings. Thereafter, a categorization, namely the themes in the information, was identified, and a structure was created. For the scope of the present paper, the relevant categories are environmental requirements. Beyond this, information has not been included, but is available in Sterner (1999).

Results from the interviews

The cross-case analyses were performed to identify similarities and differences among the clients' answers (Table 3).

Stipulating environmental requirements

The clients had all developed project specific requirements to reflect the environmental goals decided at the company level. To facilitate future work, two of the clients have included or will include general environmental requirements such as environmental plans and environmental management systems in their administrative instructions (AFs). Stipulating the requirements is considered straightforward. The reason for this, expressed by the clients, was that once the prioritized areas for the project are decided, the problem with formulation is more or less resolved. It is considered to be relatively easy to formulate requirements for projects that have a well defined and specific theme for environmental work.

Evaluating environmental aspects

If the selection of materials is not left to a consultant, the clients use their own evaluation models influenced by the LCA method. Presented here is LKF's model, where each material is assessed in six different categories: manufacturing; construction; occupation; cost; operation and maintenance; and recycling possibilities (together with their underlying assessment areas, see Table 4). Within each assessment area a scoring between one to four points is given, where a low point indicates a good choice.

Similar scoring is used in the Akademiska Hus model, where the assessment is performed within four categories: manufacturing; construction; occupation; and demolition. For each category an assessment of material use, energy consumption and emissions is made. The assessment is further related to a reference product, e.g. the most commonly used on the market. The environmental assessment is performed quantitatively. A product will be awarded a score of 1–5 points in each of the categories, where 1 indicates a case much worse than the reference material.

The interviews revealed the complexity of the client's problems in evaluating environmental impact. The difficulty in evaluation springs from the lack of relevant and operational models for evaluating the

Table 3 Category: environmental requirements

	Stipulate	Evaluate	Verification
LKF	• Based on environmental goals • Project specific • Based on environmental goals	• Tender evaluation • Own evaluation system for materials • Tender evaluation	• Evaluation of a specific project • Continuous follow up of all projects
Akademiska Hus i Stockholm AB	• Project specific • Will be included in AF[a]	• Own evaluation system for materials	
Locum Bygg	• Based on environmental goals • Project specific • Is included in AF[a]	• Tender evaluation • The Chemical Inspectorate's lists	• Continuous follow up of all projects • Environmental programme

[a]Instead of legislating in favour of procedures for procurement, clients in Sweden use AF (administrative instructions), which are included in the tender document. AF controls the terms under which a contract is set up.

Table 4 Assessment parameters for evaluation of construction material used by LKF

Manufacturing	Construction
• Impact the environment as little as possible during its lifecycle • Has low energy consumption in manufacture • Is made of renewable resources	• Contribute to a good working environment during construction • Act well together with the completed structure • Do not contribute to high levels of moisture in the building • Do not extend the construction time through complicated construction methods
Occupation	**Operation and maintenance**
• Provide a healthy indoor environment • Is not a source of static electricity	• Have a long length of life • Contribute to a good operation and maintenance economy
Recycling possibilities	**Cost**
• After use the material can be reused, recycled or will naturally decompose	• Investment cost

environmental impact of materials. An assessment based on the parameters shown in LKF's model, Table 4, undoubtedly will lead to subjective views, since a material might show good qualities in one category and be poorer in another. Furthermore, the categories will each have a different significance in their impact across the total environmental, making the assessment uncertain. Even LKF considers this evaluation to be misleading, since the result does not, with any greater certainty, verify that the best alternative has been selected. The model, however, offers a straightforward approach that hopefully will give some indication on which materials not to select.

Verifying environmental requirements

In an attempt to guarantee the contractor's fulfilment of the requirements, the contractor's environmental policy and environmental management system (EMS), e.g. ISO or EMAS, is requested. To follow up the environmental progress continuously, however, the client has to develop additions to traditional project management. Within an environmental programme the client describes the environmental goals for the project and provides a summary of the environmental aspects. Within the framework of the environmental programme, architects, consultants and contractors are required to develop their own environmental plans, which are followed up continuously. During the design phase, meetings with the project manager and client are held during which the environmental plan for the project is discussed. The project manager is also required to show how environmental work is progressing and how it is followed up. Using the same procedure, the contractor's work is evaluated. Since consultants and contractors then adopt similar work routines, and seek advice from each other and the client, a more continuous building process can be achieved.

Discussion

The way in which environmental requirements are stipulated in procurement documents is significant for the development of a project's environmental features. If requirements are stipulated so that they prescribe technical solutions, then this can inhibit the development of new and more environmentally conscious methods. On the other hand, consultants and contractors must also be able to fulfil such requirements, answering affirmatively to the question of sufficiency of knowledge and skill in developing and implementing environmental strategies. Stipulation of relevant and achievable requirements is a further indication of the client's professionalism within this area. The majority of the requirements identified in this study target waste reduction or material use. For waste separation, financial incentives and the creation of a positive attitude within and about the company can be compelling reasons for clients to include this aspect in their contract conditions. Furthermore, the environmental agenda for the building sector has developed from this approach and must now be broadened.

Energy use during operation of buildings is considered to have the largest environmental impact because most buildings have a long life expectancy. However, few requirements related to the operation of the building are found. This might depend on Swedish building codes, which already regulate energy use in buildings, or on the budgets available at the time of investment. Usually, higher investment costs are difficult to accept, even though they will reduce the cost over time. Introducing lifecycle cost analysis into procurement, and basing tender evaluation on these costs, can be a stimulus for focusing on more energy-efficient buildings.

Tender evaluation including environmental parameters can also serve as an incentive for development of ecological sustainable construction. Today, the parameters evaluated are the contractor's environmental policy and/or environmental management system (EMS), neither of which stimulates this development. Documented policies are often so similar as to make comparisons difficult. Facilitating an assessment that includes other environmental parameters requires the development of operational models. The clients in the study reported that the evaluation relating to the environmental impact of materials was the most challenging task when performing 'green procurement'. This factor arises from the lack of models that, in a rational way, could support impact assessment. Without an accepted model, or standard, it is difficult to conclude which is the best option, thus complicating the chances of including environmental impact evaluations within tender assessments.

Conclusions

The state of environmental considerations among clients in the Swedish building sector is varied. Government and private clients have developed more rigorous procurement documents addressing environmental aspects than most municipal and SABO clients. The latter still have to make considerable efforts in order to develop the procurement process so that it properly addresses ecological sustainable construction. In general, when clients stipulate environmental requirements they do so by focusing on the selection of particular materials that limit the use of resources and quantity of waste. Few clients consider requirements relating to operational matters or, more specifically, to energy use. The latter is considered by the Ecocycle Council to be the most important environmental aspect, and in the future clients will need to improve in this area. Using lifecycle cost analysis in procurement and basing tender evaluation on such costs can be a stimulus for more energy-efficient buildings.

Clients found the evaluation of environmental impacts complicated due to the lack of operational models. Methods assisting clients in their assessments are needed in procurement, in tender evaluation and in the evaluation of the environmental impact of materials. Future work could usefully include pilot projects to demonstrate the economic effects of ecological sustainable construction in a lifecycle perspective. This is necessary if participants in the building sector are to be educated and stimulated towards genuine environmental concern and action.

Acknowledgement

The author gratefully acknowledges the financial support of the Foundation for Strategic Research (SSF) for the project 'Life cycle cost/profit and environmental assessment for tender procedures', which forms part of the Swedish national graduate school and research programme 'Competitive building'.

References

Adalberth, K. (2000) Energy use and environmental impact of new residential buildings. Ph.D. thesis, Lund University.

Björklund, T. and Tillman, A.-M. (1997) *LCA of Building Frame Structures. Environmental Impact over the Life Cycle of Wooden and Concrete Frames*, Report 1997:2, Technical Environmental Planning, Chalmers University of Technology, Sweden.

Cole, J. R. (1999) Building environmental assessment methods: clarifying intentions. *International Journal of Building Research and Information*, 27(4/5), 23–6.

Ecocycle Council (2000) *Byggsektorns betydande miljöaspekter*, Ecocycle Council, Stockholm, Sweden.

Erlandsson, M. (1995) Environmental assessment of building components. Licentiate of Engineering thesis, Royal Institute of Technology, Stockholm, Sweden.

Gunter, A. and Langowski, H.-C. (1997) Life cycle assessment study on resilient floor coverings. *International Journal of Life Cycle Assessment*, **2**(2), 73–80.

Hill, R. C. and Bowen, P. A. (1997) Sustainable construction principles and a framework for attainment. *Journal of Construction Management and Economics*, **15**, 22–9.

Jönsson, Å. (1998) Life cycle assessment of building products, case studies and methodology. Ph.D. thesis, Chalmers University of Technology, Sweden.

McDonald, B. and Smithers, M. (1998) Implementing a waste management plan during the construction phase of a project: a case study. *Construction Management and Economics*, **16**, 71–8.

Miles, M. B. and Huberman, A. M. (1994) *Qualitative Data Analysis: An Expanded Sourcebook*, 2nd Edn, Sage, Thousand Oaks, CA.

Ministry of the Environment (1998) *Miljöbalken*. SFS 1998: 808, Stockholm, Sweden.

Ministry of the Environment (2000*) Tänk nytt, tänk hållbart: att bygga och förvalta för framtiden*, Miljövårdsberedningens dialog ByggaBo. In Swedish.

NCI (1996) *Begränsningslistan*, The National Chemicals Inspectorate, Stockholm, Sweden.

NCI (1998) *OBS-listan*, The National Chemicals Inspectorate, Stockholm, Sweden.

Patel, R. and Tibelius, U. (1986) *Grundbok i forskningsmetodik*, Lund, Sweden.

Peng, C.-L., Scorpio, D. E. and Kibert, C. J. (1997) Strategies for successful construction and demolition waste recycling operations. *Construction Management and Economics*, **15**, 49–58.

Poon, C. S., Yu, A. T. W. and Ng, L. H. (2001) On-site sorting and demolition waste in Hong Kong. *Resources Conservation and Recycling*, **32**, 157–72.
Sterner, E. (1999) Miljökrav på byggnader och byggande, åtgärder för miljöanpassning. Licentiate thesis, Luleå University of Technology.
Swedish Building Industry (2000) *Fakta om byggandet*, The Swedish Building Industry, Stockholm, Sweden.
Swedish Environmental Protection Agency (1998). *Miljöanpassad effektiv uppvärmning och elanvänding*, The Swedish Environmental Protection Agency, Stockholm, Sweden.
Tukker, A. (2000) Life cycle assessment as a tool in environmental impact assessment. *Environmental Impact Assessment Review*, **20**, 435–56.

Appendix: Interview manual

Part 1: Questions concerning the company

1. Who have initiated the environmental work within the company?
2. Is there a person within the company who is responsible for environmental issues?
3. Do you use an environmental management system or are you planning to introduce such a system? What result has it given or are you expecting?

Part 2: General questions concerning the project

4. In what phase of the project was it decided to include environmental aspects?
5. Why were environmental aspects considered?
6. How has the consideration of environmental aspects changed the cost of the project? What is this answer based on: own estimations or calculations and follow up?
7. Are there environmental aspects that you did not consider because costs were expected to be too high? State which aspects.
8. Has any subsidy been granted to the project? If so then from where?
9. What is the subsidy intended to cover and is the intended cost covered?
10. Was there any price reservation concerning environmental requirements in the procurement, and if so then how were those formulated?
11. Is this the first project the company has performed with an environmental profile?
12. If not which aspects were considered in that/those projects?

Part 3: Project design and procurement

13. What is your perception of the concept of green procurement?
14. When did your company introduce environmental aspects in procurement?
15. What type of procurement method has been used in this project? Has this affected the environmental work?
16. Who have participated in the design of the project? Indicate on a scale from 1 (weakly) to 4 (strongly) how they have driven the environmental work.
17. Who have decided on the environmental aspects considered in the project?
18. Are there any environmental aspects that have a high priority, which are they and why have these been selected?
19. What are the complications when considering environmental aspects in procurement?
20. How complicated is formulation, evaluation, or verification of environmental requirements? Indicate on a scale from 1 (no difficulty) to 4 (great difficulty).
21. State which complications are present when formulating, evaluating, and verifying environmental requirements.
22. How is the environmental work followed up?
23. What parameters were included in the tender evaluation, what weight was each given?
24. Which environmental aspects have been evaluated in the tender assessment and how have these been evaluated?
25. Have you considered hazardous substances and components when selecting materials? What criteria were used for assessment and which products have been examined?
26. Have you considered health aspects when selecting material and how materials work together in the building and, if so, how is that done?
27. How is reduction of waste from building considered?
28. Have you prioritized reuse of materials and materials that are able to be recycled, and if so how is such a priority carried out?

The following information, related to the project, was requested from each company in advance of the interview.

- General presentation of the company, turnover, number of employees, etc.
- General description of the project.
- Administrative instructions and procurement documents.

