

Energy Performance, Energy Efficiency & Commercial Buildings: How do they all link up?

A quantitative and qualitative analysis of energy efficiency in buildings
according to Directive 2002/91/EC

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“Your manuscript is both good and original, but the part that is good is not original and the part that is original is not good.” ~ Samuel Johnson (1709 - 1784) (attributed)

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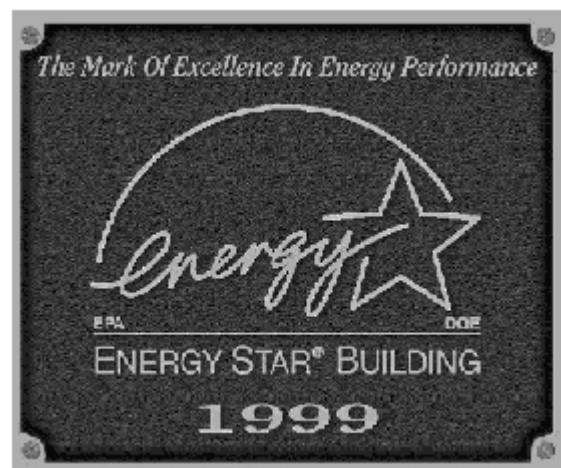
It is my sincere hope that this thesis does some justice to the time and effort you all invested.

“Try as hard as we may for perfection, the net result of our labors is an amazing variety of imperfectness. We are surprised at our own versatility in being able to fail in so many different ways.”

~ Samuel McChord Crothers

From an exceptionally surprised and similarly amazed author,

Kristy



Abstract

Buildings alone consume more than a third of the final energy consumption in Sweden, and contribute to approximately 20% of carbon dioxide (CO₂) gas produced. This trend is especially worrying in the commercial building sector, because of the rate of increasing use of electricity, as compared to heat or primary fuel consumption. The requirements for energy performance of buildings has since been crystallized into Directive 2002/91/EC on the 16th of December 2002, calling for, amongst other things, the establishment of a standardized calculation method for energy performance in buildings, the corresponding minimum requirements, and a certification scheme for rating the performance in buildings.

This thesis focuses on the existing commercial building stock in Sweden, and the necessary requirements to be established by authorities and industry, when the Directive comes into force in January 2006. The approach of the thesis is principally from the industry's point of view. It looks at the three main categories of concern raised by the Directive for existing buildings, and the implications that these concerns may have on the building and construction sector, with trends and information drawn from supporting European Union (EU) Member States.

The outcome of the thesis presents:

- An integrated framework methodology for assessing energy performance in existing office buildings, based on an integration of existing standardized calculation methodologies established at the European Committee for Standardization (CEN) and the establishment of performance-based standards in limiting the maximum energy use in buildings.
- The verification of the framework methodology, and an approach to building energy performance certification, based on the framework proposed, developing current practice in Sweden.
- A discussion into the variance of the simulated energy performance versus the actual energy performance of buildings, why such discrepancies occur, and how they can be reduced.
- Lastly, the implications this Directive has on the EU level of governance, the national level of authority, the building and construction industry, the consumer and the building occupant.

The sum of this thesis analyzes the impact of Directive 2002/91/EC in satisfying Kyoto Protocol commitments as ratified by the EU Member States, including Sweden.

It is important to note that the list of future research in relation to this Directive is extensive, and there exists a wide range of interpretations and opinions from different stakeholders and academics. The analysis presented in this thesis presents just one such approach deemed feasible for implementing Directive 2002/91/EC within the limited span of available time.

Executive Summary

The energy efficiency of a building is dependant on the performance of the total building system, and in other words, the energy performance of the building system. Buildings alone consume more than 40% of the final energy consumption within the European Union (EU), and contribute to a corresponding amount of carbon dioxide (CO₂) gas, a greenhouse gas scientifically proven to contribute to the global warming phenomenon. In Sweden, similar figures for the energy consumption in buildings are reflected. This trend is especially worrying in the commercial building sector because of the rate of increasing use of electricity, as compared to heat or primary fuel. Therefore, in order to reduce greenhouse emissions, energy efficiency issues are addressed by a reduction in the energy consumption of buildings and the enhancement of energy performance.

The need for assessing the energy performance of buildings has since been crystallized into Directive 2002/91/EC on the 16th of December 2002, calling for, amongst other things:

1. The establishment of a standardized calculation method for energy performance in buildings,
2. The corresponding minimum requirements for energy performance, and,
3. A certification scheme for rating the energy performance in buildings.

The Directive has been called the “the greatest step change in energy in buildings” because of the extent of its impact on all 160 million buildings within the EU, and these Articles listed in the Directive are to be adopted and in force by January 4, 2006. However, the problem is that there is no such methodology used or requirements yet in place in many of the EU Member States, including Sweden.

Focus & Objectives

This thesis focuses on the existing office building stock in Sweden, and the necessary requirements to be established by the according stakeholders, when the Directive comes into force in 2006. The approach of the thesis is principally from the industry’s point of view. The objective is to look at the 3 main categories of concern raised by the Directive, as listed above, and what implications it may have on the building and construction sector in Sweden, with trends and information drawn from supporting EU Member States. The objectives of the thesis address these 3 listed categories of concern through:

1. The assessment and the formulation of an integrated framework methodology for evaluating the energy performance in existing commercial buildings.
2. The verification of the framework methodology, in ensuring that corresponding performance standards are met.
3. The discussion of a corresponding certification scheme for building energy performance, where a variance analysis between building energy simulation versus on-site performance is compared.

In addition to the addressed concerns, the implications of such an approach to the Directive are analyzed. This is conducted through a study of possible future scenarios arising in the

building and construction sector with regards to the Directive is assessed on the EU, national, industry and consumer levels.

Analysis Presented

In the course of the analysis, literature was reviewed in relation to these 3 main aspects, together with the evaluation of existing applicable tools. These include building codes and regulations, standardized methodologies, in form of European Standards issued by the European Committee for Standardization (CEN), commercial environmental assessment tools, and energy modeling software commonly used in Sweden. The application of the information reviewed supports the framework methodology and proposals presented in the latter parts of the thesis.

In assessing the energy performance of existing office buildings in Sweden, a study into the energy consumption trends in the commercial sector was conducted. This is to determine the aspects in an office building that has the greatest impact on energy use, and which consume the most significant amounts of energy. The 6 identified aspects of the building system were:

Building Envelope	Lighting	HVAC	Electrical	Lifts & Escalators	Service Water Heating
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These aspects were identified according to the literature reviewed, consumption patterns, the aspects listed in the Annex of the Directive, and other non-quantifiable qualitative aspects of a building that impact energy performance.

The method of analysis is presented both qualitatively and quantitatively, in order to formulate an integrated framework for assessing the energy performance in existing office buildings. This method of qualitative and quantitative analysis is as shown in the following table, where the 6 components were evaluated according to the nature of energy consumption - namely, heat or electricity use.

	Qualitative Analysis	Quantitative Analysis
Procedure	Aim: To provide an overview on the non-quantifiable aspects of a building that influence energy performance in a building.	Aim: To provide quantifiable procedures that assesses the energy performance of a building and its systems, in an integrated approach.
Reviewing literature	Reviewing non-quantifiable aspects of a building that may influence building energy consumption. Qualitative aspects are listed based on a review of existing literature.	Reviewing the existing national energy codes, established CEN methodologies, environment assessment tools, etc. Identifying the 6 energy-intensive aspects in a building from different approaches.
Analysis	Description of qualitative aspects based on the “Building Description Survey” shown in Table 5-3, and presented in Appendix C: Qualitative aspects.	Current energy performance assessment procedure in Sweden reviewed, where computer modeling is conducted w.r.t a reference model. [$Q_{actual} < Q_{reference}$] Analysis into component-based performance standards for heat and electricity consumption, and integrated for whole building performance.
Methodology proposal	The proposal of a qualitative methodology to explain the variance if a building performs unexpectedly in terms of energy consumption. Presented in Figure 5-2.	The proposal of an integrated quantitative framework where existing codes, methodologies and standards are applied. The framework methodology is presented in Figure 5-5, where a range of minimum

		requirements and performance-based standards is applied. Discussion into identifying improvements.
	Qualitative Analysis	Quantitative Analysis
Verification	Not verified. Sensitivity of the proposed methodology relies on the specifics provided in the “Building Description Survey”.	Verified with the use of computer simulation tools in re-iterative testing on a reference model, as is the current practice in Sweden. Methodology proposal verified based on parallel studies conducted in UK, with assumptions on the general applicability in Sweden.
Integration	The summary of these qualitative and quantitative components of the analysis is presented in Figures 5-6 and 5-7. The approach of reiterating the procedure, within the range of minimum requirements, prescriptive requirements and performance-based standards, aims for the building energy performance to comply within this energy efficient range There are limitations to the approach listed, given the wide range of office building types; therefore, assessing every single building component in one methodology is not possible.	

Results

The aim of the proposed methodology is to integrate the 6 identified energy-intensive aspects in a framework so that the overall building energy performance can be assessed. Presently, the application of CEN standard methodologies is not made mandatory or applied in Sweden. Therefore, an integrated framework describing the method of assessment, applying these existing CEN calculation methodologies, prescriptive requirements and performance-based standards, is presented. The maximum benefits of energy performance can be deduced from the qualitative and quantitative iterative procedure presented thereafter in the thesis.