PAPER II

RECONCILING THEORY AND PRACTICE OF LIFE-CYCLE COSTING

Cole, R.J, Sterner, E. (2001) Published in Building Research and Information
Vol 28, (5/6) 2000, page 368-375

Building Research & Information (2000) 28(5/6), 368–375

Reconciling theory and practice of life-cycle costing

Raymond J Cole[1] and Eva Sterner[2]

[1]*School of Architecture, University of British Columbia, Vancouver, Canada V6T 1Z2*
E-mail: cole@architecture.ubc.ca

[2]*Department of Civil and Mining Engineering, Luleå University of Technology, Luleå, Sweden*
E-mail: eva.sterner@ce.luth.se

The notion of Life-Cycle Costing (LCC) is generally recognized as a valuable approach for comparing alternative building designs – enabling operational cost benefits to be evaluated against any initial cost increases. However, a host of practical difficulties conspire to limit its widespread adoption. This limited acceptance is particularly important in green building where many of the benefits of strategic choices can often only be understood and justified when cast in a life-cycle context. This paper identifies some of the critical gaps between the theory (and promise) and practice of Life-Cycle Cost analysis to discover strategies that encourage greater use.

Il est généralement admis que la notion de coût du cycle de vie fournit une approche utile pour comparer les différentes stratégies de conception de construction car elle permet d'évaluer les avantages en terme de coût d'exploitation par rapport à toute augmentation du coût initial. Une foule de difficultés pratiques contribue néanmoins à limiter son adoption générale. Cette acceptation restreinte est particulièrement importante pour les bâtiments écologiques car de nombreux avantages des choix stratégiques peuvent uniquement être compris s'ils sont replacés dans un contexte de cycle de vie. Le présent document identifie plusieurs lacunes majeures entre la théorie (et la promesse) et la pratique de l'analyse du coût du cycle de vie, afin de découvrir les stratégies qui favoriseront une utilisation plus large.

Keywords: Life-cycle cost, building design, practice, economics, whole life costs, risk assessment, green building, finance, procurement

Introduction

Environmental responsibility requires taking a long-term view – understanding that the initial design decisions have profound impacts over a building's life. Life-Cycle Assessment (LCA) methodologies have emerged as a means to profile the environmental performance of materials, components and buildings through time and have been generally accepted within the environmental research community as the only legitimate basis to compare competing alternatives. They have successfully entrenched the notion of an extended time context for examining the environmental characteristics of buildings beyond the short horizons that dominate current design and construction.

Whereas the research community and manufacturers are concerned with quantifying and profiling environmental consequences, building design practice requires that choices also be set within a cost framework, whether formal or otherwise. Life-Cycle Costing (LCC) has traditionally been considered as the means by which initial and operating costs are combined into a single economic figure to then be used as the basis for making informed and effective decisions. LCC provides a basis for contrasting initial investments with future costs over a specified period of time. The future costs are discounted back in time to make economic comparisons between different alternatives strategies possible. There are many parallels between LCA and Life-Cycle Cost Analysis in that both methods attempt to profile performance through time using a common 'currency' – natural units (energy, CO2 equivalents, etc.) and economic (dollar, etc.) respectively.

LCC has a much longer history than LCA but, despite the fact that theories and techniques for performing LCC analyses are well developed, its application in the building sector remains limited. In practice, life-cycle costing has only found significant application in owner occupied facilities but, as Bordass alludes, in the rapidly changing global marketplace, this is a 'diminishing client base' for new commercial buildings (Bordass, 2000). In the absence of a LCC analysis, the initial cost remains as the sole litmus test dictating the economic acceptability of competing design strategies. The limited adoption of LCC appears to be fairly universal. Clift and Bourke (1999) report on UK experience, Sterner (2000) characterizes a similar situation in Sweden, and Larsson reports that even though the C-2000 programme in Canada requires the use of LCC, to date, all 14 participating project teams 'have successfully avoided using this technique' (Larsson, 2000).

This paper identifies and discusses some of the critical gaps between theory and practice of Life-Cycle Cost analysis, and describes and categorizes some of the key reasons for its limited use in practice.

Life-cycle costing: theory requirements

LCC was first developed in the mid-1960s to assist the US Department of Defence in the procurement of military equipment. Later in the 1970s, it was used to assess and compare relative benefits of alternative energy design options in buildings and its principal current building application remains in this role. LCC involves the systematic consideration of all 'relevant' costs and revenues associated with the acquisition and ownership of an asset. In the context of buildings, this consists of initial capital cost, occupation costs, operating costs and the costs incurred or benefited from its disposal (Arditi and Nawakorawit, 1999).

Life-cycle costing is one of several methodologies that can be used to account and provide for a more comprehensive view of costs. Figure 1 illustrates how LCC relates to 'total cost' or 'full-cost' accounting – the differences being in the number and type of costs incorporated in the analysis that

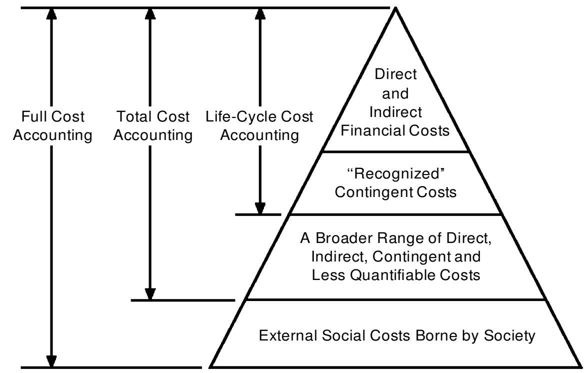

Fig. 1. Alternative cost accounting methods (adapted from BC MELP, 1997).

may or may not be incurred at some point in the future – the 'contingency' costs. LCC, although a clear advance over the single use of initial cost, remains a limited approach to account for the broader environmental and social costs associated with buildings.

The past decade has witnessed greater interest in the life-cycle of buildings and many of the characteristics of green building are set within this context. Green designs typically have significant operating benefits – low energy and water operation costs, lower maintenance costs because of more robust design, etc. However, although reducing energy and maintenance costs are beneficial in their own rights, and the cost savings can be considerable, these components often actually represent a very small percentage of the total costs incurred in many buildings. Over a 40 year life cycle of a typical office building, the cost of people to process information (salaries, benefits etc.) have been estimated in the order of 92% of the total costs incurred in an office, the operating, maintenance and replacement costs approximately 6–8%, and the remaining 2% for the cost of the building itself (Wineman, 1985). As such, striving to make improvements in 2–8% of the costs may be viewed as economical marginal if it could potentially conflict with occupant productivity or other aspects of user satisfaction. However, for many clients such a comprehensive view of costs may not be useful in making decisions about alternative building design options. Isolating the building operation and maintenance cost can account for approximately 55% of the total cost seen over a 40 year life cycle (Flanegan and Norman, 1987) and in this case the LCC methodology is a useful tool.

Building owners and tenants are becoming increasingly sensitized to the issue of indoor environmental quality. By offering enhanced internal environmental conditions, a building owner will have more desirable accommodation that, in a tight market, offers a competitive edge. Moreover, a higher quality tenant might subscribe to the idea of a healthy, high quality environment implying that the owner could attract and retain a higher cost per square foot. Further, an increase in environmental quality in the workplace and associated improved occupant satisfaction often translates to improved productivity and reduced absenteeism (Leaman and Bordass, 1999; Heerwagen, 2000). There is a strong implication, therefore, that issues such as lost work time, insurance costs, lost revenue, and other financial consequences of poor building performance should be explicitly considered in the life-cycle cost analysis (Ramsey, 1973). This suggests that before LCC finds more widespread application it must account for the issues that clients and the development community perceive as critical issues – that is, LCC will have to embrace more contingency issues.

LCC techniques are usually used to compare the cost of alternative building components or systems over their economic or technical life. The purpose is to assist in making more informed decisions or choices – a strategy with the lowest life-cycle cost being deemed more appropriate than with the one with the least initial capital cost. In addition to being a valuable tool for clients and developers evaluating specific choices on individual projects, LCC can be useful in establishing appropriate insulation standards in energy regulations or recommendations and other similar forms of governance.

The theoretical basis for LCC are well developed (Flanegan *et al.*, 1989; Bon, 1989; Kirk and Dell'Isola, 1995) as are the decisions and activities required to undertake a LCC assessment:

- Declaration of alternative strategies to be evaluated.
- Identifying relevant economic criteria.
- Obtaining and grouping of significant costs.
- Performing a risk assessment.

Declaration of alternatives

LCC analyses are most typically used to ascertain the most cost-effective strategy amongst a range of competing options that meet specified functional and technical requirements, e.g. alternative glazing systems, HVAC strategies, floor coverings etc. LCC analyses can be undertaken at various stages throughout design but the possibilities to effect the design and associated costs are typically largest in the early stages. While LCC comparisons of specific strategies are useful, whole building LCCs offer the advantages of capturing interrelationships and cost trade-offs. Depending on the scope of the issues considered, they may also be accompanied by a commensurate increase the complexity of the analysis.

Identifying relevant economic and performance criteria

Since LCC relies on projections into the future, the selection of the economic criteria and speculation of future changes is critical. These include the choice of methodology (equivalence approach, cash flows etc.) discount rate, analysis period etc., selection of appropriate escalation rates for energy, maintenance schedules, frequency of component replacement, administrative, staffing etc. (Kirk and Dell'Isola, 1995) – criteria that vary from project to project. Structurally, they embody two distinct types – information and decision that are solely within the purview of the client and design team, and information that is contextual and beyond the control of the client and design team.

Generating and grouping of significant costs for each alternative

Different costs are incurred during different stages in a building's life-cycle, e.g., design, construction, use, refurbishment, decommissioning etc. Further, building elements and their associated cost can be categorized in a variety of ways: site work, structure, finishes, systems, etc. Different countries have systems for this type of classification, in North America, for example, UNIFORMATII (Bowen *et al.*, 1992) is generally accepted and in Sweden, BSAB system (1987) finds similar application. Collectively, the life-cycle stages and categories provide a frame of reference within which LCC data may be organized. The critical decisions here relate to the required level refinement of the framework – greater detail offering greater accuracy. Decisions of this type are shaped by the specific requirements of the organisation commissioning the analysis. Once the recurring costs have been appropriately grouped they can be easily summarized on an annual basis, discounted back to a common base and subsequently examined alongside the initial costs.

Risk assessment

A LCC analysis involves the uncertainty embodied in the assumptions concerning future costs, cost growth, future inflation rates and the anticipated life of the component or facility. Economic risk assessment, using either probabilistic approach or the sensitivity approach, can be used to reduce uncertainties. The probabilistic approach provides a result that indicates if the relative ranking of two alternatives are conclusive, while the sensitivity analysis examines how LCC is influenced by changes in some of the key economic variables. Computerised methods are essential to enable such risk assessments to undertaken in a comprehensive and systematic manner.

LCC in practice

Despite its relatively long history, LCC has yet to significantly enter the parlance of decision-making in contemporary building design. A host human and technical factors conspire to limit its general acceptance, including:

- A general lack of motivation to use LCC
- A number of contextual factors that restrict its use
- A host of methodological problems and limitations
- Access to reliable data

Motivation

LCC is a service that involves time and effort. Clearly there must be a *motivation* to use LCC techniques on the part of the client – it must be seen as a worthwhile endeavour. Evidence suggests that irrespective of the recognized benefits, because of a perceived lack of value, clients generally are often not prepared to fund the initiative:

- A recurring concern is the *confidence* that can be placed in the results of LCC almost irrespective of the level of the sophistication of the analysis. This primarily stems from the uncertainty in forecasting the future. Capital or initial costs can be typically determined relatively easily and reliably since unit prices and other cost data can be found in a number of different publications and databanks. Given this confidence, initial cost is used as the primary basis for decision-making. Recurring maintenance, operation, and decommissioning costs are on the other hand less predictable (Arditi and Messiha, 1996), because they extend into the future.
- Motivation is, in part, driven by awareness of the benefits. Since there is a perception of limited benefit and a general lack of understanding of LCC, it is often given a low priority with clients. In the speculative market, initial costs and short term economic decisions are the greater, if not sole, basis for key decisions.
- Ferry and Flanegan (1991) reference the 'artificiality' of the LCC process in that:

  'Nobody is actually proposing to put away the sum of money calculated for future expenditure, whereas the present capital and maintenance costs and spending limits are real.'

Contextual issues

Even though there may be motivation and commitment to use LCC techniques, several other interconnected contextual constraints or changes in circumstance may restrict the ability to do so. These diminish the significance of the assessment and limit its perceived value:

- If a client demands that a LCC be used to compare alternative strategies and is willing to provide the additional fees for this service, it will be undertaken by the design team and cost consultant. However, unless it is formalized in contractual terms, it will typically not be volunteered by the design team.
- Often the basis to commit to one particular strategy or another is a *fait accompli* irrespective of cost ramifications (e.g. unacceptable risk and embarrassment of failure, budgetary constraints that preclude seeking alternatives, etc.)
- A LCC is one piece of information that affects the decision to implement one option over

another and it is therefore inappropriate to consider the results in isolation. The development community has a host of other measures to anticipate market acceptability that profoundly influence many cost related strategies, e.g. incorporating new features in a percentage of new housing development to test market response. Other factors, such as the tax structures, can also profoundly affect the economic viability of different strategies and confound the LCC exercise (Clift and Bourke, 1999).

- Although public institutions are typically obligated to evaluate long-term implications of capital projects, internal bureaucratic structures can severely restrict the adoption of LCC. Many public clients' budgets, for example, are structured as 'capital' and 'revenue' budgets with management of each making decisions and choices in isolation of the other.