In the verification of the framework, an iterative testing procedure with computer simulation modeling is proposed. Together with the application of CEN standards and comparing parallel studies conducted within the United Kingdom (UK), results show that the outcome of the proposed integrated methodology for assessing the energy performance in existing office buildings reflect:

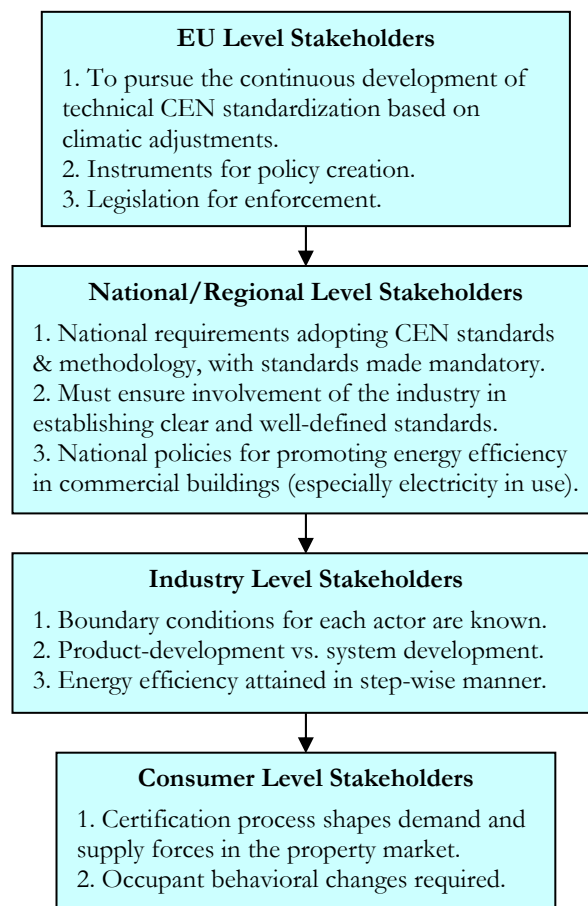
- The fact that compliance with CEN standards will narrow the range of total building energy performance in a well-defined, transparent manner, as opposed to subjective and diverse computer modeling procedures that are highly dependant on the designer’s experience and expertise, as is the practice in Sweden today.
- That the energy consumption from the application of CEN standards will be less than the targets set by the Boverket, therefore the upper bound for energy consumption in office buildings is reduced, and a more energy efficient range of energy use is obtained.

Therefore, based on the narrowed band of energy performance, an energy performance certification scheme is consequently developed. This hybrid method of building energy performance certification is thus based on targets determined by the Boverket and the current best practices simulated from computer software, instead of the quality of the existing building stock. Therefore, the drive for improvements from this method would be more pronounced as compared to a statistical certification approach, which is currently voluntarily employed in Sweden by the EnergiledarGruppen.

Nevertheless, the thesis discusses some of the problems with building design based purely on building model simulations with computer software, and the variances that may arise from this. In summary, this is because an efficiently designed building with energy efficient technologies is only one facet of an energy-enhanced building. For a building to perform in an energy efficient manner, both the building management and occupant must operate in an energy-conscious manner. Therefore, the use of energy modeling software is not without its limitations and designers must be aware of them in order to design and verify applications that are valid, and which will approximate actual building performance.

Future Implications

The future development of the building and construction sector, and its implications from this Directive are analyzed on 4 levels. Cooperation between the stakeholders is particularly important because of the interrelated nature of the Directive, where actions from one level of stakeholders have implications for the next, as shown in the following diagram.



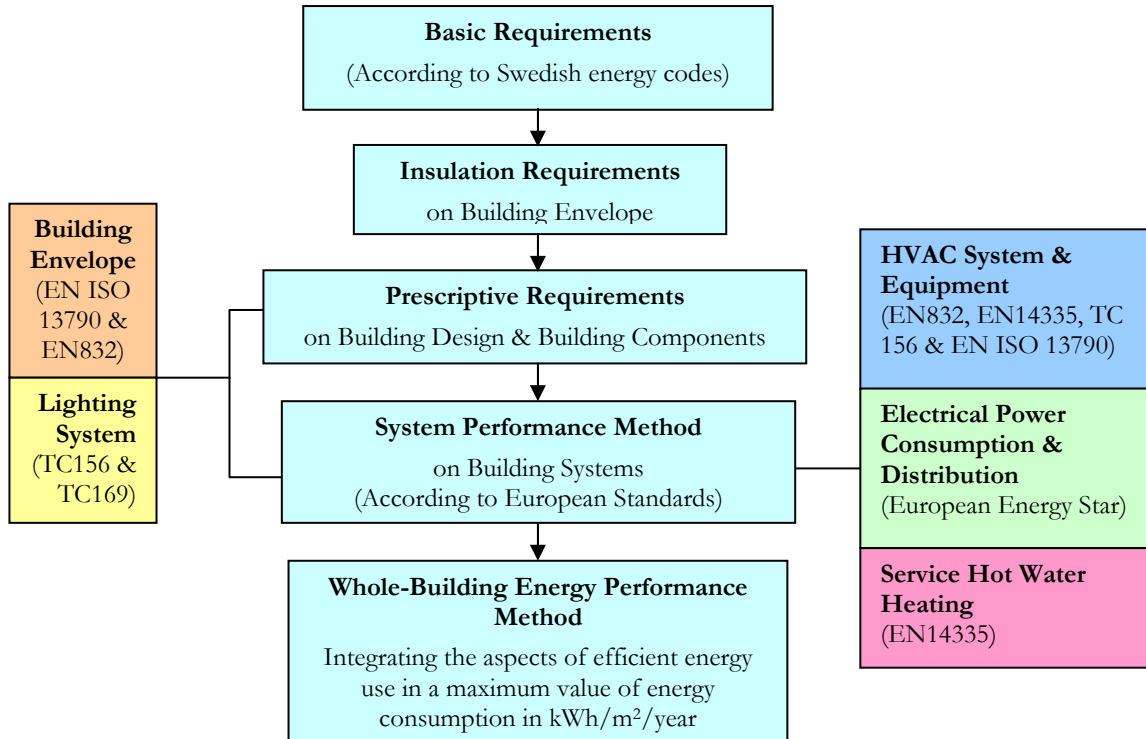
In addition, the scenarios of satisfying the obligations to the Kyoto Protocol by Sweden and the EU are discussed, with the emphasis on the need for reducing the increasing trends in electricity use, which drive targets further away. This can be achieved by the integrated approach presented in the thesis, where energy savings are maximized through the analysis of the whole building system.

Conclusions & Recommendations

Therefore, in concluding the thesis, a holistic approach towards the Directive 2002/91/EC is presented by integrally assessing the energy performance of an existing office building, and by

including the other main concerns of the Directive. In recommending changes, the most crucial of those discussed include:

- The adoption and mandatory use of CEN standards, in parallel with the existing prescriptive requirements and performance-based standards established by Boverket.
- The integration of the use of CEN standards, prescriptive requirements and performance-based standards in a systematic manner, for the assessment of energy performance, and efficiency, in commercial office buildings, as shown below.



- The inclusion of a descriptive qualitative assessment of the building assessed, in addition to the quantification of energy performance to include for non-quantifiable aspects of building energy consumption.
- To base building energy certification schemes on targets set by Boverket, instead of the statistical existing building stock, due to the possibility of general inefficiencies throughout the stock.

On reflection, no new methodology was formulated in the thesis, but instead, existing established calculation methodologies were combined in a logical integrated manner in order to address the energy performance and efficiency of an office building systematically.

It is important to note that there are many different interpretations of the Directive with differing opinions from authorities, industry and academics, and the challenges facing its smooth and successful implementation are similarly extensive. Nonetheless, the analysis presented in this thesis presents one such approach deemed feasible for implementing Directive 2002/91/EC within the limited span of available time till 2006. In reflection to the challenges faced, the opportunities presented by the Directive, and potential of benefits arising from this driving force can similarly be labeled the “greatest step” in advancements towards energy efficiency in buildings.

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1. Introduction

Why do we need buildings with better energy performance?

The need to build better buildings stems from the situation of a scarcity in conventional energy sources in which the world is faced today. Currently, buildings consume considerable amounts of energy and although the effects of which are not immediately apparent, the source of the energy used in buildings contribute significantly to the accumulation of the green house gas (GHG), carbon dioxide (CO₂), in the Earth's atmosphere - especially when the energy is derived from fossil-based sources. This resulting amount of CO₂ content disturbs the natural balance of the Earth's temperature cycles, threatening severe environmental consequences.

Within the European Economic Community (EEC) alone, the European Commission (EC) has estimated that the total final energy consumption in the residential and tertiary sector, largely made up of buildings, amounts to over 40%, and expects the trend to increase in later years.¹ What is of concern is the fact that this value is higher than the consumption of final energy from the EEC's aggregated traffic and industrial sectors, which stand at 31% and 28% respectively.² Estimates in Europe have correspondingly shown that the CO₂ emissions from buildings account for almost 50% of the total greenhouse gas emissions.³ Therefore, initiatives to reduce the total energy consumption of buildings can be identified as important leverage points in efforts to reduce additional emissions of CO₂ into the atmosphere.