Methodological limitations

The LCC methodology itself introduces other impediments to its widespread acceptance and adoption:

- A LCC comparison of alternative strategies is relatively straightforward since the basis of comparison is clear and many of the variables requiring future projection are common to each. It can also be straightforward for whole buildings if the analysis is limited to the significant performance issues that can be easily monetorized. By contrast, a *comprehensive* LCC comparison for complete buildings can be an extremely demanding task involving the combination of considerable amounts of hard and soft data, the inaccuracy of which is compounded by extrapolation into the future. However, even if the LCC estimates for a whole building are preliminary and approximate they can still expose significant cost areas and therefore provide an informed basis for subsequent planning.
- The lack of universal methods, standard formats and useful software are often cited as key reasons for limited acceptance and use of LCC (Clift and Bourke, 1999). However, experience suggests that many of those organizations currently employing LCC typically require a considerable amount of customization to relate the technique to both their own organizational requirements and the specific projects to which it is applied. This does not, however, discount the notion that a widespread adoption of methods would be enhanced by the creation of a more consistent, common language, sharing of experience and documented studies showing the successful application of LCC.
- Since the use of LCC is more common in other industries and is increasingly performed in manufacturing, there may be characteristics of building as a process and product that limit its application, e.g. the one-of-a-kind nature of buildings as distinct to a repetitive product, the longer life-time of buildings relative to other consumer products and processes, lack of access to reliable performance data, etc.

Access to reliable data

A LCC analysis is a data intensive process and the final outcome is highly dependent on the accessibility, quality and accuracy of input data:

- Operational cost data is often difficult to find and there are many inconsistencies across the various sources, particularly when a complete building is to be evaluated. Clearly, the earlier in the design that the analysis is undertaken, the greater the potential use of the results in shaping decisions. However, at this stage the cost and performance data are less accessible and assumptions are more speculative.
- Lifecycle performance information (durability, maintenance and replacement schedules etc.) is limited for many materials, components and systems and context specific. HAPM's *Component Life Manual* (1992, 1999) and *Guide to Defect Avoidance* (1999) and *Workmanship Checklists* (1999) are representative of an emerging body of information that enables designers, clients and their insurers to evaluate a design in terms of component performance and durability. Although often driven by the need to reduce risks and defects, such data has application for life-cycle costing techniques. However, one of the critical issues in green design is the use of innovative environmental materials and technologies for which experience and life-cycle performance information is, for the main part, completely speculative.

Reconciling theory and practice

There is clearly a disparity between the theory (and promise) of LCC and its practice in building design. Much of the discussion presented earlier relates to the *direct* application of LCC methods in the decision-making process and the conclusion one is left with is the limited influence of this important technique. It is, however, difficult to assess the extent to which LCC is used *indirectly* in building design through codes and standards, e.g. required thermal resistance levels in many national energy codes are the result of LCC analyses. The indirect incorporation of LCC in this way, of course, creates generic results that remain in place until the next revision of the code or standard.

Several strategies have been advocated to encourage a greater degree of adoption (Clift and Bourke, 1999). Two of the most prominent issues are:

- Improved communication of the merits of LCC
- Improved cost and performance data

Improved communication of the merits of LCC

The use of LCC is a strategic choice. The widespread adoption of LCC and other assessment techniques depends on demonstrating their merits. Although this is fundamentally an educational effort that is required across the entire industry, a critical issue is how cost information is accommodated within the specifics of the project delivery process. Relevant and timely information used in building design and construction is typically brought to the table in the form of the experience of participating consultants. Thus the inclusion of LCC in design is largely about who brings this knowledge to a project, and when.

The higher performance goals for green buildings has initiated and, to a degree, institutionalized the notion of a team approach to design where all the relevant players are engaged in the project from the outset. Spiegal (1999), suggests that the most accurate estimates are the result of a competent design team working with a:

> 'Competent Quantity Surveyor, to ensure that the budget is, in the first instance, reasonable for the intended building project, and thereafter working together through all stages of the project to co-operatively ensure that the project, when built, respects the budget parameters including the life cycle cost aspects of operating and maintaining it.'

The real education process therefore resides equally in the way information is communicated within the design team as it to it.

Improved cost and performance data

Given the data-intensive nature of LCC methodologies, improved data quality and accessibility will considerably reduce the effort required and increase the confidence in the results. Comprehensive cost data bases are large, expensive to create and maintain and tend not to trusted those who did not prepare them. There are numerous barriers to obtaining current, reliable and consistent operational cost information outside one's own organizational structure – including commercial confidentiality and insurance/litigation. This tends to restrict the flow of information within the building industry. Clift and Bourke (1999) suggest that there is strong support for a whole life costs forum for exchange of data and feedback. Where such a forum sits within the industry would, of course, be a critical decision.

In contrast to the above, Ferry and Flanegan (1991) suggest that extensive historical data bases are not essential to the implementation of LCC and, in areas of technological advance, can actually be misleading. Given issues of accuracy and uncertainty, they argue that experience and judgment derived from building an 'intimate knowledge' of operating and maintenance will often suffice.

The notion of improved data raises the issue of *accuracy*, and is the most direct parallel with methodological discussions in Life Cycle Assessment (LCA). Like LCC, the primary role of life cycle assessment is to provide a better basis for choosing one alternative over another – the former with respect to cost and the latter with respect to environmental concerns. Life-cycle assessments are, therefore, only a means to an end. The degree of rigour and comprehensiveness of the analysis need only be such that the result facilitates that choice and it is obviously inappropriate to spend considerable effort obtaining highly accurate cost data for minor components, when more significant ones are crude estimates. Indeed, rather than asking how accurate *must* we be in such analyses, in many cases it may be more appropriate to ask how crude *can* we be in arriving at the same conclusion. This is, of course, not to deny the issue that the aggregation of a host of loosely defined criteria can make a mockery of the final result.

Cost estimates can be generated in a variety of ways but the basic requirement is for comparability between alternatives. Clearly accuracy is a desirable feature but, as Ferry and Flanegan (1991) observe, the nature of cost forecasting precludes 'correctness'. An attempt should be made to relate perceived accuracy with the importance of the resulting figures and the use to what they are going to be put. This, to a certain extent, presents a counter argument to the use of *uncertainty* as an impediment to the use of LCC. Although striving to find the best available data in order to make the analysis as relevant as possible is an important goal, in practice, the accuracy of a LCC result may be of secondary importance. Often the role of LCC is simply one of arriving at ranking different alternatives and get an indication of which one is the most cost-effective. Here, 'consistency' and 'fairness' of data emerge as more important considerations (Ferry and Flanegan, 1991).

Discussion and conclusion

This paper has illustrated that the limited direct use of LCC in building design is mainly related to constraints data accuracy and in current design practice. Also, in the absence of using a formalized LCC approach, cost related issues typically default to using capital cost as the primary basis of comparing alternatives. Future incurred costs are assimilated as part of the decision making process in other simple, less formal ways – typically by extrapolating past experience into the future. While there is clear merit to an experienced-based approach, this typically penalises the exploration and adoption of new, innovative materials and technologies. This is particularly important in the context of green design. If green materials, systems and strategies are to be adopted, confidence must be instilled in both the client and the design team that there will indeed be significant benefits – reduced operating cost etc. associated with that choice. LCC is a tool that can provide supporting evidence.

LCC is typically viewed as a tool that can be applied discretely at almost any point of an assets life cycle to assess the least cost option among competing alternatives. This paper has demonstrated that this is not currently widely practice. Before LCC is taken seriously and used successfully in practice, Ferry and Flanegan (1991) argue:

> 'A continuum is needed which links the Life Cycle Cost across different stages of the asset's lifecycle and with management accountability resting on these calculations.'

This suggests that a major role for Life-Cycle Costing lies as much in providing a more comprehensive *framework* for decision-making as it does evaluating specific choices.

References

Arditi, D. and Messiha, H. (1996) Life cycle costing in municipal projects, *Journal of Infrastructure systems*, **2**, 5–14.

Arditi, D. and Nawakorawit, M. (1999) Designing buildings for maintenance, designers perspective, *Journal of Architectural Engineering*, **5**, 107–116.

Bon, R. (1989) *Building as an Economic Process: An Introduction to Building Economics.* Prentice Hall, Englewood Cliffs, NJ.

Bon, R. and Hutchinson, K. (2000) Sustainable construction: some economic challenges, *Building Research and Information*, **28**(5/6), 310–314.

Bordass, W. (2000) Cost and value: fact and fiction, *Building Research and Information,* **28**(5/6), 338–352.

BC MELP (1997) *Total Cost Assessment Guidelines: Assessing the Business Case of Environmental Investments*, BC Ministry of Environment, Lands & Parks.

Bowen, B., Charette, R. and Marshall, H. (1992) UNIFORMAT II – A Recommended Classification for Building Elements and Related Sitework. NIST Special Publication 841, Gaithersburg, VA, National Institute of Standards and Technology.

Brunskog, (1985) Kostnadsinformation Regler for gruppering och registrering av bygtprogektets kostnader.

BSAB systemet, tabellar ochtillämpningar (1987) AB Svensk byggtjänst, Stockholm.

Clift, M. and Bourke, K. (1999) Study on Whole Life Costing Report prepared for DETR, February 1999 Report Number CR 366/98.

Ferry, D.J.O. and Flanegan, R. (1991) *Life Cycle Costing – A Radical Approach*, CIRIA Report #122, Construction Industry Research and Information Association, London.

Flanegan, R. and Norman, G. (1987) *Life Cycle Costing: Theory and Practice*, RICS, Surveyors publications Ltd. London.

Flanegan, R., Norman, G., Meadows, J. and Robinson, G.

(1989) *Life cycle costing: theory and practice.* Blackwell Scientific Publications Ltd, Oxford.
HAPM, Component Life Manual (1992: CD ROM 1999) and Guide to Defect Avoidance, 1999, Housing Association Property Mutual Ltd, London.
Heerwagen, J. (2000) Green buildings: a strategic perspective, *Building Research and Information*, **28**(5/6), 353–367.
Kirk, S. and Dell'Isola, A. (1995) *Life Cycle Costing for Design Professionals*, McGraw-Hill, New York, second edition.
Larsson, N. and Clark, J. (2000) Incremental costs within the design process for energy efficient buildings, *Building Research and Information*, **28**(5/6), 411–416.
Leaman, A. and Bordass, W. (1999) Productivity in buildings: the 'killer' variables, *Building Research and Information*, **27**, 4–19.
Ramsey, R.G. (1973) Here you have it; Life Cycle Costing, *AIA Journal*, **60**, 11–17.
Spiegel, T.J. (1999) Accurate Cost Estimates, Paper Presented to the Cost and Value in Building Green Symposium, Vancouver, British Columbia, Canada, November 18–19.
Sterner, E. (2000) Life cycle costing and its use in the Swedish building sector, *Building Research and Information*, **28**(5/6), 385–391.
Wineman, J. (1985) *New Developments in Office Setting Research*. in Proceedings: The Architectural Research Centers Consortium Workshop on the Impact of the Work Environment on Productivity held at Washington, D.C. April 17–19. Dolden, M.E. *et al.* (eds) Washington DC, Architectural Research Centers Consortium, Inc.

PAPER III

LIFE-CYCLE COSTING AND ITS USE IN THE SWEDISH BUILDING SECTOR

Sterner, E. (2001) Published in Building Research and Information Vol 28, (5/6) 2000, page 387-393

Building Research & Information (2000) **28**(5/6), 387–393

Life-cycle costing and its use in the Swedish building sector

Eva Sterner

Department of Civil and Mining Engineering, Luleå University of Technology, Sweden
E-mail: Eva.Sterner@ce.luth.se

The results from a survey examing the extent that Swedish clients in the building sector use life-cycle cost (LCC) estimations are reported. The limits and benefits from the client and user perspectives are also explored. The interest in using LCC approaches for economic evaluation of investment decisions is large. However, constraints exists at a number of levels: uncertainties related to the long term forecasts used, difficulties in achieving relevant input data and lack of experience in using LCC models, incentives for consultants and contractors. Nonetheless, the LCC perspective is proving to be most useful during the design phase where the possibilities of cost reductions related to operation and maintenance are large. LCC can provide motivation for environmental progressive building despite the sometime higher initial cost. The implication for expanding the use of LCC are considered for government, clients/developers, professionals.

Le présent document livre résultats d'une étude menée auprés de clients suédois travaillant dans le sucteur de la construction. L'objet de cette étude était de déterminer l'importance des critères d'évaluation du coût du cycle de vie (investissement, exploitation et entretien) des bâtiments. Ce document expose également les avantages et les inconvénients du point de vue du client et de l'utilisateur. Les approaches basées sur le coût du cycle de vie dans l'évaluation économique des décisions d'investissement présentent un grand intérêt. Certaines contraintes existent néanmoins à plusieurs niveaux: incertitudes liées à l'utilisation de prévisions à long terme, difficultés à acquérir des données d'entrée pertinentes et manque d'expérience dans l'utilisation de modèles de coût du cycle de vie, primes pour les consultants et les entrepreneurs. Cependant, la perspective d'une estimation du coût du cycle de vie s'avère la plus utile au cours de la phase de conception car les possibilités de réduction des coûts liés à l'exploitation et à la maintenance sont nombreuses. Le coût du cycle de vie peut inciter à la construction de bâtiments dont l'impact sera positif pour l'environnement, malgré un coût initial parfois supérieur. Ce document examine les conséquences de l'utilisation accrue du coût du cycle de vie pour le gouvernement, les clients/développeurs et les professionnels.

Keywords: building economics, life cycle costing, building operation, maintenance, clients, procurement, green building, Sweden

Introduction

The building industry in Sweden is facing many substantial and demanding challenges in the future. One challenge is to meet society's requirements for sustainable development, based on greening buildings and processes. Another is to reduce the costs of buildings and their operation and maintenance.

Building costs, in Sweden today, are too high and the main causes for this are several as for instance taxes and fees along with poor productivity development (Jonsson, 1996). Initial costs can be lessened by reduction of built areas, adoption of appropriate construction methods, simple structural systems and standardization of designs and components (Sherif, 1999). However, not only the initial costs require reduction. Operation and maintenance costs currently account for approximately 55% of the total cost, over a span of 40 years (Flanegan and Norman, 1989). One way to

Building Research & Information ISSN 0961-3218 print/ISSN 1466-4321 online
http://www.tandf.co.uk/journals

create a more comprehensive view of costs in the different phases of a building project is to perform life cycle cost (LCC) analysis. A LCC perspective consists of estimations related to initial costs for acquisition together with operation and maintenance costs. The main motivation to use LCC is to increase the possibility of cost reductions during operation even if that means spending somewhat more during planning and development (Kirk and Dell'Isola, 1995). Another important use is in updating older buildings.

Despite the advantages LCC models bring in order to optimize costs, there are some indications that the building sector in Sweden has not fully adopted the methodology. This paper contains results from a performed survey examining to what extent Swedish developers and clients use life cycle cost estimations, in which phases they use it, what their perception of the limitations and benefits are. The limits and benefits from the user perspective are also explored.

Constraints for adopting LCC

Former regulations

During late 1960s and early 1970s the construction market in Sweden was more profitable for contractors and material manufactures than for clients and property managers. One reason was the 'million-programme', initiated by the Swedish Government. The intention of the programme was to produce one million apartments over a time period of 10 years. Due to this programme, the costs for building increased rapidly and the economy for property owners became difficult to handle. At the same time, the energy price increased rapidly. High capital and operating costs did not leave any room for savings for maintenance and alteration (Westin, 1991). The Swedish Government also subsidized the financing which made financing of building projects very advantageous but contributed to the increase in overall construction costs. Consequently, the actual costs for building have not been fully paid for by the client, developer and investor. As a result, contractors have not been forced to increase efficiency and productivity in order to increase profits. Since the costs for initial investments are high in Sweden, the focus has been on construction and not on operation and maintenance costs.

Time and cost data

The relevance of the result of a LCC calculation is often considered to be somewhat uncertain. This is mainly due to lack of sufficient cost data and accepted industry standards for describing the life cycle behaviour of facilities and internal processing systems (Abraham and Dickinson, 1998). The deficiency of sufficient cost data is primarily related to the limited ability to foresee future consequences and the omission of reliable historical information on costs. Therefore, many parameters are uncertain and have to be estimated in the calculation. Examples include the length of the actual life cycle, production, operation, planned and unplanned maintenance costs. Although building owners usually have a variety of records and databases (book-keeping, facility and apartment records, operation and maintenance plans), these records are not often arranged in such a way that it is possible to cross-reference the information and use it for LCC calculations.

Another critical variable is the discount rate (composed of the time value of money and the effects of inflation) which affects the result significantly. Inflation may be considered as a general increase of prices of goods and services over time in the economy as whole, without a corresponding increase in value (Kirk and Dell'Isola, 1995). Choosing a discount rate which is too high will bias decisions in favour of short-term low capital cost options, while a discount rate which is to low will give an undue bias to future cost savings. Since the accuracy of choosing a certain discount rate is uncertain, the result of an LCC calculation can always be questioned. Despite this problem, there are possibilities to lessen the uncertainties in the result by performing sensitivity analyses where parameters, which are of the greatest importance to the result, can be varied.

Swedish clients use of LCC

Although the theoretical concepts of LCC techniques are well developed it was suspected that LCC use in the Swedish building sector was limited. To examine this a survey was conducted.

Questionnaire

To gather information about the practical use of LCC estimations by Swedish clients a questionnaire was sent to 83 public and private clients in order to examine:

- Which clients use life-cycle cost analysis and to what extent do they use it?

The clients included in the study are all members of Byggherreföreningen, which is an organization for professional clients in Sweden including 94 larger private and public companies. Those clients who had not answered the questionnaire in due time were sent a reminder (with the same questions) within a three weeks period. A total of 53 (64%) clients answered the questionnaire. From these 35 clients use a LCC perspective when making decisions about investments. The motivation to use a questionnaire, in order to gather information, is the ability to reach a large target group in a practical and efficient way.

Extent of use

Figures 1 to 4 represent the findings from the survey where a total of 35 clients have used LCC estimations. The x-axis in Figs 1, Figs 2 and 4 indicates the percentage of the client's answers.

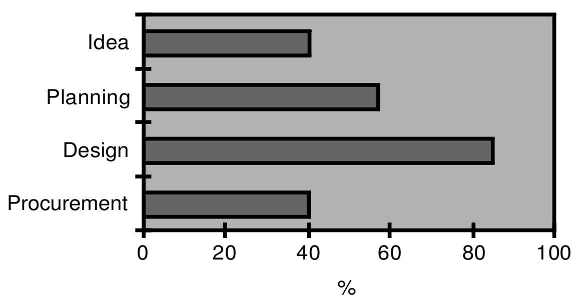

Fig. 1. Phases of projects when LCC estimations are usually done.

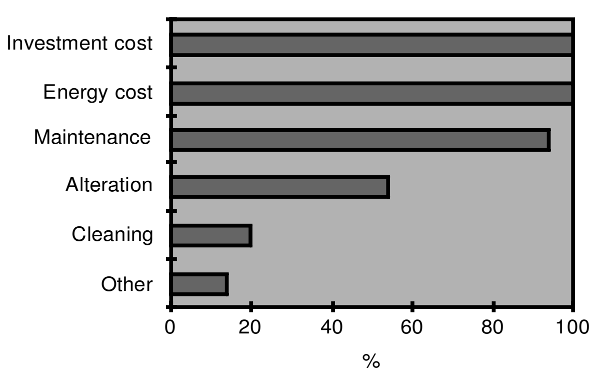

Fig. 2. Parameters clients include in LCC estimations.

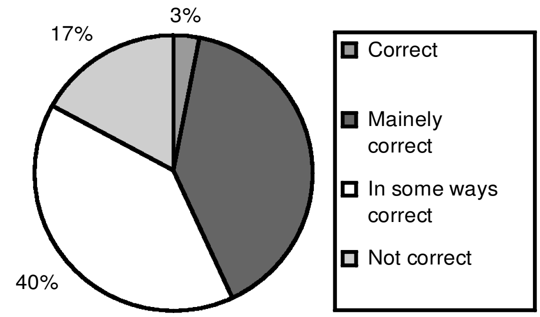

Fig. 3. Clients' experiences of using LCC.

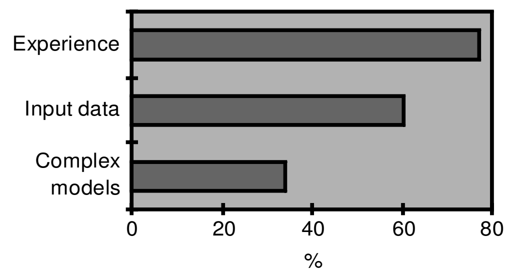

Fig. 4. Constraints when calculating LCC.

Figure 1 indicates the different phases of the building process, from idea to procurement, in which clients perform LCC estimations or calculations. LCC calculations are usually performed in the design phase of projects where they also are most useful since there is the opportunity to explore and compare different options against each other. After the design is determined and the construction work has commenced, the cost for creating changes increases rapidly. In the design phase the calculations are either done by the consultants or by the client. The trend seems to be that governmental clients perform the calculation inhouse, while private clients hand it over to the consultant.

Figure 2 indicates the parameters that are usually included in a LCC calculation. For evaluation of different design alternatives clients consider investment, energy and maintenance costs to be of greatest importance. Fewer clients consider alteration costs. One reason can be difficulties in predicting such costs. Two of the clients include environmental parameters associated with demolition and disposal fees. The reason is higher disposal cost for certain materials due to differented disposal fees and taxes.

Figure 3 shows how clients experience the accuracy of a performed LCC calculation. As shown most clients consider the calculations to be mainly or in some ways correct.

Figure 4 shows which kind of constraints clients find in adopting and using LCC calculation models. Lack of experience in using the calculation models is a major obstacle. The lack of significant input data is another large constraint. Most clients base their calculations on their own input data collected through years of running buildings. This data is mainly related to operation and maintenance. However, clients do not have adequate input (LCC) data for new materials or new operating systems. Subsequently, they have to estimate these in order to perform an analysis. These estimations effect the result of the analyses and this acts as a constraint in using LCC calculations. Some clients also consider the available models to be too complex, that is the models include too many parameters and it will take too long a time to perform an analysis (especially if the input data are not easily accessible).

Calculation models used

To gather information about what type of calculation models are used, additional questions were sent to 12 of the clients, who were identified through their responses to the initial questionnaire as having the most experience in using LCC estimations. Eight (67%) answered the additional questions. Table 1 presents the result divided in two different categories – advanced models and simple models. As illustrated, most of the clients in the survey use the advanced type of model.

Advanced calculations are mainly used to compare costs of installations. Two of the clients use the calculation program ENEU 94 K, developed by the Swedish mechanical association and NUTEK (Swedish National Board for Industrial and Technical Development). The intention of the program is to provide the user with a calculation model for energy efficient procurement of machines and equipment. The program also provides prepared forms for procurement, based on LCC for installations.

In some cases, advanced models are used for comparing costs of materials, building elements or building components. Usually sensitivity analyses are performed and the parameters varied are changes in energy prices, discount rate and the expected life cycle. The models are computer based; the most common type of program used is Excel. Input data for initial costs, maintenance and operation are generated from own empirical data and also from public publications. Some clients use LCC models for the design phase, others use them for procurement, when evaluating tenders.

The simple type of model is used to compare cost increases in initial investments with cost savings for operation and maintenance. Usually the calculations are not computer based and do not include

Table 1. Calculation models used

	Advanced model	Simple model
Number of users	5	3
Parameters included in the analysis	Acquisition cost Salvage value Life-cycle Interest Energy costs Operation Maintenance Environmental costs	Acquisition costs Operation Maintenance
Sensitivity analysis	Yes	Sometimes
Parameters included in the sensitivity analysis	Energy prices Discount rate Life cycle	Discount rate
Calculation made for	Ventilation, heating systems, Building elements and materials	Ventilation, heating systems, Building materials

a simulation of the parameters as is done in a sensitivity analysis.

Implications for expanded use

Government

It should be of primary interest to adopt a LCC perspective related to building for governmental clients because the total cost for operation and maintenance of existing buildings in Sweden are larger than the investments made on production of new buildings. The influence of the government both as a major client and a major example of best practice to the rest of the Swedish building sector should not be underestimated. Even a very small improvement within the operation phase will have large economic benefits for society as a whole. Buildings that are managed with a rational and long term perspective will also remain attractive during a longer time period and the need for replacement is lessened (Bejrum, 1991). Replacing old buildings with new is both economically and environmentally resource demanding and the durability of the building is in this context important. However, buildings are getting more technically complex with an increasing number of installations and equipment. These installations usually have shorter life spans than the building itself. It is suspected that this will increase maintenance costs compared to older buildings due to a faster ageing of components and installations. This implies that components will be replaced although their technological life has not ended (Bejrum and Lundström, 1986). Governments could promote and encourage that buildings are built and managed over a long term perspective since this would benefit society economy as a whole. It may also be the case that the building is easier to manage and maintain. Lower LCC can also be achieved if the building is prepared for alternative use.

The government also has a major influence on the building industry when creating building codes and regulations. Codes concerning energy use for buildings already include a life-cycle perspective of costs so it would be possible to have such a similar approach for other parts of the building. Minimum requirements stated in codes highly affect development within the building industry. Therefore, it is important that codes are formulated in such a way that further LCC development is encouraged. By putting the life cycle perspective in focus, governments can influence and address the importance of a total cost perspective.

An alternative to voluntary use of LCC is increased regulation through stated requirements. However, most companies within the Swedish building sector are trying to avoid legislation concerning these matters.

Clients

Clients have several reasons for embracing long term economic models into the different phases of a building project. Most use is in the early stages of design where the possibility to effect costs are the greatest. However, the initial investment cost is of great importance to the overall cost so the potentially increased cost in the design stage can be viewed by clients as barriers. Even if the initial investment can be somewhat higher when performing LCC calculations, it must be placed within the context of cost savings during operation and maintenance. As low operation costs increase the profit, this can be a way for the developer/ client to attract tenants.