Despite vast improvements of efficiency within the individual fields of building materials, installations equipment and building technology, such as the development of better insulation material, walls, and higher-efficiency heating ventilation and air conditioning (HVAC) systems, etc, there has been a lack of initiatives in integrating the use of such energy-efficient material in whole building systems. The traditionally conservative building and construction industry has yet to fully incorporate this for use in high performance buildings with low energy consumption. This negatively affects both environmental initiatives promoted for the reduction of CO₂ emissions into the atmosphere, as well as building occupants through higher operating costs because of the inefficient use of energy.

The integration and assessment of energy performance in buildings is therefore crucial in order to ascertain the efficient level of energy consumption of a building. In establishing this, building energy efficiency is assessed and with identification, certain aspects can be improved in order to extract the maximum benefits out of a more efficient building system. This initiative provides an avenue for reaping the double-dividend benefits of reducing operations and maintenance costs from the reduction in the use of final energy consumption, and it facilitates national commitments of European Union (EU) Member States in compliance with their obligations to the Kyoto Protocol.

¹ Council Directive 2002/91/EC (6) of 16 December 2002.

² Skanska. (2003). <http://www.skanska.com> [2003, April 30].

³ Eurisol (2003). *Energy Performance of Buildings Directive*. www.eurisol.com/pages/EPDirective.html [2003, June 6].

1.1 Background history

This initiative has been discussed extensively within the EEC for a decade, beginning with the Council Directive 93/76/EEC of the 13th of September 1993, which calls for the limiting of CO₂ emissions by improving energy efficiency (SAVE).⁴ The Directive required Member States to “develop, implement and report on programmes in the field of energy efficiency in the building sector”.⁵ Therefore, in line with the developments in the building and construction industry and in order to extract the maximum benefits of a concerted regional effort towards energy efficiency in the building sector, a new Directive has since been entered into force regarding the energy performance of buildings.

This new Directive, crystallized in the European Parliament’s drive for greater energy efficiency where the “prudent and rational utilization” of natural resources of energy, such as “oil products, natural gas and solid fuels” is encouraged, has emerged in the adoption of Directive 2002/91/EC of the European Parliament and the Council of 16th December 2002 on the energy performance of buildings.⁶

The official Directive was passed on the 16th of December 2002, and Member States’ compliance with the framework of necessary laws, regulations and administrative provisions is expected to be in place latest by the 4th of January 2006. The main articles within the Directive call for the adoption of:

1. The formulation of a methodology for the calculation of energy performance of buildings.
2. The setting of minimum energy performance requirements with respect to both new and existing buildings of different categories, with adequate consideration for the indoor environment of the building.
3. The establishment of a building energy performance certificate scheme, where the certificate remains valid for a maximum period of 10 years.
4. Inspection systems for the heating and cooling installation equipment within the building.

While the Directive will come into force in 2006, a flexible 3-year period is allowed for aspects pertaining to Articles 7, 8 and 9 of the Directive.⁷ Currently, the respective national authorities are in the process of reviewing existing standards in adoption of Articles 3 - 6 of the Directive, although interpretations in individual Member States differ significantly. Nonetheless, it is the Community’s general concern that there is a lack of time for successful implementation within the time schedule presented, even with the additional provision of a 3-year period, where Member States remain staunchly skeptical.

⁴ Council Directive 2002/91/EC of 16 December 2002.

⁵ Official Journal L 237, 22.9.1993, p. 28.

⁶ Council Directive 2002/91/EC (2) of 16 December 2002.

⁷ The respective Articles are presented in the final draft of Directive 2002/91/EC in Appendix A.

1.2 General trends

A European sustainability task group examining the reduction of CO₂ emissions in the EU building sector was formed when Directive 93/76/EEC entered into force, and in 1999, concluded that the total potential of CO₂ mitigation within this sector was up to 150 million tons by 2010.⁸ However, as realistically reflected by the task group, Member States' compliance with Directive 2002/91/EC may only save an expected 45 million tons of CO₂ gas by 2010, or even less.

The European Alliance of Companies for Energy Efficiency in Buildings (EuroACE), formed in 1998, has produced more ambitious results by analyzing the pool of residential, industrial and commercial buildings. Results reflect potential savings of 20-25% of the building sector's final energy consumption. Their studies determined an upper bound of emissions reduction, up to 430-452 million tons of CO₂ by 2010, "if an energy efficiency programme were to begin in 2000".⁹ These imply a savings in the current EU CO₂ emissions by 12.5%, which is over and above Kyoto Protocol commitments by the EU, satisfying all obligations if undertaken.

The trend of building energy consumption within the EU can be seen from Figure 1-1; whereby a major part of the domestic and tertiary sector largely consists of buildings. The disturbing fact is that the trend is increasing; and the call for the efficient use of energy in buildings is undoubtedly timely. Table 1-1 similarly reflects values that exhibit the increasing trend in building energy consumption within the EU, with different projection scenarios.

Table 1-1. Average annual growth 1990-2020 in percent of building energy consumption according to different scenarios

Zone	Growth based on:		
	Business as Usual	State of the Art	Environmentally Driven/Advanced Technology
OECD	1.0	0.8	0.4
East Europe/Former Soviet Union	3.7	2.7	1.7
Developing Countries	3.7	2.8	1.8
World	2.4	1.7	1.0

Source: EU (2003)

⁸ Eurisol. (2003).

⁹ European Alliance of Companies for Energy Efficiency in Buildings. (1999). *The Cost Implications of Energy Efficiency Measures in the Reduction of Carbon Dioxide Emissions from the European Building Stock*. CALEB II report. <http://www.styrax.org/demons/EuroACE/doclib/Documents/998495688.904> [2003, June 23].

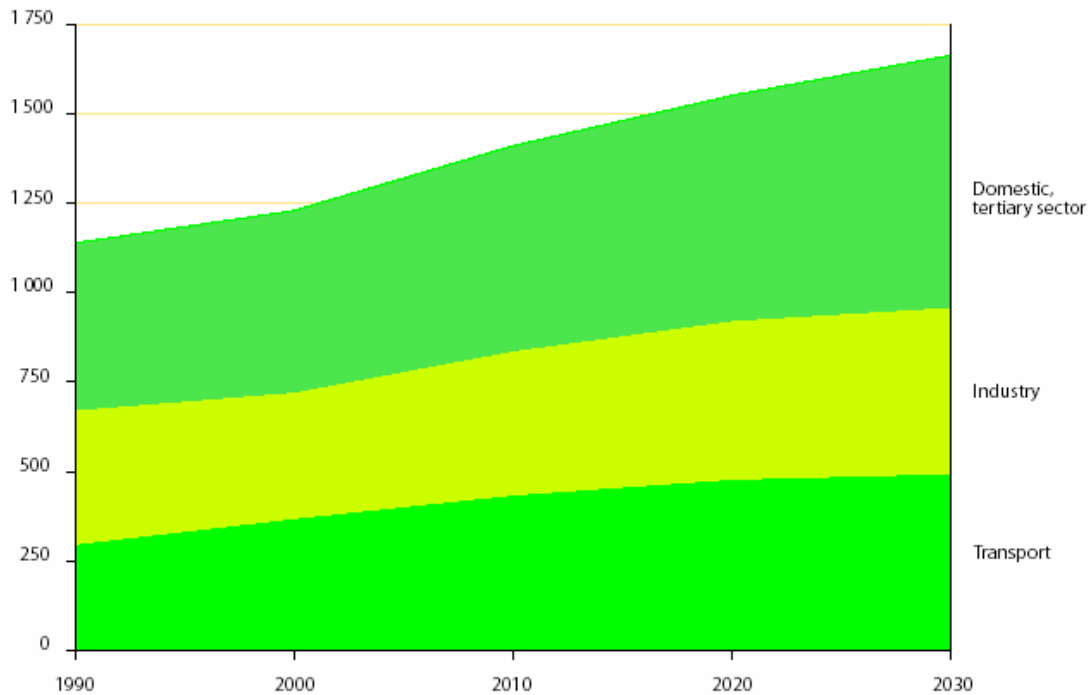


Figure 1-1. Final energy consumption (in million toe)

Source: Green paper COM(2000) 769 final

1.3 Focus problem

In view of the alarming rate of increase in building energy consumption within the EU and the highly conservative nature of the buildings and construction industry, one can applaud the timely adoption of the Directive¹⁰. This has a direct impact on national, or regional, legislation as Member States are obligated to comply with the articles adopted in the Directive. In Sweden, the National Board of Housing, Building and Planning, “Boverket”, is currently drafting the necessary standards and requirements in compliance with the Directive as the Board receives the onus of drafting a national standard calculation methodology for the energy performance of buildings and the setting of the corresponding minimum design requirements, for differing categories in new and existing buildings.

While the formulation of an energy performance methodology is not required from the industry, the building and construction industry anticipates the release and adoption of updated national regulations. With its release, the responsibility is then transferred to the industry through the compliance with the requirements as assessed and stated by the Boverket. Therefore, the role of the industry would involve the use of tools, established in order to assist in compliance with the rules. Such tools do exist, but are currently not integrated in order for energy efficiency within the whole buildings system. Therefore, the initiative for the integration and use of tools within the industry facilitates compliance to the new standards. It is important to note that although the standard methodology calculation and minimum requirements are not as yet published and issued by Boverket, the current

¹⁰ “The Directive” from hereon refers to the Directive 2002/91/EC of 16 December 2002 on the energy performance of buildings, or otherwise stated.

assessment of quantitative and qualitative tools in preparation for the new standards positions the industry favorably in line with energy efficiency issues and will ease the transition and adoption of the Directive towards their added advantage.