By expanding the cost perspective to include LCC in tender evaluation, new and improved construction methods can be encouraged. Clients must be prepared to abstain from forms of construction organization that determines technical solutions since stated technical requirements can prevent development of new and better methods. If the client decides on which technical solutions to be used at the briefing stage, this will both limit the design team's creativity and also the contractor's ability to develop new and better construction methods to carry the work out.

Instead, requirements should be stated on functions, quality and costs. The contractor must have the possibility to find the best available methods for carrying out the construction work. Today, the design team is usually represented by several groups as architects, structural, mechanical and electrical consultants, etc. the building is considered as different parts rather than as a whole, resulting in each group's decision casting costs onto the others. Increased co-operation between clients, design team and contractors could lead to lower costs and higher quality. However, legislation may limit these forms of co-operation and also the competitiveness among practitioners may be hindered which can increase costs.

Clients must also, in procurement documentation, clearly specify how the evaluation is going to be performed (which parameters are included and how they are evaluated). If this is not done in an accurate way, there is a possibility to come in conflict with laws associated to the procurement process.

For the public client, an extended use of LCC can cause some constraints related to the funding policies used by them, especially if capital costs and operation costs are handled separately. Administrators are usually limited by annual budgets, which limits the time perspective.

Professionals

If a LCC perspective is to be used, the largest benefits are made in early stages of design. This usually implies that it is up to the consultant to perform the analysis. Unfortunately LCC analyses can be time demanding which may translate into higher professional costs and design fees. The inducements for the designer, in terms of compensation, to perform such analyses is often limited. The driver for change is that clients should recognise the added value being provided and, as a result, pay for this service. Until this is done, consultants will provide the largest resistance to use LCC techniques.

More prominent consultants might use a LCC perspective to validate a more complex and sophisticated design with a higher initial cost, provided that the long term costs are equal or less than competing alternatives. Consultants who are interested in environmental progressive building design will also have an excellent opportunity to promote their designs since 'green' building often translates into lower operation costs.

Environmental aspects

Operation of a building is cost demanding and the environmental impact caused, due to energy use amongst other factors, is large. If economics and ecology are considered together from a life-cycle perspective, another implication for expanded use of LCC models is found. By looking at life cycle costs, an environmentally progressive building design, which might have a higher initial cost, can be motivated since these types of buildings often have low operation costs. These lower costs are due to utilization of natural ventilation, effective use of day lighting and passive solar energy use. If the initial and operation costs are not seen through a long term perspective, the true economic benefits of green building design will not be displayed.

Life-cycle assessment models have generally been accepted as the only legitimate basis to make environmental comparison of alternative materials, components and services (Cole, 1999). To perform such analysis is time demanding and there is a need to develop simpler, more operational models which can be used by clients and consultants for design and procurement of buildings (Sterner, 1999). One way to simplify the assessment could be by quantitative measuring environmental impact through costs in a life cycle perspective.

Spreading application

The theoretical concepts of LCC models are well developed and programmes for calculations are available, but the practice within the building sector in Sweden today is limited. One reason can be that the connection between theory and practice is not successful and that the limitations for a practical use are not fully understood. More studies concerning difficulties in implementation between practicality and theory could benefit further use.

For investors the focus is mainly on the cost of the initial investment, which is an important part of the overall cost. This makes the investors' acceptance in using an overall time perspective very important for a wider use of LCC methods.

To encourage and stimulate to a more widespread use of LCC within the building sector it is also important to evaluate and display the cost reductions made by using long term investment appraisal techniques. This might result in a number of demonstration projects which are monitored and disseminated widely to different sectors within construction. There may also be a need for widespread educational programmes for the sector to make consultants and investors experienced in using these types of programmes.

Another alternative is regulation through stated governmental requirements. Most of the companies within the Swedish building sector are trying to avoid legislation concerning these matters.

Conclusions

- The use of LCC models by Swedish clients during 1999 is limited. From the performed survey 66% indicated that they use a life-cycle perspective when making investment decisions. However, this does not necessarily imply that they perform LCC calculations.
- If advanced LCC calculations are used, they are primarily related to installation systems such as HVAC and not for the building projects as a whole. The models used are computer based, include sensitivity analysis and usually the following parameters: acquisition, energy, operation, maintenance and environmental costs, salvage value, length of life cycle and discount rate.
- The parameters generally considered to be the most important for the LCC of a building are investment, energy and maintenance costs. Some clients include costs related to disposal and the environmental disturbance it causes.
- From the survey, two main constraints for implementation of LCC techniques can be identified: lack of relevant input data and limited experience in using LCC calculations. To encourage and increase the use of the LCC, these two obstacles must be overcome. It could be achieved by creating databases that are compatible with LCC calculation models. It is also important to display examples of how LCC is successfully performed and which benefits a company can attain. Educational programmes within the building sector can also encourage further use.

Acknowledgements

This project is joint financed by LE-Lundbergs stipendiestiftelse and Competitive Building. The author also which to acknowledge the input provided by Professor Raymond J. Cole at School of Architecture, University of British Columbia, Canada.

References

Abraham, D. and Dickinson, R. (1998) Disposal costs for environmentally regulated facilities: LCC approach. *Journal of Construction Engineering and Management,* **124**(2), 146–54.

Bejrum, H. (1991) *Livscykelekonomiska kalkyler för byggnader och fastigheter.* Statens råd for byggnadsforskning. Tekniska högskolan i Stockholm. TRITA-FAE 1033. Rapport 5, 33. Stockholm, Sweden (In Swedish).

Bejrum, H. and Lundström, S. (1986) Hyresfastighetens ekonomi i långtidsperspektiv-analys av empirisk data. Meddelande 5, 23. Inst för fastighetsekonomi, Tekniska högskolan i Stockholm. Stockholm, Sweden (In swedish).

Cole, R. (1999) Energy and greenhouse gas emissions associated with the construction of alternative structural systems. *Building and Environment,* **34**, 335–58.

Flanegan, R. and Norman, G. (1989) *Life-Cycle Costing: Theory and Practice.* RICS, Surveyors Publications Ltd, London.

Jonsson, J. (1996) Construction site productivity measurements, Luleå: Luleå University of Technology, Doctoral thesis, 185 D.

Kirk, S. and Dell'Isola, A. (1995) *Life Cycle Costing for Design Professionals,* 2nd ed., McGrawHill Book Co. Inc., New York.

Sherif. A. (1999) Hospitals of developing countries: Design and construction economics. *Journal of Architectural Engineering,* **5**(3), 74–81.

Sterner, E. (1999) Miljökrav pa byggnader och byggande. Åtgärder för miljöanpassning. Licentiate thesis, Luleå University of Technology, Luleå, Swdeden (in Swedish).

Westin, T. (1991) Kostnadskalkylering med LCC-modell, Doctoral thesis, Byggforskningsrådet R27:1989. KTH. Stockholm (in Swedish).

PAPER IV

LIFE-CYCLE COSTING AND ENVIRONMENTAL IMPACT: A CASE STUDY AND TENDER EVALUATION MODEL

Sterner, E. (2002) Submitted to Construction management and economics

Combining life-cycle cost and environmental impact: a case study and model for tender evaluation

EVA STERNER*

Division of Steel structures, Luleå University of Technology, 971 87 Luleå, Sweden

Environmentally responsive construction processes must inevitably draw on life-cycle methods to justify and help determine design, construction and operational strategies and requirements. This paper uses a Swedish based building project, Greenzone, to demonstrate how environmental performance has affected the life-cycle cost of the project. The life-cycle cost and environmental impact from operation energy use is established and compared to similar conventional buildings in which no specific effort to improve environmental performance has been taken. Uncertainties in the primary cost analysis, due to discount rates and energy price escalation rates are explored using sensitivity analysis. Results show that the conventional project carries the lowest initial cost, but energy consumption and environmental impact is significantly higher. Also, a model developed for use in tender evaluation, integrating life-cycle cost and environmental impact is demonstrated. By use of such model clients can award the consultant/contractors that develop energy efficient buildings giving lower life-cycle cost and reduced environmental impact.

Key words: life-cycle cost, life-cycle assesment, sustainable construction, procurement, tender evaluation

Introduction

Improving environmental performance of buildings includes e.g. efficient use of resource and energy, waste minimising, avoiding use of hazardous substances etc. Of these aspects energy use is considered to have the largest environmental impact (Ecocycle Council, 2001). By stipulation of environmental requirements in procurement documents clients are, to varying extent, emphasizing the importance of these concerns (Faith-Ell and Sterner, 2000). In the Swedish building sector most requirements have so far concerned material use and waste handling (Sterner, 2002) whereas energy use has been devoted less attention. One possible reason is that Swedish building codes regulate minimum requirements for energy, therefore offering no motivation for clients to exceed the established standards.

For buildings in cold climates energy for heating and ventilation accounts for a significant part of the total energy use. Adalberth (2000) has examined the life-cycle energy for seven new residential buildings in Sweden and found that approximately 15 % of the total energy use was embodied energy and 85 % was related to the occupation phase of 50 years. Also Cole and Kernan (1996) examined the energy use for typical office buildings in Canada with same assumed life length and found that 80 to 90 % of the energy use was related to operational energy. Though, when operational energy becomes lower, through efficiency improvements, the embodied energy will become a larger factor. Conclusions from studies in Australia show that the embodied energy use is significant relative to operational energy use for a residential building, Fay et al. (2000). Treloar et al. (2001) concludes that a life-cycle approach is required if energy consumption and environmental impacts attributable to the construction and operation of buildings are to be reduced to a manageable level. Aye et al. (2000) uses a life-cycle costing approach to examine a range of construction options for a commercial office building. The result show that the construction cost is higher for a new environmentally designed building compared to using a standard office building design but that the life-cycle cost is lower since energy use is reduced.

To obtain environmental conscious and cost effective building processes it is necessary to develop procurement methods emphasising use of life-cycle approaches. This call for clients to stipulate requirements, develop the tendering process and to allow consultants when competing for work to develop the best solutions. The aim of this paper is to demonstrate the use of life-cycle cost estimations in the context of three environmentally designed commercial buildings. In particular, the effects of initial cost increases, possible operational cost savings and environmental impact reduction from energy use is addressed and compared with three similar conventional projects without environmental design. Furthermore a simplified model that can be used as one part in a tender evaluation is offered. The model integrated an environmental impact index with the life-cycle cost. Awarding reduced environmental impact from energy use in tendering competitions can then be a stimulus for the development of environmentally and cost effective construction.

Case study: project description of Greenzone

The case study project is known as Greenzone and was designed by Anders Nyqvist Arkitektkontor AB, the contractor was PEAB and the project includes three commercial facilities. The project is located on the Swedish east coast, in the city of Umeå situated at latitude 64°. The initial and operation costs of these three reference buildings have been compared to three equally sized buildings, without explicit environmental consideration.

Figure 1. Greenzone site layout (from www.Greenzone.nu)

Carstedts, GZ 1: offers various services related to automobiles. The building floor area is 3350 m^2 and includes offices, a car workshop, storage and sales areas divided on two separate floors. The east facade consists of large window areas to reduce the need for electric lighting. A comparison of the life-cycle cost and environmental load for a reference building (Ref 1) owned by the same client in Örnsköldsvik, 250 km south of Umeå was made.

Statoil, GZ 2: provides various services for motorists. The building floor area is 590 m^2 in a single story and includes a sales area, a grocery store, a car wash and a petrol station. The energy demand to provide cooling in freezers, refrigerators and for the car wash is dominant over heating and ventilation energy. For the comparative study, Statoil provided data on one of their other equally sized conventional buildings (Ref 2) with the same floor plan located in Hudiksvall, 410 km south of Umeå.

McDonalds, GZ 3: is a single story building with a floor area of 310 m^2 including a fast food restaurant with kitchen and staff areas. The energy demand in the building is in large represented by electricity for ventilation, grills, deep fryers, refrigerators and freezers. For the comparative study, data was obtained for one equally sized conventional buildings (Ref 3) with the same floor plan located in Härnösand, 350 km south of Umeå.

Environmental features of the buildings

Some of the approaches used to improve the environmental performance compared to conventional building standards are:

Materials: The structure has been designed to enable future reuse most other building materials are possible to reuse or recycle. During construction, waste was separated for reuse, recycling and energy extraction.

Hazardous substances: Content declarations of the materials used were a requirement to facilitate a comparison with the National Chemical Inspectorates inventories which specifies substances considered to involve a risk in use.

Indoor air quality: To improve the air quality in the buildings, green plant boxes are installed which also reduce the need of cooling the buildings.

Water use: To reduce the need for supplied water, extensive work has been carried out in the surrounding area where creeks have been built to collect and purify surface water. The groundwater level at the site is high, making it possible to use groundwater for irrigating the area as well as supplying water for low water-consuming vacuum toilets and the car wash. Sewage water is not led to the municipal net since it is sorted at the source and treated locally in a ground filtration system. All three buildings have a sedum tile roof i.e. a roof with a layer of plants that insulates against heat in the summer when holding rainwater. When the water evaporate a cooling effect is caused.

Energy use: Daylight is allowed to pass through large window areas to reduce the need for artificial lighting. Daylight is also introduced through lantern skylights that are built into the roof. Both designs reduce the need for electrical lightning. Several other measures have been taken to improve the energy performance in the buildings. One important aspect is the recovery of heat from ventilation air and recycled surplus heat from grills and deep fryers.

Moreover the heat supply system is based on: a heat pump, electric hot boiler and a sun catcher to warm incoming ventilation air. The electric boiler is connected in a series with the heat pump and only provides additional heat during peak periods. The electricity used for powering the building service systems and activities is supplied by a connection to a wind power generator.

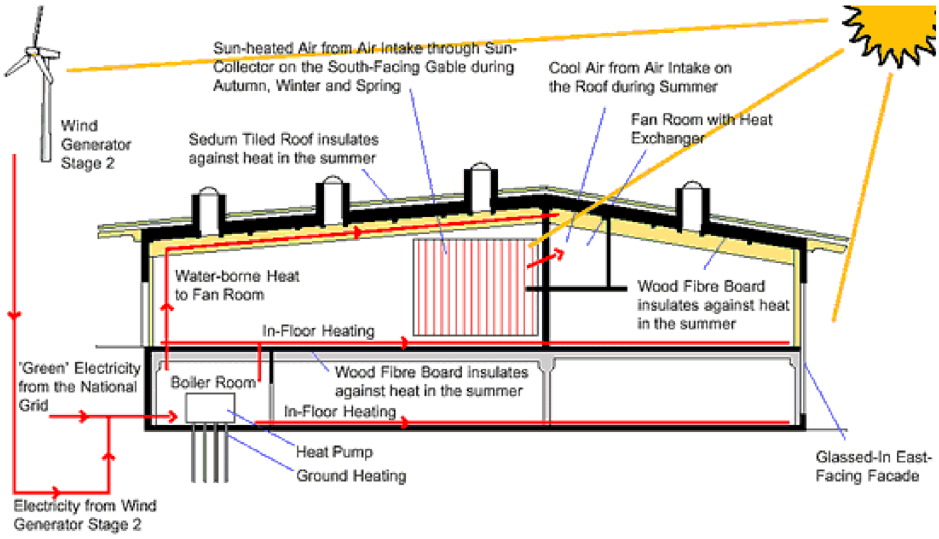

Figure 2. Climate system used in GZ 1 where the electric boiler and heat pump supplies heat to buildings GZ 2 and GZ 3 (from www.greenzone.nu)

Life-cycle cost analyse

A life-cycle cost approach, as described by for instance Flanegan and Norman (1983), is used where the life-cycle costs of an asset is defined as the total cost of that asset over its operating life, including initial acquisition costs and subsequent running costs where the major life-cycle cost components are:

- Initial costs (I) (including site costs, design fees, building cost etc.);
- Operation costs (O) (annual costs including energy, cleaning, etc.);
- Maintenance (M) cost (annual costs and costs for replacement, alteration); and
- Salvage value (S)

The life length, *N*, is assumed to be 50 years. Many buildings however have a significantly longer technical useful life and a salvage value, *S*, from sale can be added. Alternatively this can be a cost for demolition. The discount rate, *r*, has been set to 4 %, which is selected to be corresponding to the long-term cost of borrowing money. The discount rate is varied in a sensitivity test, as this is one of the major factors of uncertainty in this analysis. For calculation of all costs the base year to which future costs are compared is the year 2000.

Initial cost

Initial project costs are the investors costs which arise directly from the project including costs for: land, fees on acquisition, design team fees, demolition and site clearance, construction costs which is the construction price for building works, etc. (Ruegg, 1978). Performing a life-cycle cost analysis of a building requires the collection of a variety of information. Initially, an visual inspection of the three environmental designed buildings was undertaken followed by a meeting with the architect to comprehend the planning and design process used and the development of the project's environmental features. Further meetings with the contractor and the service installation consultants followed to obtain information about the construction work, the heat and ventilation system, and the initial costs associated. Initial construction costs have been followed up based on invoices from the general contractor. Design costs and costs for mechanical and electrical services etc. is provided by the HVAC consultant as a lump sum, which has been allocated to the buildings with the initial building cost as a base. Total initial cost is found in Table 1 and a more detailed cost distribution in Diagram 1.

Table 1. Total initial cost used for a comparison of costs

	Building area (m^2)	Initial cost (SEK/m^2)	Cost comparison
GZ 1	3350	10 053	+17%
Ref 1	3350	8 355	
GZ 2	590	17 592	+4%
Ref 2	590	16 179	
GZ 3	310	22 903	+13%
Ref 3	310	20 000	

Comparing initial costs with the reference buildings, an increase is found. These increases can be traced to: 1.integrated heating system, making it possible to use surplus energy; 2.installation of vacuum toilets; 3.facades of screwed wood panel; 4.wood fibre insulation in exterior walls and roofs; 5.layer of green plants on the roof; 6.lantern sky lights; 7.green plants to purify the indoor air; and 8. sun catcher. Also the cost for external work is higher than for conventional buildings due to extensive work on the area surrounding the facility including creeks and streams to purify used water. For the life-cycle cost calculation, initial costs are applied as a lump sum present value amount occurring at the beginning of the base year. The dominating initial cost elements for the Greenzone buildings are shown in Figure 1.

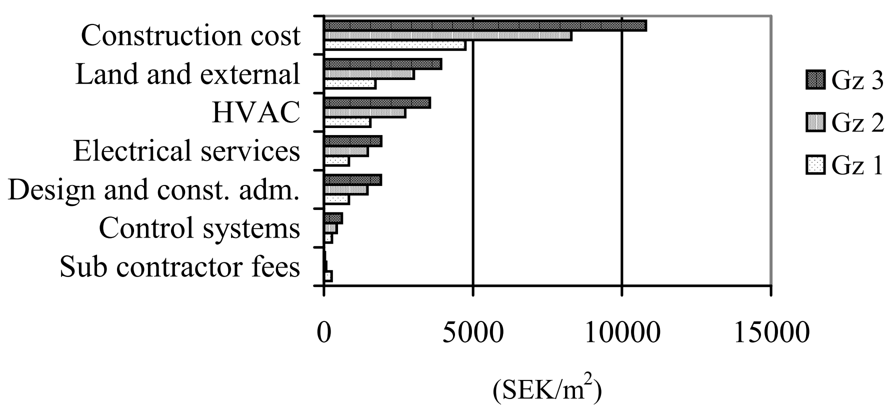

Figure 1. Distribution of initial costs for the Greenzone buildings

Of the initial costs is the construction cost represented by 47 %, land and external works 17 % and costs for service installation systems 16 %.

Operating cost

The operating costs can be defined as the costs associated with operating the building itself including costs for cleaning, rates, energy and security (Al-Hajj and Horner, 1998). For a typical commercial facility operating costs are in large represented by variable costs for energy and cleaning and to a smaller extent, by fixed costs, such as rates, insurances, security, care taking and management administration. The HVAC consultant provided data on energy use for heating and ventilation, Table 2. For the Greenzone buildings the total amount of bought electricity is measured over a full normal year. The electricity for activities is assumed to have no dependence on the design of the buildings. However is the electricity for lighting reduced for all Greenzone buildings due to the lantern skylights, large window areas and motion sensors.

Table 2. Energy use as heat and electricity for Greenzone and the reference buildings.

		Case I		Case II		Case III	
		GZ 1	Ref 1	GZ 2	Ref 2	GZ 3	Ref 3
Area	(m2)	3350	4800	590	590	310	310
District heating	(kWh)	0	141	0	0	0	0
Electricity (heat)	(kWh /m2)	26	0	105	0	110	0
Electricity other	(kWh/ m2)	53	104	733	1017	1029	1452
Total energy use:							
Electricity	(kWh/ m2)	79	104	838	1017	1139	1452
District heating	(kWh/ m2)		141				
Reduction of energy use	(%)	68		18		21	

It is worth noticing that the amount of energy supplied for heating has been significantly reduced especially for GZ1 much due to the heat pump.

Maintenance of the grounds, buildings and services installation, which is performed annually, forms part of the care-taking or facilities management function which, together with refuse disposal, administration and insurance, is assumed to not depend upon the design of the buildings. Water use is however reduced which have an economical effect. The other costs are deemed to be the same for both the Greenzone and the reference buildings. The data required for calculating these other costs has, for the most part, been estimated here by using published statistical data from REPAB (2000). In Figure 2 the distribution of annual costs is shown. To calculate the energy cost, tariffs for Umeå Energi AB, valid in the autumn 2001 have been used for electricity and are 0.464 SEK/kWh. The cost applied for district heating is 0.52 SEK/kWh. Costs represented by salaries vary over time and the cost level for the year 2000 is used.

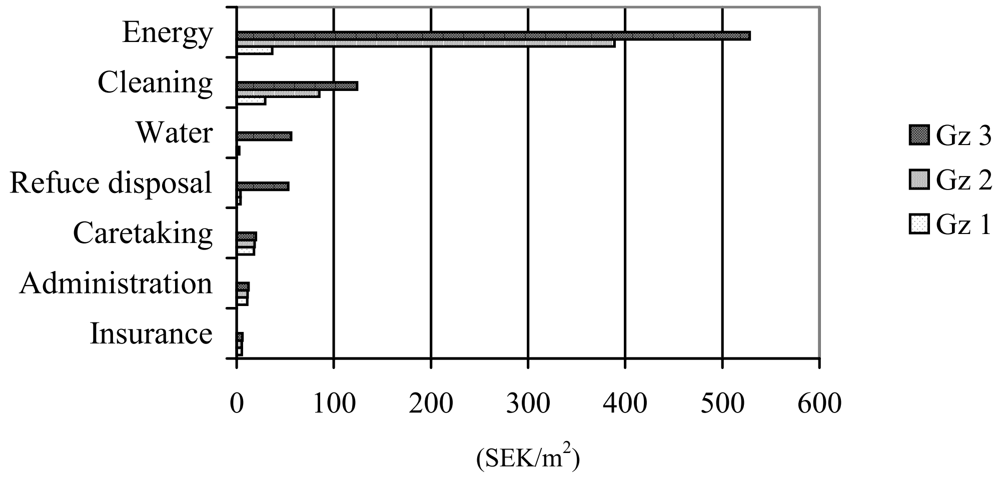

Figure 2. Annual operating costs for the environmentally designed buildings.

The energy costs followed by cleaning, are the most significant of the annual costs especially for GZ 2 and GZ 3 who have quite energy demanding enterprises. For GZ 1 the distribution of annual costs is more traditional where energy costs represent 39 %, cleaning 36 % and care taking 18 %. The water supplied to the carwash is from the ground source system and is normally high. The water costs have here been reduced compared to the reference building. For GZ 3, the costs of water and refuse disposal are relatively large because of the nature of the activities in the buildings.

Maintenance costs

Maintenance needs should be kept under constant review to ensure that the building is in an acceptable state of repair. The cost of repairs and replacement can vary widely, depending on the state of the building and how users look after it. Initially, costs are less than when the building has begun to deteriorate (Flanagan and Norman, 1983). Prognoses of maintenance costs have been classified into:

- envelope (external walls, roof, windows, doors);
- internal finishes (walls, floors, ceilings, windows, doors); and
- mechanical and electrical systems (heat pump, boiler, ventilation)

On the assumption that no substantial reconstruction is undertaken, the maintenance of the main structure can be omitted since the structure's life is the same as the length of analysis. Also, the effects of modernisation and adaptation of the buildings is not included. For remaining elements, the frequency and cost of replacement was found in REPAB (2000). The present values of the maintenance costs are shown in Figure 3. One simplification made is that maintenance costs are assumed to be equal for Greenzone and the reference buildings even though some differences are present.

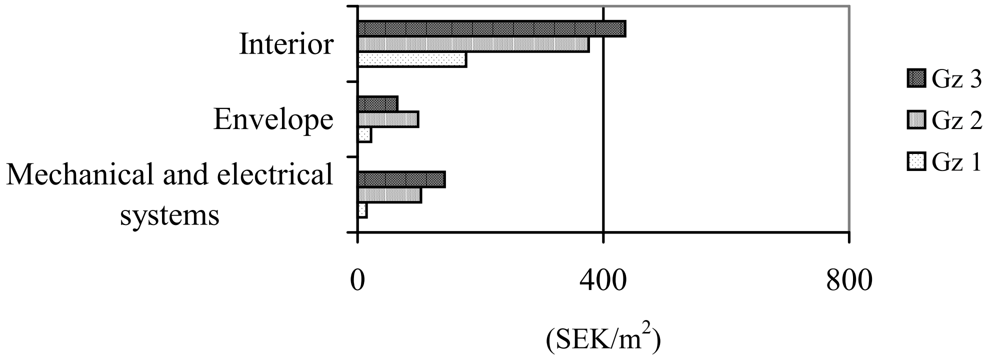

Figure 3. Present value of maintenance cost

Salvage value

The salvage value, *S*, represents the net sum to be realised from disposal of an asset at the end of its economic life, at the end of the study period or whenever it is no longer to be used (Ruegg, 1978). If a salvage value is occurring at the end of a long study period, it tends to have relatively little weight in the analysis because the diminishing effect of the discounting operation. For GZ 2 and GZ 3, the market for the buildings after 50 years is limited due to their specific enterprises and it is assumed that the buildings are dismantled. The effect due to discounting is however small and therefore the disposal cost is neglected in the study. For GZ 1 it is supposed that a higher sales value, due to the environmental performance, can be obtained and is here assumed to be the present value of the initial building cost after 50 years.