There is no such integrated and normalized tool currently used, and the concept of energy efficient buildings is not standardized in Sweden.¹¹ Although the application of energy simulation programs, such as the Swedish Building Regulations (BBR) based program, Enorm 1000, is widely used in Sweden for assessing energy performance in all building types, its use is found to be highly erroneous and non-reflective of the actual energy consumption in buildings.

1.4 Area of focus

Directive 2002/91/EU differentiates building energy performance between new and existing buildings, including the different categories defining building use. This thesis will cover the analysis of commercial buildings, designated for office use. The focus of research can be justified by the significant amount of energy consumed during maximum peak load in the daylight working hours, exerting an additional burden on local utility supply systems. In order for initiatives to have a direct impact on energy consumption, effective peak-shaving alternatives should be studied for the reduction of peak energy use. Therefore, with this purpose in mind, the impact from commercial buildings, comprising of a major portion of the tertiary sector, cannot be ignored.¹² This is the motivation behind the purpose of the assessment of energy performance and hence efficiency.

Figure 1-2 shows the typical breakdown of energy use in commercial buildings within the EU.

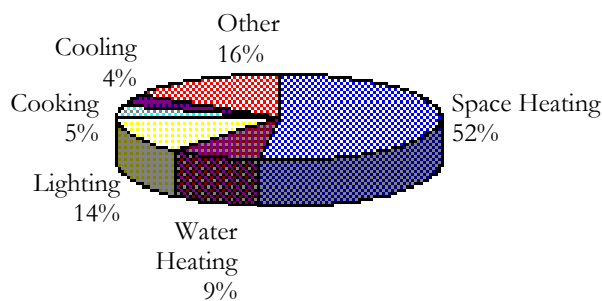


Figure 1-2. Breakdown of energy consumption by end-use in the commercial sector

Source: EU (2003)

The focus of this thesis lies predominantly in the study of existing commercial buildings; this is because the assessment of existing buildings has a larger impact than in new buildings. Although studies have reflected that up to 90% of all energy consumption in a building is

¹¹ Femenias, P. (2002). Demonstration Projects as Support for Sustainable Development of Building Practices. In Chalmers Institute of Technology. *MISTRA – Sustainable building: Experiences from a cross-disciplinary research programme*, p. 51. Gothenburg: Chalmers University of Technology.

¹² Thuvander, L. (2002). The Swedish Building Stock – A conceptual model for describing resource deposits and resource flows. In Chalmers University of Technology. *MISTRA - Sustainable building: Experiences from a cross-disciplinary research programme*, p. 39. Gothenburg: Chalmers University of Technology.

determined at the design phase, the total potential of general improvement is limited in the scope of new buildings.¹³ This is justified by the fact that the rate of construction in Europe today represents a minor pool in comparison to the existing built environment, and the building turnover rate in Sweden is only at about 2%.¹⁴ 90% of the buildings slated for use till 2020 has been built and 75% of these would remain till 2050, while up to 50% of the current building stock has been built before 1965.¹⁵ This typically holds true for the current state of the building and construction industry in Sweden, where commercial buildings are designed for a typical life span of 50 years, therefore, the general potential for improvements are larger in the existing building stock.

1.5 Scope and objectives

The geographical scope of this thesis covers the general commercial office building sector in Sweden. It is of interest to note that the Board of Housing, Building and Planning in Sweden has existing building regulations in place containing “mandatory provisions and general recommendations” in Sections 6 and 9.¹⁶ These Sections cover building design regulations and standards in the areas of “Hygiene, Health and the Environment” and “Energy Economy and Heat Retention” respectively.¹⁷

Within the technical scope, this thesis does not strive for the technical assessment of mechanical and electrical (M&E) solutions for the improvement of energy performance in existing commercial buildings, neither will the study be technology-specific. Nevertheless, the integrated assessment of general energy performance, and the identification of energy efficiency aspects in a commercial building, will be analyzed with respect to the major energy-consuming components of a building. These aspects include space heating, cooling, water heating and lighting as reflected from Figure 1-2.

This involves an initiative towards the quantitative and qualitative assessment of energy efficiency in existing commercial office buildings in Sweden,¹⁸ and how improvements should be positioned for the smooth transition of the Directive. An objective of this thesis would also be to assess the implications of the standards and regulations to be brought about by the Directive, with respect to the building and construction industry. The principle viewpoint of this thesis is based on the approach of the industry in relation to the Directive and its adopted Articles. Cooperating with Skanska AB, a multi-national company operating in

¹³ Building and Research Establishment Ltd. (2002). *Renewable energy: Constructing the future*. Issue 12. p. 11. <http://projects.bre.co.uk/sustainable/SusConstructionData.pdf> [2003, May 5].

¹⁴ European Union. (2003). *Buildings Overview*. http://europa.eu.int/comm/energy_transport/atlas/htmlu/boverview.html [2003, June 6].

¹⁵ National Board of Housing, Building and Planning, Boverket. (2003). <http://www.boverket.se> [2003, June 6].

¹⁶ Building Regulations BBR: *Mandatory provisions and general recommendations*. BFS 1993:57 with amendments up to BFS 1998:38 and BFS 2000:22.

¹⁷ The analyses of these existing buildings design standards and regulations will be covered in Chapter 4: Review existing tools and literature, of the thesis.

¹⁸ The inclusion of a qualitative assessment is important because certain non-quantifiable aspects can significantly affect the energy performance of a building, and the quantitative analysis only covers the efficient technical design of a building. This is only one facet of energy efficiency, and other facets such as efficient building management practices and occupancy is similarly crucial. This will be elaborated further in Sections 5 and 6.

construction-related services and project development, facilitates the assessment of key aspects in this thesis.¹⁹

In order to arrive at this objective, 3 sub-objectives are analyzed in the course of this thesis:

1. The assessment and the formulation of a framework methodology for the integration of energy performance in existing commercial buildings, in order for the extraction of maximum benefits.
2. The verification of the framework methodology and the discussion of a corresponding certification scheme for building energy performance, where a variance analysis between building energy simulation versus on-site performance is compared.
3. The study of future scenarios arising in the building and construction sector with regards to the Directive on the EU, national, industry and consumer levels.

It is important to note that the issues of energy performance and efficiency in buildings are closely tied to aspects of indoor air quality and comfort levels. To segregate the analysis in order to study only the energy consumption patterns in commercial buildings would prove inadequate, as a complement study on indoor air quality is necessary for the results to be of value. Therefore such issues would also be covered in this thesis.

On the other hand, issues pertaining to a common phenomenon known as the “sick building syndrome”²⁰ relating to occupant health and risk would be left largely untouched. Such buildings have extremely effective insulative properties and energy performance but do not correspond with adequate occupant comfort levels. The scope of this area will not be covered in the thesis. In this thesis, it is assumed that the current standards in the Swedish building regulations conform to the necessary requirements for occupant health, environment and hygiene. It is similarly assumed that the shortcomings found previously in “sick buildings” have since been corrected, with deficiencies in the requirements regulating the minimum indoor air quality conditions rectified.

¹⁹ Skanska. (2003).

²⁰ The “sick building syndrome” refers to a situation where “reported symptoms among a population of building occupants can be temporarily associated with their presence in that building”. *What is the sick building syndrome?* <http://www.drirotors.com/articles/article2.htm> [2003, May 29].

1.6 Research questions

In addressing the objective and sub-objectives listed above, and within the defined approach, focus and scope, this thesis endeavors to address the following academic research questions:

1. How can one assess the building energy efficiency of existing commercial buildings in an integrated transparent manner, and which aspects can/should be identified for the extraction of maximum benefits?
2. How can one verify the proposed assessment procedure, and how can it be applied in the existing commercial building stock?
3. What implications does this Directive have for the future of the building and construction sector in relation to what has been proposed, and why?

1.7 Methodology

Based on the abovementioned research questions, this section covers the approach adopted in answering the specific questions, with the specific research method undertaken explained.

First, a literature review of the existing standards and codes was conducted, in relation to the developments in energy efficiency in the building sector. This facilitated the compilation of information based on the existing regulations and level of efficiency already in place. The similar review of other existing methodologies for energy performance calculations and tools used facilitated the formulation of a framework methodology. This is because the framework methodology proposed should apply currently used techniques and consist of established methodologies, incorporating the wealth of information already available.²¹ The approach adopted for incorporating the existing information into an integrated framework involves both a quantitative and qualitative analysis of energy performance in existing office buildings.

The application of specific energy metrics, indexes, standardized methodologies and set indicator tools is applied in the above case.

In the verification analysis, the application of building energy simulations, using energy modeling software, is proposed in order for the presented framework to be tested and verified. A procedure for verification with reiterative simulations was developed. Results are largely based on the supporting reviews of existing reports conducted on similar case studies within the United Kingdom. It is assumed that the energy performance of existing office buildings within Sweden would reflect similar results.

In being aware of the limitations with building energy simulations, an additional discussion into the limitations of the use of computer-simulations was provided in a variance study between simulated data generated and the energy consumption reflected in audits conducted on commercial office buildings. The discussion of several qualitative factors that contribute to the divergence is provided and based on the review of supporting literature.