Life-cycle cost estimation

To determine the buildings total life-cycle cost, a period of 50 years is used for the analysis. A discount rate of 4 % is selected to be corresponding to the long-term cost of borrowing money. It is assumed that the price attached to operation and maintenance will change, at about the same rate as prices in general, i.e. they will remain constant over the study period. Table 4 show the present value of future costs and the life-cycle cost for the buildings.

Table 4 Life-cycle costs in SEK/m^2

Cost elements	**Comparison I**		**Comparison II**		**Comparison III**	
	GZ 1	Ref 1	GZ 2	Ref 2	GZ 3	Ref 3
Initial cost	10 053	8 355	17 592	16 880	22 903	20 000
Total operation cost	2336	4163	10 820	13 620	17 166	20 281
Maintenance cost	239	239	536	536	678	678
Salvage value	1415	1176	0	0	0	0
Life-cycle cost	11 213	11 581	28 948	31 036	40 747	40 959

The initial cost for the environmental designed buildings is 17 %, 8 % and 13 % higher than for the reference buildings. But the life-cycle cost for GZ 1 and 2 is 7 % lower respectively while the life-cycle cost for GZ 3 is equal. The initial building cost is a dominant element over operating and maintenance cost for all the Greenzone buildings. The maintenance cost has small impact on the total result, less than 4 %. One reason is that annual expenditure for caretaking is included in the operation cost and that no major reconstruction or adaptation is included.

Sensitivity analysis

A sensitivity analysis has been used to simulate the effect of uncertainties in the selected discount rate, energy price and life length of study. Sensitivity analysis is essentially a univariate approach that identifies the impact of a change in a single parameter value within a project with an assumption holding all other parameters constant, described for instance by Flanegan et al. (1987).

The Swedish electricity market is open to competition and the customers are free to buy the electricity from the supplier best suited. The market price is therefore determined by supply and demand and traded on spot markets making it difficult to predict the future development of prices. Due to environmental reasons as possible phase out nuclear of power plants and tax increases in general create an assumption that the total price of electricity can be expected to escalate more than the general inflation. To examine the effect of variation in electricity price the escalation rate is presented as a function of the break-even point. To find the break even point the relation between the life-cycle cost of the Greenzone buildings and the conventional buildings are set equal according to:

$$LCC_{(GZ)} = LCC_{(ref)} \tag{1}$$

$$LCC_{(GZ)} = I_{0(GZ)} + \sum_{t=0}^{N} O_{E(Gz)} \cdot PV_{Esc} + \sum_{t=0}^{N} O_{other(GZ)} \cdot PV_{sum} + \sum_{t=0}^{N} M_{(GZ)} \cdot PV \tag{2}$$

$$LCC_{(ref)} = I_{0(conv)} + \sum_{t=0}^{N} O_{E(ref)} \cdot PV_{Esc} + \sum_{t=0}^{N} O_{other(ref)} \cdot PV_{sum} + \sum_{t=0}^{N} M_{(ref)} \cdot PV \tag{3}$$

where $PV_{sum} = \left[\frac{(1+r)^t - 1}{r(1+r)^t}\right]$ and $PV = \left[\frac{1}{(1+r)^t}\right]$

For the comparison the discount rate, *r,* applied is the rate above the general economy inflation, *i,* where all costs are assumed to increase in price at the same rate as the inflation. However if a cost escalation for a particular item (for instance energy) differs from inflation another procedure that includes the escalation price rate in the discount rate can be used. Such growth in cost is commonly referred to as *differential escalation*, (Kirk and Dell'Isola, 1995). If for instance the energy price escalation rate is less than the discount rate the differential escalation rate, *d'*, is calculated according to (4) and replaces *r* in the PV_{sum} formula. If the energy price escalation rate is higher than the discount rate, $PV_{esc,}$ can be determined according to (5).

$$d' = \frac{1+r}{1+i} - 1 \text{ for } r > i \tag{4}$$

$$PV_{Esc} = \frac{\frac{1+i}{1+r} \cdot \left(\left(\frac{1+i}{1+r}\right)^N - 1\right)}{\frac{1+i}{1+r} - 1} \text{ for } r < i \tag{5}$$

For the sensitivity analysis the discount rate and the escalation rate of the electricity price has been varied, Diagram 4 and 5. It is shown that a high escalation of the electricity cost combined with a low discount rate benefits the environmental design. If the electricity price follows the inflation, the economical beneficial life length of GZ 3 begins after approximately 25 years and for GZ 2 after 44 years. Higher escalation rates reduce the effect of the inital cost, as are lower discount rates. The curves in Diagram 4 and 5 indicates under what circumstances the environmental design is economical profitable, valid for the conditions used in this analysis. When the electricity escalation rate and life length for analyse are found below the curve the environmental design is not profitable. If the parameters are found above the curve the environmental design is profitable.

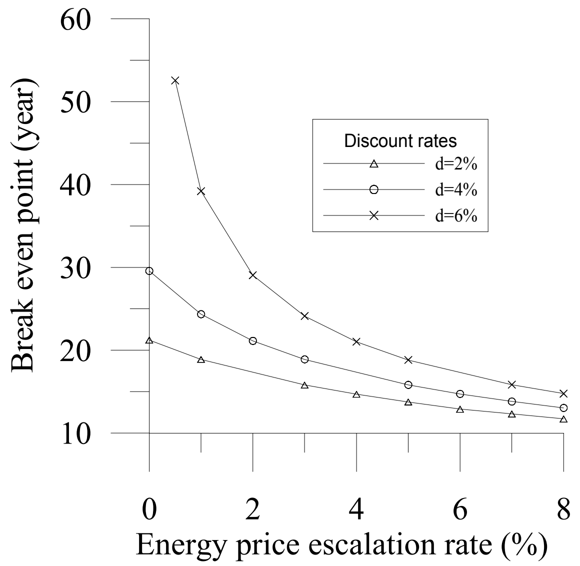

Diagram 4. The break even point as a function of variation in discount rate and energy escalation rate for Comparison I.

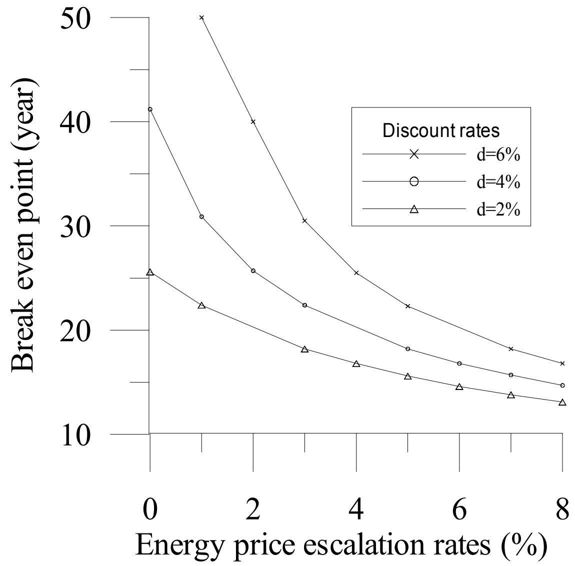

Diagram 5. The break even point as a function of variation in discount rate and energy escalation rate for Comparison III.

If studying Table 4 (Comparison II) this building have the largest economical profit due to the environmental design. With a discount rate of 4 % and no escalation in energy price the initial cost increase will have paid of in approximately 6 years.

Environmental impact analyse

Uppenberg et al. (2001) have quantified the environmental impact from energy production basing the results on available literature of life-cycle inventories and life-cycle analyses. The inventories includes emissions and use of resources during the whole life-cycle and are calculated per unit of useful energy. This implies consideration of the efficiency factor of the production plant i.e. how much of the energy content in the fuel used can be transformed to heat, electricity or work. The inventories presented in Uppenberg et al. (2001) have been used to calculate the potential environmental impact into following categories: global warming potential, acidification and eutrophication. Characterisation factors, which indicates the relation between different substances within one category, is used and from which the potential environmental impact for each category is calculated. The global warming potential (GWP) is for instance estimated by translating other emissions into CO_2 equivalents where the characterization factors are found in IPCC (1994). The characterization factor indicates how effective one gas is on influencing the climate in relation to the CO_2 emission, seen from a one hundred year perspective. The environmental impact represented by categories due to electricity production and district heating is presented in Table 5.

Table 5. Potential environmental impact per kWh electricity production and district heating during 1999 calculated in environmental categories

Environmental impact categories	Equivalents	Swedish electricity production	Hydropower produced electricity	District Heating
GWP, 100 years	g CO_2-equiv.	32,7	5,2	122
Acidification	g SO_2-eqviv.	0,086	0,06	0,458
Eutrophication	g NO_3^{-}eqviv.	0,076	0,009	0,402
POCP	g $C_2H_2^{-}$eqviv.	0,004	0,001	0,014

Emissions from electricity production have been calculated to represent the Swedish electricity mix also including the import from Norway, Finland and Denmark during 1999. The Swedish production consisted of 44,3 % nuclear power, 48,2 % hydropower, 0,2 % wind power and 7 % fossil and bio fuels (SEA, 2001). For the analysis herein it is assumed that the mix of the year 1999 is used during the entire life-cycle and that the energy supply system for heating remains the same in the buildings.

The method applied to calculate a weighted index, *WI*, for combining the environmental impact categories is inspired by Erlandsson (2000) and is based on the Swedish Environmental Quality Objectives (EQO) (Swedish EPA, 2001). The EQOs are in many cases expressed to specifying a maximum discharge allowed for some specific substances (the believed acceptable environmental impact), which are of importance for achieving a long-term acceptable state of environment. By assuming that all of the goals for reduced environmental impact set in the EQOs, to be realised at the latest year 2010, are equally important a weight factor for each category can be calculated and are presented in Table 6.

Table 6. Weight factors for environmental categories based on the Swedish Environmental Quality Objectives.

Environmental impact categories	Weight factor, wf	Unit
GWP	1/7980	kg CO_2-equiv.
Acidification potential	1/31	kg SO_2 – equiv.
Eutrophication potential	1/45	kg NO_3 – equiv.
Photochemical ozone creation potential	1/9.33	kg C_2H_2- equiv.

$$WI = \sum_i \frac{PI_i}{wf} = \frac{PI_{GWP}}{7980} + \frac{PI_{AP}}{31} + \frac{PI_{EP}}{45} + \frac{PI_{POCP}}{9.33}$$

WI weighted environmental impact
PI potential contribution from the impact category
wf weight factor for the impact category

The criteria for green electricity have been presented by the Swedish EPA (and includes only electricity from renewable energy sources such as electricity based on bio fuels, wind power, hydro power built before 1996, and sun power. The green electricity supplied in Umeå represent 100% hydro power. In Diagram 5 to 9 the environmental impact from energy use is based on green electricity for the Greenzone buildings and the Swedish electricity mix for the other buildings.

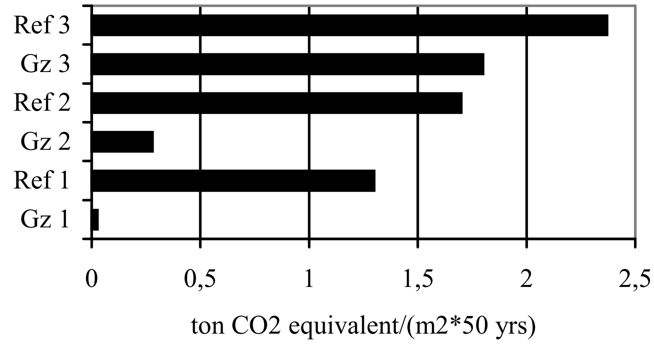

Diagram 5. Environmental impact as greenhouse gas emissions from energy use during the occupation phase.

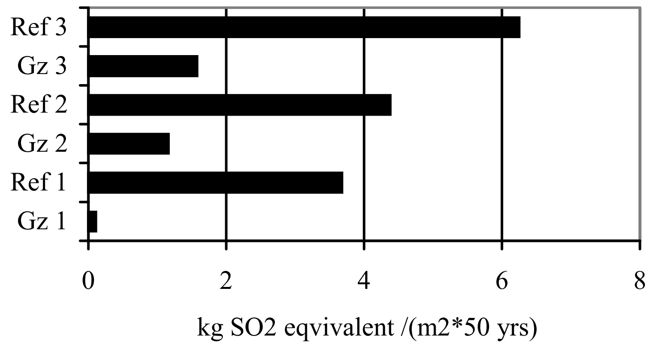

Diagram 6. Environmental impact as acidification from energy use during the occupation phase.

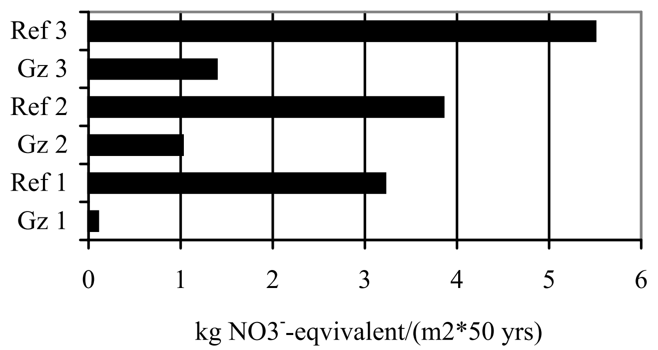

Diagram 7. Environmental impact as eutrophication from energy use during the occupation phase.