²¹ O'Neill, H., Warren, A. (2001). *European Efficiency Report: European Union Member States*. Association for the Conservation of Energy, UK. 92-97. http://www.euroace.org/reports/R_090101.pdf [2003, June 6].

As called for by the Directive, a certification scheme that certifies the efficient energy performance of buildings should be developed. Therefore, the analysis of an approach of such a required certification scheme was based on:

1. The verified framework methodology for assessing energy performance proposed in the Section 5 of the thesis.
2. The review of current tools available and used with the EU. These commercial assessment tools benchmark performance.
3. Current developments within Sweden in the voluntary EnergiledarGruppen certification procedure.

Recommendations to improve the EnergiledarGruppen's certification are proposed in the concluding parts of the analysis. This is presented using a hybrid approach of computer-simulated results and targets to limit the energy consumption in office buildings.

Lastly, for the discussion into the future implications of the Directive, the approach of a qualitative analysis on what implications the Directive has on 4 different levels, was discussed, with supporting information obtained from EU Member States. These implications were divided to include the possible impacts on:

1. The EU level of governance;
2. The National/regional level of authority;
3. The building and construction industry; and,
4. The consumer level.

Based on these implications, an assessment into the prediction of future short- and long-term scenarios was conducted, and a description of a Business As Usual (BAU) scenario was analyzed in relation to commitments and the progress required in satisfying Kyoto Protocol obligations within Sweden and the EU. Therefore, the sum of the thesis analyses the greater picture in potential contributions to Kyoto Protocol obligations through energy efficiency in the existing commercial building sector.

2. Definitions

This chapter provides normalized definitions to frequently used terminology in this thesis. This facilitates referencing and prepares the reader for the subsequent analysis sections, where a clear understanding of the terms and metrics would prove highly beneficial.

2.1 Standard definitions

Table 2-1 lists the standard definitions of frequently used terminology in this thesis.

Table 2-1. Standard definitions of frequently used terminology

New Buildings	New buildings are considered, within the scope of this thesis, to be buildings either: (i) In the process of being built, at the design or construction phase; or, (ii) Completed buildings that are less than 3 years old.
Existing Buildings	Existing buildings refer to the total existing building stock, discounting the “new buildings”.
Building Envelope	This consists of the walls, windows, floor, roof, doors and foundations of a building. ²² The external skeleton, which determines a significant portion of the heating and cooling load, contains conditioned air for the health and comfort of the occupants. In summer, the heat transfer is through the building envelope and into the building, while in winter the reverse occurs.
Thermal Bridges	This refers to a particular element, or an assembly of elements, in the building envelope where heat transfer is at a significantly higher rate than through the surrounding building envelope. ²³
Energy Performance of a Building	This refers to the amount of energy consumed, or estimated to be consumed, to meet the demand of energy required with the standard use of the building. ²⁴

The energy performance of a building may, amongst other things, include the aspects, such as: (i) Heating, (ii) Hot water heating, (iii) Cooling, (iv) Ventilation, or, (v) Lighting.

And as suggested in the Directive 2002/91/EC, “the amount of energy shall be reflected in one or more numeric indicators which have been calculated, taking into account, insulation, technical and installation characteristics, design and positioning in relation to climatic aspects, solar exposure and influence of neighboring structures, own-energy generation and other factors, including indoor climate, that influence the energy demand.”²⁵

²² Energy Saving Now. (2000). <http://energy.saving.nu/tips/envelope.shtml> [2003, May 5].

²³ United States Department of Energy. (2003). *Office of Energy Efficiency and Renewable Energy: Building energy codes*. http://www.energycodes.gov/support/metal_faq.stm#b [2003, May 5].

²⁴ Directive 2002/91/EC of 16 December 2002, Article 2: Definitions.

²⁵ Directive 2002/91/EC of 16 December 2002, Article 2: Definitions.

2.2 What is an energy efficient building?

Very often vague claims to energy efficiency are substantiated by mere compliance to minimum requirements, or the installation of particular energy-efficient equipment.²⁶ Currently, “energy efficient” aspects are impossible to assess, because of the lack of knowledge of what exactly is an energy efficient building. The 3 features listed by Meier, Olofsson & Lamberts, cover an adequate definition of an energy efficient building.²⁷ Therefore, a commercial building satisfying these 3 elements can be found to be “energy efficient”:

1. Containing energy efficient technologies, operating as designed, in reducing energy use.
2. Supplying the required amenities and features expected for the standard use of the building, for at least 60 hours per week.
3. Operated in a manner to be efficient, which gives evidence of low energy use when compared to other similar buildings.

2.3 Standard energy metrics and indicators

The use of several indicators quantifies energy use with respect to certain units of energy consumption. Table 2-2 lists the standard indicators and energy metrics used in this thesis and the application of their use. These indicators can be used with reference to either a single building, or in relation to the total building stock.

It is interesting to note that the definition of “area” defers in context with different literature. For example, as defined in the Sweden, the net area of a building corresponds to the usable heated area of the building, while in other literature; this is referred to as the net building area, or total “useful” floor area.²⁸ For simplification, this thesis assumes that these terms for “area” refer to the same thing, with the main definition derived from the code of statutes of the Boverket - where “area” refers to the usable heated area of a building, heated to one or more given set point temperatures.²⁹

Likewise, for the definition of “energy consumption”, when defined with established performance-based standards in Sweden, it refers to the “net energy consumption”, and in other literature, “final energy consumption” figures are used. The distinction here refers to the “final energy” which is delivered to the building site, as compared to the “net energy” use in the building.³⁰ The difference being the cumulative losses between the sources of input and output respectively, which may distort figures by up to +20%. Although the use of “net energy” is more extensive in Sweden, the figures used in this thesis refer mainly to the “final

²⁶ Meier, A., Lamberts, R., & Olofsson, T. (2002). *What is an energy efficient building?* p. 1. http://www.labeee.ufsc.br/arquivos/publicacoes/ENTAC2002_meier.pdf [2003, May 3].

²⁷ Meier, A., et al. (2002). *What is an energy efficient building?* p. 10.

²⁸ Directive 2002/91/EC of 16 December 2002, Article 6.

²⁹ Jonsson, Carl. (2003, July 1). *Re: Assessment criteria document*. Email to Kristy Heng.

³⁰ Thomsen, K. E. (2002). *Enquiry on Global Philosophy of the energy performance calculations*. p. 13. http://butler.cc.tut.fi/~keranen/save/B1_laskenta/T1/1_Global_philosophy_data.doc [2003, June 6].

energy consumption”, unless otherwise stated. This is because the use of “final energy consumption” incorporates losses and reflects true energy performance.

Table 2-2. Standard indicators and energy metrics used

Indicator	Energy Metric (Units)	Application of use
Annual final energy consumption	kWh/m ²	Also known as the Building Energy Performance Index when expressed in GJ/m ² /year. ³¹ Applied in general calculations summing both heat and electricity energy consumption in final energy use.
Annual final energy consumption per volumetric space	kWh/m ³	For volume-adjusted final energy use comparisons. This indicator takes ceiling height into account.
Annual final energy consumption per thousand annual person hours of occupancy	kWh/kaph	Building energy consumption figure normalized for occupancy densities. ³² Facilitates the comparison of <i>building design</i> , without occupancy distortions. ³³
Annual electricity consumption	kWh/m ²	For the quantification of electricity use in electrical applications within a building’s final energy use.
Annual heat consumption	kWh/m ²	For the quantification of heat use in non-electrical applications within a building’s final energy use.
Annual primary energy consumption	kWh/m ²	Adjusted to normalize the discrepancies between final and primary energy, given the difference in the practical and monetary value of heat and electricity. In Sweden, the factor of 2.5 is applied to electricity energy in converting final energy into primary energy, based on the national fuel mix. ³⁴
Peak power consumption	W/m ²	Includes the power consumption of “lighting, appliances and miscellaneous loads” on the building. ³⁵
Annual final energy use per occupant	kWh/person	Final energy figure normalized with respect to the occupancy densities only.
Annual final energy use per occupant per room (office space)	kWh/person.m ²	Annual final energy consumption normalized in terms of net building area and occupants. Facilitates absolute comparisons in different regions.
Annual final energy use per degree-day	kWh/degree-day	Climate-adjusted data for effective space heating and electricity consumption comparisons. Facilitates both relative and absolute comparisons.
Simulated annual final energy use	kWh/yr	Simulated final energy use values from building energy modeling programs, with variances not exceeding ±20%.

³¹ Cole, R. J., Larsson, N. (2002). *Green Building Challenge: Environmental performance indicators*. p. 1. http://jbase208.eunet.be/Workshop/Report/presentations/Cole_&_Larsson.pdf [2003, May 5].

³² Cole, R. J., Larsson, N. (2002). *Green Building Challenge: Environmental performance indicators*. p. 5.

³³ Cole, R. J., Larsson, N. (2002). *Green Building Challenge: Environmental performance indicators*. p. 5.

³⁴ Gräslund, J., Johansson, L. (1999). *Miljöpåverkan avseende primärenergibehov och CO₂-utsläpp för kontorsfastigheten. Skanska Teknik AB*. Malmö: Skanska Teknik AB.

³⁵ Yik, F. W. H., Burnett, J., Jones, P., Lee, W. L. (1998). Energy performance criteria in the Hong Kong Building Assessment Method. *Energy and Buildings Journal*. Issue 27. p. 212.

Source: Heng, K. (2003)

While the indicators listed in Table 2-2 may be extensive, the tendency to simply compare indicators numerically cannot be representative of a true assessment of a building.³⁶ Even within the category of office space buildings, variances within building orientation, building aspect ratios, occupancy densities and operation frequencies may skew numerical results. Therefore, the inclusion of a qualitative assessment is necessary. This qualitative assessment should describe features of the building that cannot be otherwise quantified. Whether or not this assessment should be standardized and compared against a set of qualitative criteria will be analyzed in the following sections the thesis.

2.4 Standard procedures for measuring metrics

Assessments based on metered building data may give rise to skewed results in the evaluation if the data is incorrectly collected.³⁷ Often, “typical” input data might be taken on a day that does not reflect typical climate and user patterns; meaning that the weather was usually warm or cold, and/or occupants may have manually-adjusted the indoor climate differently. Similarly, data collected from inappropriate locations, or a lack of measurement points, may give rise to gross inconsistencies. To avoid such, and other, problems associated with incorrect data collection and input, the building “should be tracked for one year” and comprehensive energy audit documentation over a period of 2 years should be obtained.³⁸ It should be noted that data collection of the indoor conditions should not be taken near existing heaters, vents or other appliances.

It is good practice to have energy consumption figures referenced against the systematic monitoring of indoor air quality levels and the environment, performed with hourly intervals, to ensure that systems are working as designed in providing the required air quality conditions.³⁹ Corresponding information, such as the outdoor climate and actual internal conditions of occupancy, intermittent heating, etc, should be collected with surveys, measurements or monitoring, as far as reasonable costs apply. Likewise, the energy-metered values should be verified with annual bills with regards to the actual cost and the actual amount of energy used.

If simulations are performed on the collected input data from existing office buildings, “the confidence intervals of the output should be assessed” with the experimental energy consumption.⁴⁰ While this verification method is not deemed mandatory, it often provides good judgment regarding the validity of the collected results. If the confidence intervals

³⁶ Heng, K. (2003). *Energy efficient buildings*. p. 14. International Institute for Industrial Environmental Economics. [2003, June 6].

³⁷ Yik, F. W. H., Burnett, J., Jones, P., Lee, W. L. (1998). Energy performance criteria in the Hong Kong Buildings Environmental Assessment Method. p. 210.

³⁸ United States Green Building Council. (2002). *LEED Green Building Rating System for Existing Buildings, LEED EB version 2.0*. p. 20. http://www.usgbc.org/Docs/Existing_Buildings/LEED-EBvPilot.pdf [2003, June 6].

³⁹ US Green Building Council. (2002). *LEED EB version 2.0*. p. 21.

⁴⁰ European Standard EN 832:1998E. *Thermal performance of buildings - Calculation of energy use for heating - Residential buildings*. p. 13.

match significantly, the input can be verified correct. But if distinct intervals are reflected, the need for further on-site investigation will be required for additional verification.⁴¹

⁴¹ EN 832:1998E, p. 13.

3. Commercial building trends in Sweden

This section provides the background information on commercial building energy consumption trends in Sweden, based on some of the indicators listed in Section 2. While exact information cannot be always obtained, data from the tertiary, service or commercial sectors do reflect approximate consumption figures largely utilized in the commercial building sector. The trends in Sweden can therefore be inferred from these records

3.1 General development

The general development path of Sweden from the years 1990-2000 can be seen from Figure 3-1. Since this period, the average Gross Domestic Product (GDP) averaged a 1.7% growth every year, discounting 3 continued years of recession from 1991-1993, as seen in Figure 3-1.⁴²

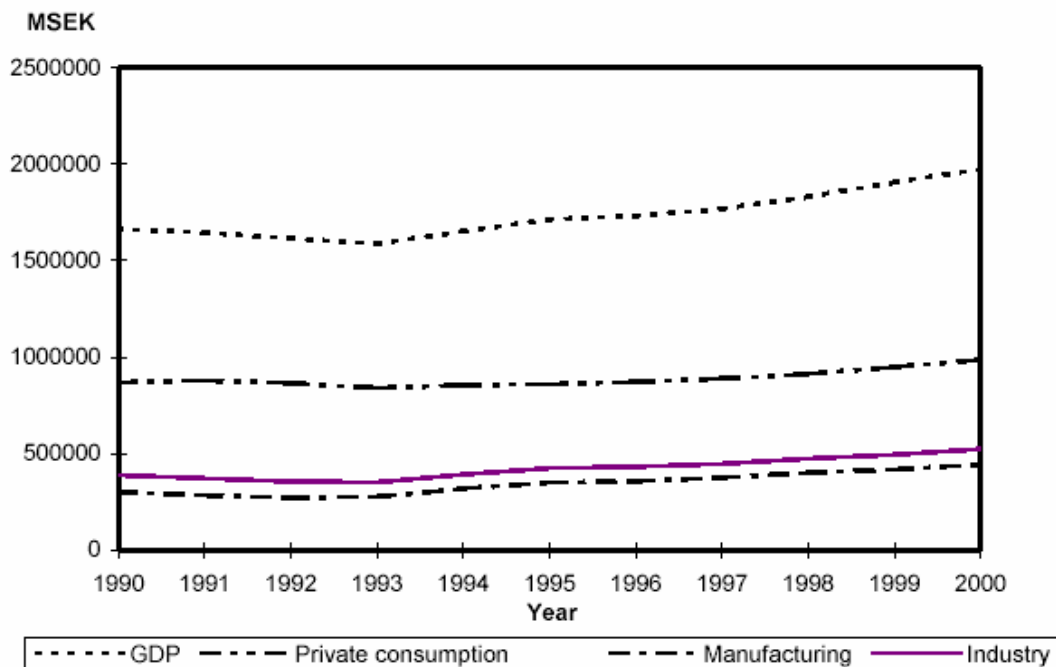


Figure 3-1. Macro-economic developments in Sweden

Source: *Energy efficiency in Sweden (2002)*

The GDP reflects substantially higher growth after the period of economic depression, and although figures for final energy consumption in commercial buildings is not shown, its trend can be deduced from the figures from private consumption included in the diagram.

Additionally, based on final energy intensity figures since 1990, it is reflected that there has been a reduction of 11% of final energy used per unit of GDP. In terms of primary energy

⁴² Swedish Energy Agency. Energimyndigheten. (2002). *Energy efficiency in Sweden 1990-2000*. p. 8. <http://www.odyssee-indicators.org/Publication/PDF/Swe-r01.pdf> [2003, July 3].

intensity, the reduction is at 16%.⁴³ With such figures, one can broadly conclude that there is an increasing performance, with respect to energy efficiency, in Sweden since the last decade. Nevertheless, it is important to note that these broad generalizations do not reflect whether this general trend can be extended to the tertiary sector, and more importantly, the commercial building sector. This would be studied in the following sections.

3.2 Energy consumption trends

Based on the growth of the country, the total final energy consumption in Sweden has been growing at a rate of 0.6% from 1990-2000, and the corresponding use of electricity, at a higher rate of 0.8%.⁴⁴ This pattern of consumption is largely influenced by the residential and service sectors, where the greatest increase in final energy consumption has been noted. The particular increase is accounted for because of changes in heating patterns, with the residential use of electricity for the generation of heat, instead of the traditional use of oil. In addition, the steep increase in the use of electricity in building service systems is also a main contributor to the increase found in the sectors.⁴⁵ Nevertheless, the share of district heating in Sweden has increased, although the growth is limited with a 1% increase over the decade.

Despite this increase, the proportions of final energy consumption by the different sectors in Sweden have been generally stable from 1990-2000, as seen in Figure 3-2.

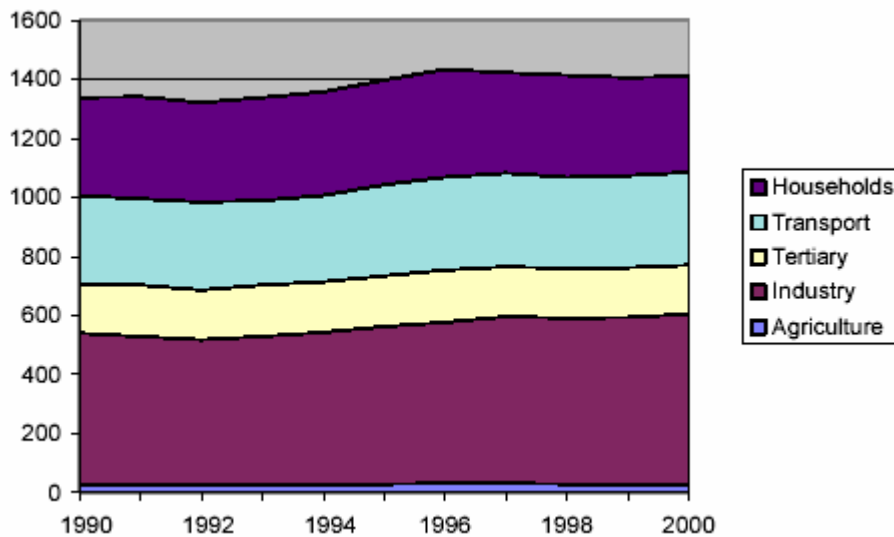


Figure 3-2. Final energy consumption by sector in 1990 and 2000 in Sweden, PJ

Source: Energy efficiency in Sweden (2002)

Figure 3-3 represents the final energy consumption from different sectors in both 1990 and 2000. Based on percentile figures from the tertiary sector, the final energy consumption from the sector has been rather constant, nevertheless the slight decrease from 13% to 12% may

⁴³ Energimyndigheten. (2002). *Energy efficiency in Sweden 1990-2000*. p. 16.