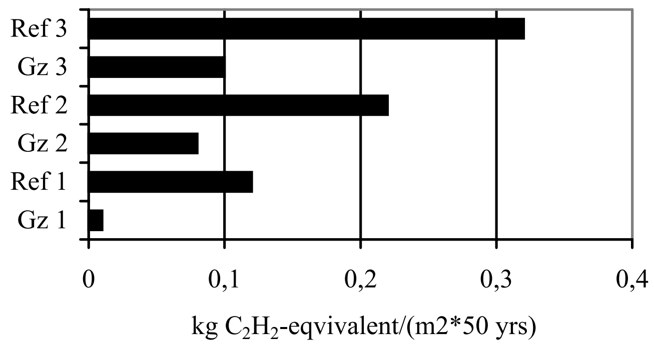

Diagram 8. Environmental impact as photochemical ozone creation potential from energy use during the occupation phase.

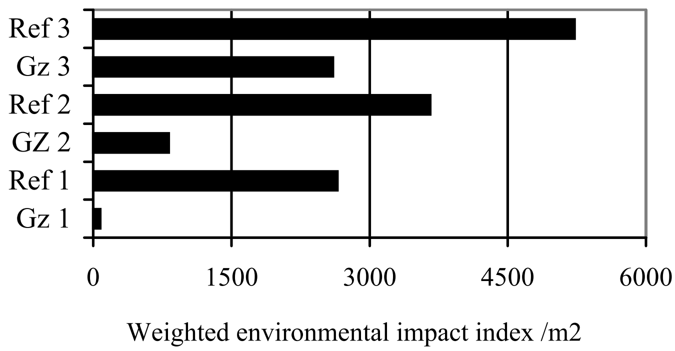

Diagram 9. Total environmental impact, *WI,* from energy use during the occupation phase

The Greenzone buildings have a lower environmental impact in all categories (global warming, acidification and eutrophication) and will conclusively also have a lower weighted impact. This is explained by use of green electricity and reduced energy use for heating. The energy source, efficiency of the heating system and use of electricity for daily activities are of major importance when reducing the environmental impact.

Model for tender evaluation

In an earlier study (Sterner, 2002) it was stated that clients find difficulties in evaluating environmental impact and those operational aspects i.e. mainly life-cycle energy use was not to any larger extent considered in procurement. Using life-cycle approaches for investment decisions combining life-cycle costs with environmental impact can provide stimulus for development of environmental conscious building processes.

The model demonstrated here is developed to be an alternative to considering the tender sum by including the life-cycle energy cost and its associated environmental impact. The motive for this combination is that consideration of future costs can increase the clients profit and that operational energy use is a major source of environmental impact which the building sector can improve by using energy efficient methods. The total combined tender (TCT) price is a function of the price *p,* the life-cycle energy cost LCC_E, and the environmental index EI_X.

$$TCT = p + LCC_E + \varphi \cdot EI_X \cdot a \qquad (6)$$

The complete TCT gives the possibility to include the environmental impact from energy use as a monetary term in the life-cycle cost estimation. For the client's who not want to exceed the perspective of life-cycle costs the environmental impact index factor EI_X can be disregarded. However if used the environmental impact is converted to a cost, here seen as a factor to promote improvements for further energy reductions, and by doing so a comparison on a single monetary criterion is possible in the tender evaluation. The client will have to specify the coefficient *a* in SEK/kWh and the higher the value used is the greater the importance a reduction of environmental impact from energy use is given. Since the weighted environmental impact, WI, is reflecting the energy sources relative impact, the same coefficient *a* can be applied for all types of energy use.

Further, for simplification the life-cycle cost is limited to energy use as being one of the major cost elements in relation to the total cost.

$$LCC_E = \sum_{t=0}^{N} O_E \cdot PV_{sum} + \sum_{t=0}^{N} M_E \cdot PV_{sum} \qquad (7)$$

Furthermore it is suggested that the environmental impact from energy use is related to some energy goals E_G (kWh/m^2, year) determined by the client.

$$\varphi = \left(\frac{(E_H + E_{EL}) - E_G}{E_G} \right) \qquad (8)$$

E_H energy use for heating [kWh/m^2, year]
E_{El} electricity use, except heating [kWh/m^2, year] related to the building
E_G goal for energy use in buildings [kWh/m^2, year]

If the energy use is higher than the set goal, the environmental index will add a cost to the tender evaluation sum. If the energy use is lower, the environmental index will accordingly deduct the cost. The EI_X translate the weighted impact *WI* to a monetary term by specifying a conversion coefficient *a*, representing the impact from energy use.

The environmental index EI_X is calculated as:

$$EI_{(x)} = \frac{\left(\frac{WI_H}{\eta} \cdot E_H \right)}{A} + \frac{(WI_{El} \cdot E_{El})}{A} \qquad [\text{kWh}_{\text{index}}/\text{m}^2 \text{ BRA, year}] \qquad (9)$$

$EI_{(x)}$ Total environmental impact index from energy use
WI Weighted environmental impact index

η The selected heat supply systems efficiency factor
A Building area (m2)

If preferred the environmental impact can be discounted in the same way as cost, implying that future impact will have a smaller effect than today. Such approach is however not suggested since the emissions potential effect on acidification, global warming etc is not likely to be reduced in the future if it is assumed that the tolerance of the nature, oceans and atmosphere is decreasing. For simplicity and clarity, the model is demonstrated on the case study buildings. This is done by first leaving out EI_X and then by inclusion of the same, electricity for GZ is based on wind power, electricity for Ref buildings Swedish mix, *a* is set to 0.13 SEK/kWh which represent the average environmental tax applied to energy. Finally, the goal factor is set to φ = 0.71 which represent the difference between energy use in the average Swedish building compared to the goals for 2005.

	p [kr/m^2]	LCC_E [kr/m^2]	$\varphi \cdot a \cdot EI_x$ [kr/m^2]	p+LCC_E [kr/m^2]	Rank	p [kr/m^2]	LCC_E [kr/m^2]	$\varphi \cdot a \cdot EI_x$ [kr/m^2]	TCT [kr/m^2]	Rank
GZ1	10053	634	-	10687	2	10053	634	134	10821	1
Ref1	8355	2102	-	10457	1	8355	2102	4774	15231	2
GZ2	17592	6723	-	24315	1	17592	6724	1422	25737	1
Ref2	16880	8159	-	25039	2	16880	8159	6464	31503	2
GZ3	22903	9137	-	32040	2	22903	9137	1933	33973	1
Ref3	20000	11648	-	31648	1	20000	12648	9228	40976	2

It is showed that just by including the life-cycle cost the ranking of project 2 changes but not for project 1 and 3. This since the difference in initial costs for building 1 is 17 % higher and for building 3 13 % than the conventional case and the energy cost reduction is not enough to equal the tenders. Inclusion of the environmental impact index changes the ranking of all three projects. This as wind power electricity has a much lower impact than the Swedish electricity mix.

Conclusion

Results from the life-cycle cost analysis show that the environmentally designed buildings are in the same cost range as the conventional buildings in spite these have significantly lower initial costs. This is an interesting aspect as the Greenzone project has been developed to meet high environmental targets and is the first of its type for the client, consultants and contractor involved. For normal procedures both McDonalds and Statoil use standard buildings which have been repeated numerous times and conclusively costs have been optimised. Also environmental designed projects often have a higher standard than conventional buildings which is difficult to evaluate in monetary terms. A broader perspective for the life-cycle cost analysis is a motivated aim for future model development.

Performing a life-cycle cost calculation on a whole project is currently time demanding since data can be somewhat difficult to obtain or estimate. Though, the possibility of reducing future costs should be a motivation for clients. Applying a life-cycle cost approach on the Greenzone buildings showed that the maintenance cost have a relatively small impact on the final result. Especially calculation of maintenance costs is relatively time demanding and better procedures as to arranging data is needed. Leaving out the maintenance cost can be an alternative to simplify the analysis but this decision is however highly dependent on the aim of a comparison, if a single system or a component is evaluated the impact of maintenance cost can be crucial to the result.

Varying the discount rate and the electricity price escalation rate in the sensitivity analysis proved under which conditions the environmental design is advantageous over the conventional design. One conclusion is that the analysis horizon should be at least 20 years to economically justify the environmental performance due to the impact of the initial investment cost on the result.

Environmental impact from energy use was calculated as environmental impact categories. A significant reduction of the environmental impact from the Greenzone buildings is found. The energy source, efficiency of the heating system and use of electricity for daily activities are all of major importance when reducing the environmental impact for commercial buildings.

In tendering it is common to base the cost evaluation on initial costs. To begin with this perspective has to change in favour of using life-cycle cost perspectives. A model, as one parameter of a tender evaluation, is offered here which can assist clients to emphases the importance of environmental impact from energy. The model combines a traditional life-cycle cost approach with an environmental impact index. By awarding reduced environmental impact from energy use in tendering competitions clients can motivate the development of environmental and cost effective construction. Compared to using a traditional life-cycle cost model the results from using this model can in addition to having a significant impact on long-term economic decisions also further motivate energy conservation and use of energy with low environmental impact. However, before using such model some general aspects have to be considered. One is the use of different energy simulation programs giving different results on buildings energy performance. The client should therefore have to determine the type of simulation program to use to make the tender evaluation as fair as possible. Another is deciding the translation factor, *a*. However these aspects are in the hands of the client to decide.

Acknowledgement

The author gratefully acknowledges the financial support of the Foundation for Strategic Research (SSF) for the project, "Life cycle cost, profit and environmental assessment for tender procedures", which forms part of the Swedish national graduate school and research programme, *Competitive Building*. Also SBUF and PEAB have financially supported the project and are gratefully acknowledged.

References

Adalberth, K. (2000). *Energy use and environmental impact of new residential buildings.* PhD thesis. Lund University, Department of Building Physics, Sweden.

All-Hajj, A., Horner, M. (1998) Modelling the running costs of buildings. Journal of Construction management and economics. 16, 459-470.

Aye, L., Bamford, N., Charters, B., Robinsin., J. (2000). Environmentally sustainable development: a life-cycle costing approach for a commercial office building in Melbourne, Australia. Construction management and economics. 18, 927-934.

Cole, R., Kernan, P. (1996) Life-cycle energy use in office buildings. Building and environment. 31, 4, 307-316.

Ecocycle Council (2001). Byggsektorns betydande miljöaspekter: miljöutredning för byggsektorn. Ecocycle Council. In Swedish.

Elmroth, A., et al. (1987) Energisvar, frågor och svar om energihushållning i byggnader. Statens råd för byggforskning, G17:1987, Stockholm, Sweden.

Erlandsson, M. (2000) Viktning av olika miljöpåverkanskategorier baserat på en vision om det framtida hållbara folkhemmet -de svenska miljökvalitetsmålen. Swedish environmental institute (IVL), B1385, Stockholm, Sweden.

Fay, R., Treloar, G., Usha, I-R. (2000) Life-cycle energy analysis of buildings: a case study. International journal of building research & information 28(1), 31-41.

Faith-Ell, C., Sterner, E (2001) The use of green procurement in the Swedish building and road maintenance sectors. 2nd Nordic conference on construction economics and organization, Göteborg, Sweden, 24-25 April, 2001.

Flanegan, R., Kendell, A., Norman, G., Robinson, G, D. (1987). Life cycle costing and risk management. Journal of Construction management and economics, 5, S53-S71.

Flanegan, R., Norman, G. (1983). Life cycle costing for construction. Journal of Construction management and economics,5, S53-S71.

IPCC (1994). Radiative Forcing of Climate Change- The 1994 Report of the Scientific Assessment Group of IPCC; Intergovernmental Panel of Climatic Change, London U.K.

Repab (2000a). Årskostnader 2000: nyckeltal för kostnader och förbrukningar. In Swedish

Repab (2000b) Underhållskostnader. In Swedish

Ruegg, R.T. (1978) Life cycle costing. A guide for selecting energy conservation projects for public buildings. NBS Building science series 113. US Department of commerce, Washington D.C, U.S.

Spedding, A. (1987). Management of maintenance- the need for and use of data. Building Maintenance and economics. E&FN Spon, London 37-47.

Sterner, E (2000) Life-cycle costing and its use in the Swedish building sector. Building research and information 28 (5/6), 387-393.

Sterner, E (2002) Green procurement of buildings: a study of Swedish clients considerations. Journal of Construction management and economics, 20, 1, 21-30.

Stone, A (1967) Building design evaluation. The Chaucer Press Ltd, Suffolk, UK.

Swedish Energy Authorities (2001). Energiläget 2001. Stockholm, Sweden

Swedish EPA (2001) Naturmiljön i siffror 2000. Stockholm, Sweden.

Treloar, G., Love, P., Holt, G. (2001) Using national input-output data for embodied energy analysis of individual residential buildings. Journal of Construction management and economics 19, 49-61.

Uppenberg, S. et al. (2001) Miljöfaktabok för bränslen, Swedish Environmental Institute (IVL), B1334A-2, Stockholm, Sweden.