⁴⁴ Energimyndigheten. (2002). *Energy efficiency in Sweden 1990-2000*. p. 9.

⁴⁵ Energimyndigheten. (2002). *Energy efficiency in Sweden 1990-2000*. p. 9.

be viewed positively. While the absolute percentage of energy use has reduced, one cannot disregard that the reduction occurred because of the switch from the use of oil into the use of electricity for heating.

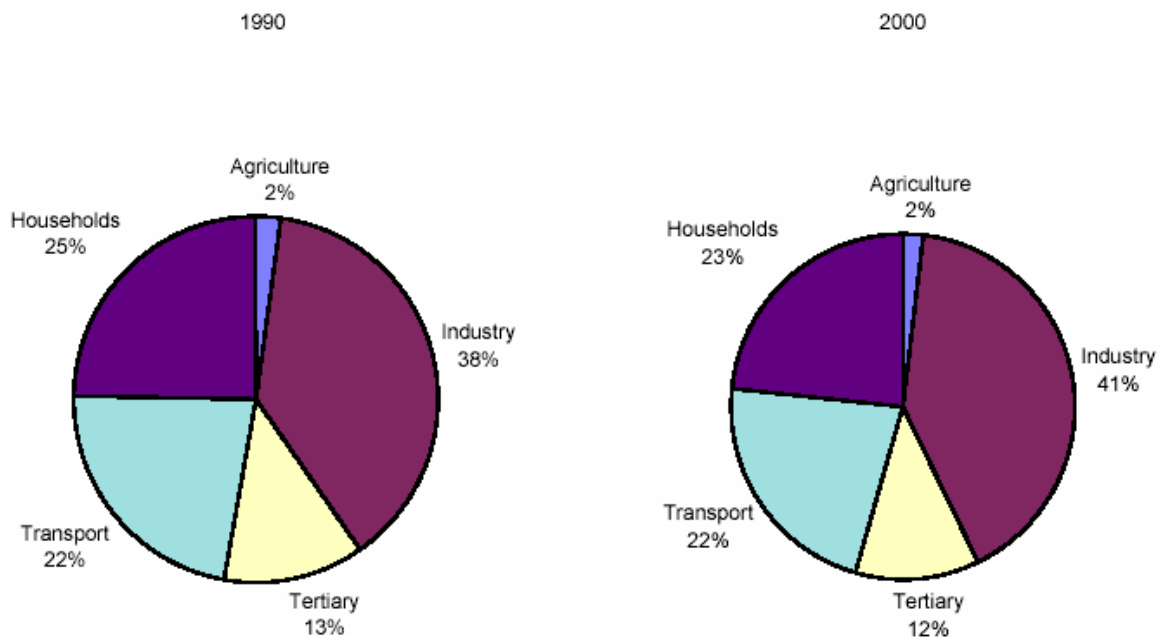


Figure 3-3. Final energy consumption by sector in 1990 and 2000 in Sweden

Source: *Energy efficiency in Sweden (2002)*

Nevertheless, in the tertiary sector, the distribution and use of district heating service increased. Based on the final energy consumption of electricity in the tertiary section, the general phenomenon is such that half the electricity is used for space-heating purposes, while the other half is used for the provision of building services and in electrical appliances. Under these conditions, while the absolute reduction in the use of final energy is reflected, the relative increase of the consumption of electricity is recorded. This progression in the past decade cannot be viewed positively, given that the primary energy conversion for electricity in Sweden is stated to be 2.5kWh of energy consumed for the production of 1kWh, significantly higher than that for heat, 1.04kWh for 1kWh.⁴⁶

Figure 1-2 outlines the general breakdown of energy consumption by end-use in commercial buildings within the EU. In Sweden, the corresponding energy consumption for commercial buildings, consisting mainly of office buildings, is represented in Figure 3-4a, with the combined final energy use figures from the aggregated residential, commercial and service sectors shown in Figure 3-4b. These temperature-corrected figures are seen to verify the energy consumption figures for the commercial sector. Similarly, Figure 3-5 shows the breakdown of electricity consumption by end-use in the commercial buildings in Sweden.⁴⁷

⁴⁶ Gräslund, J., Johansson, L. (1999). *Miljöpåverkan avseende primärenergiebehov och CO₂-utsläpp för kontorsfastigheten*. p. 10.

⁴⁷ The percentile figures shown in Figure 3-5 may be old, but current figures can be estimated based on the growth trends from the commercial sector. These trends are presented in the following paragraphs of the Section.

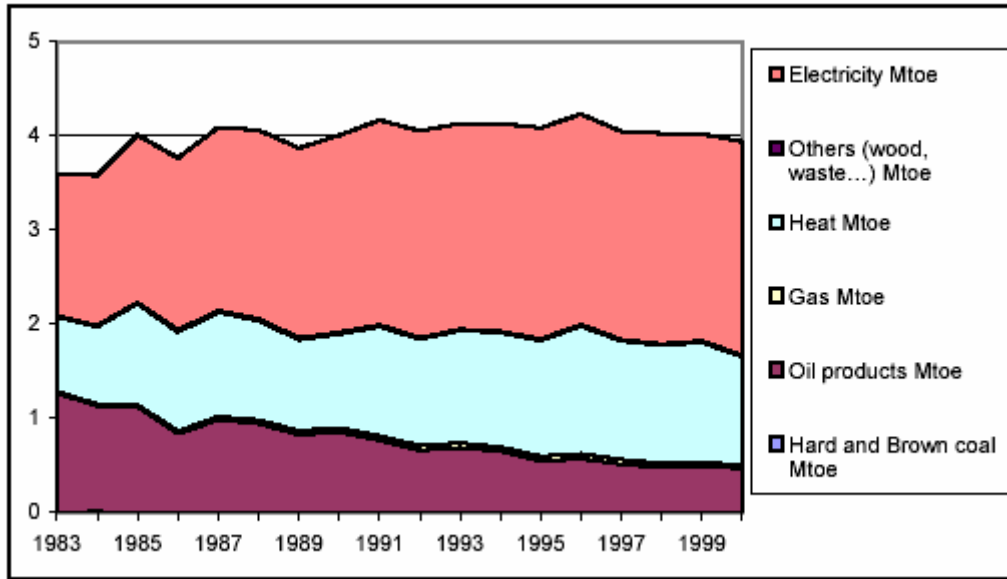


Figure 3-4a. Distribution of energy consumption for tertiary buildings in Sweden, Mtoe

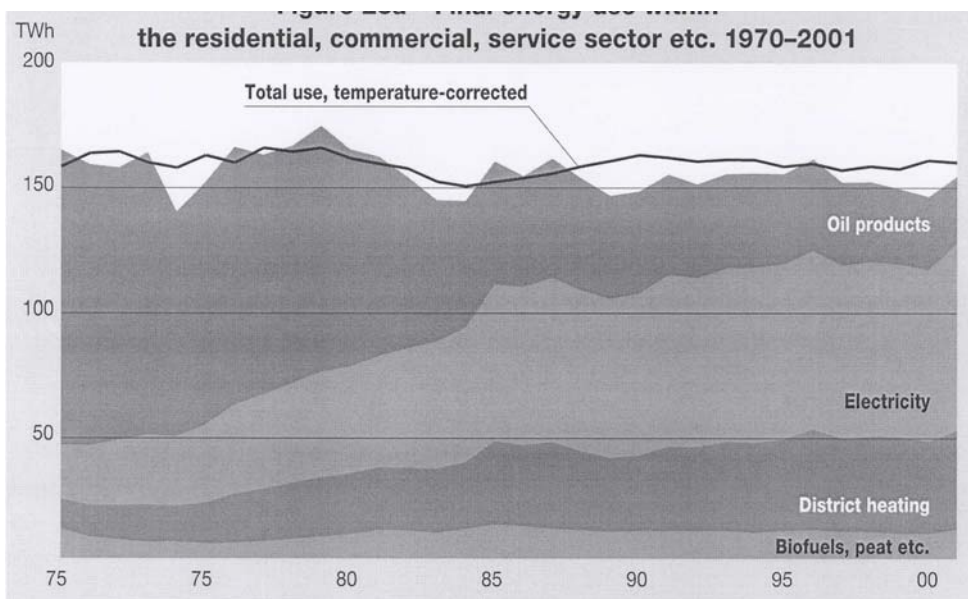


Figure 3-4b. Final energy use within the residential, commercial and service sectors, 1970-2001

Source: Energy efficiency in Sweden (2002) & Energy in Sweden (2002)

The use of electricity in commercial sector for electrical equipment and building service systems has significantly increased from 1970 to 2000 by more than 3.5 times.⁴⁸ This, as previously stated, has been due to the increase in electricity consumption for office equipment, lighting and ventilation. Coupled with a substantial increase in the total floor area of offices, the requirements for heating and cooling load have, therefore, likewise increased.

⁴⁸ Swedish Energy Agency. Energimyndigheten. (2002). *Energy in Sweden 2002*. ET 20:2002. p. 25. [http://www.stem.se/web/bibshop_eng.nsf/FilAtkomst/ET202002.pdf/\\$FILE/ET202002.pdf?OpenElement](http://www.stem.se/web/bibshop_eng.nsf/FilAtkomst/ET202002.pdf/$FILE/ET202002.pdf?OpenElement) [2003, July 7].

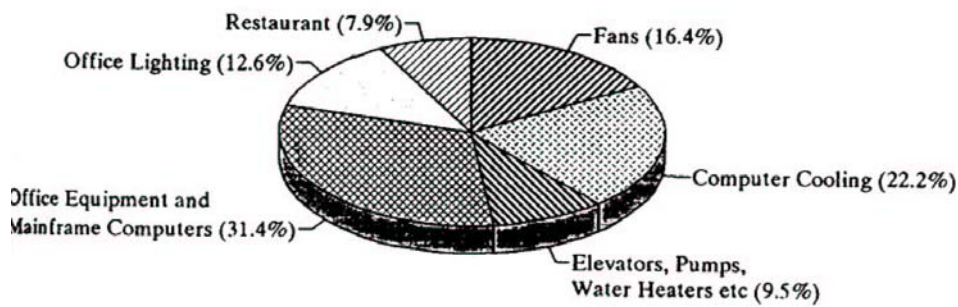


Figure 3-5. Final use of electricity in existing office buildings in Sweden

Source: Nilson, A., Hjalmarsson, C. (1994)

Figure 3-6 similarly shows the amount of CO₂ emissions from the tertiary sector. It is interesting to note that while Figure 3-3 reflects only 1% of reduction in final energy consumption with respect to the total final energy consumption, Figure 3-6 reflects a reduction of CO₂ emissions from the same sector by almost 50%. One can justify this with a number of explanations:

1. The shift from the use of oil to the use of electricity in many applications, including heating, where electricity has an end-use efficiency of 100%, as compared to fossil fuels.
2. Most of the electricity generated in Sweden has a low CO₂ value, due to the high dependencies on both nuclear- and hydro-power. Therefore, final energy consumption based on such a fuel mix produces less CO₂ emissions, as compared to a fuel mix that is based fully on fossil fuels.

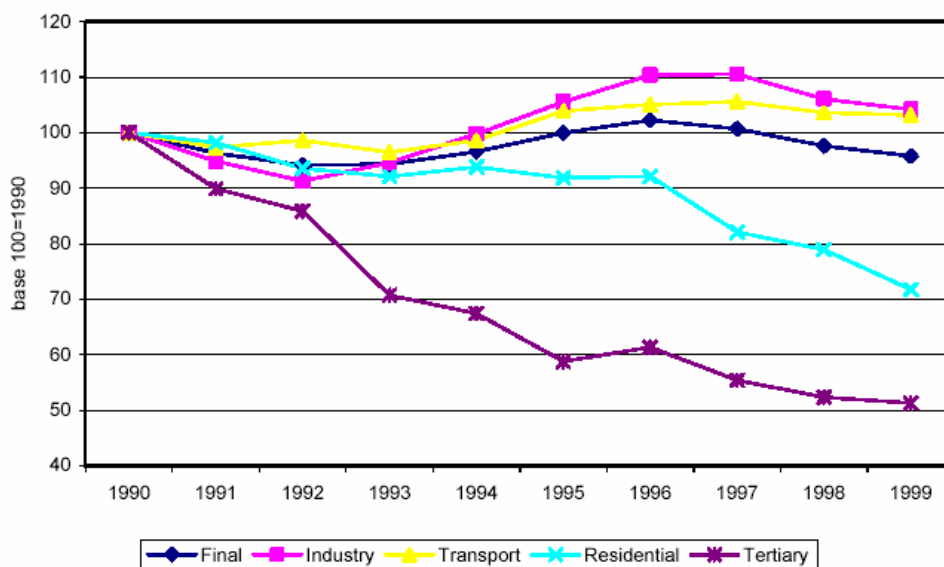


Figure 3-6. CO₂ emission by sectors in Sweden

Source: Energy efficiency in Sweden (2002)

However, with a limit in the growth of hydro-generated electricity and the eventual shut down of nuclear power stations, coupled with an increasing overall final energy consumption; the prognosis for the situation requires higher levels of efficiency together with a reduction in final energy use. Therefore, further reductions in the consumption of electricity and increasing the energy efficiency in commercial buildings present a large potential for energy savings in the tertiary sector.

Energy consumption per employee in the service sector

Electricity consumption per employee, for electrical equipment, lighting and ventilation, has increased significantly up till 1993, at a rate of increase of approximately 1.2% per year. This is shown in Figure 3-7. While the electricity consumption leveled after 1993, with an approximate 0.7% increase per year, the total final energy consumption, measured in toe, per employee in the service sector fluctuated significantly, with the highest values recorded in the year 2000.

Energy consumption per employee per square meter in the service sector

As seen from the increasing trend, the total energy efficiency of the sector has in fact worsened from 1990-2000. When comparing final energy consumption per square meter, it is also found that figures have risen “dramatically” up to the early 1990s, decreasing thereafter.⁴⁹ This phenomenon can be explained by the increase in building floor area per employee and the addition of more electrical equipment used per employee. This can be verified with figures reflected in Figure 3-8. Moreover, the situation is compounded with the declining employment of personnel in the service sector, given the decreasing trend of the number of employees employed in the service sector in Sweden from 1985-2000, as seen in Figure 3-9.

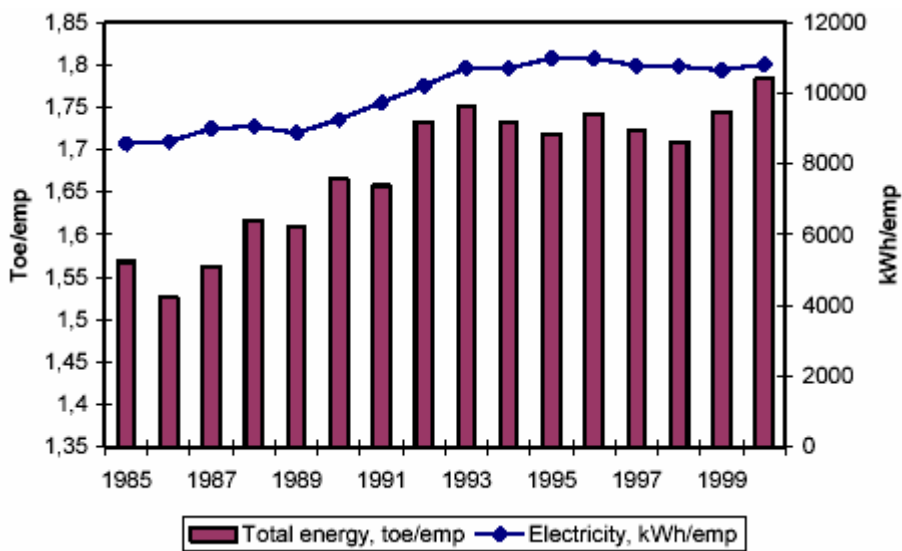
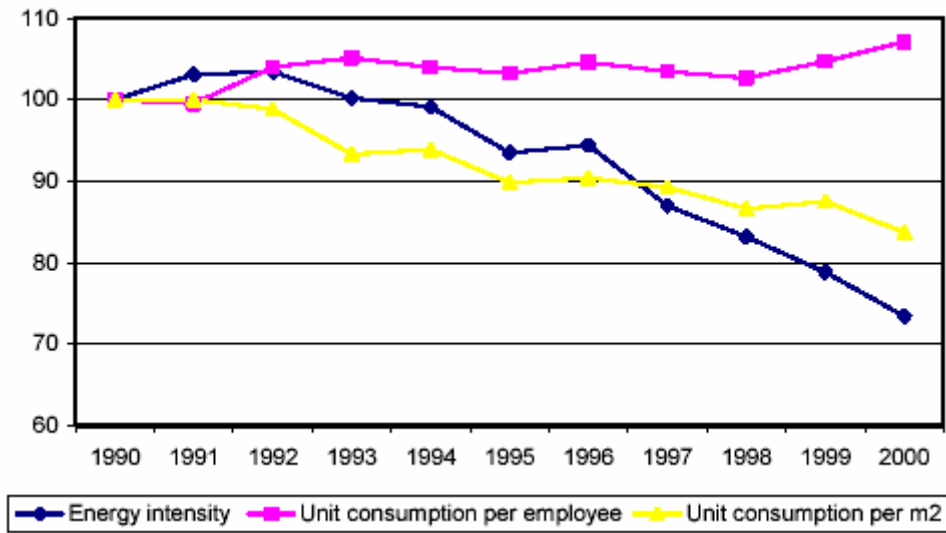


Figure 3-7. Energy consumption per employee in services in Sweden, 1985-2000

Source: Energy efficiency in Sweden (2002)

⁴⁹ Energimyndigheten. (2002). Energy efficiency in Sweden 1990-2000. p. 16.



where

Energy intensity	Final energy consumption per meter square of net building area
Unit consumption per employee	Final energy consumption per employee
Unit consumption per square meter	Final energy consumption per employee per square meter

Figure 3-8. Trends of the energy intensity and unit consumption in services, 1990-2000

Source: Energy efficiency in Sweden (2002)

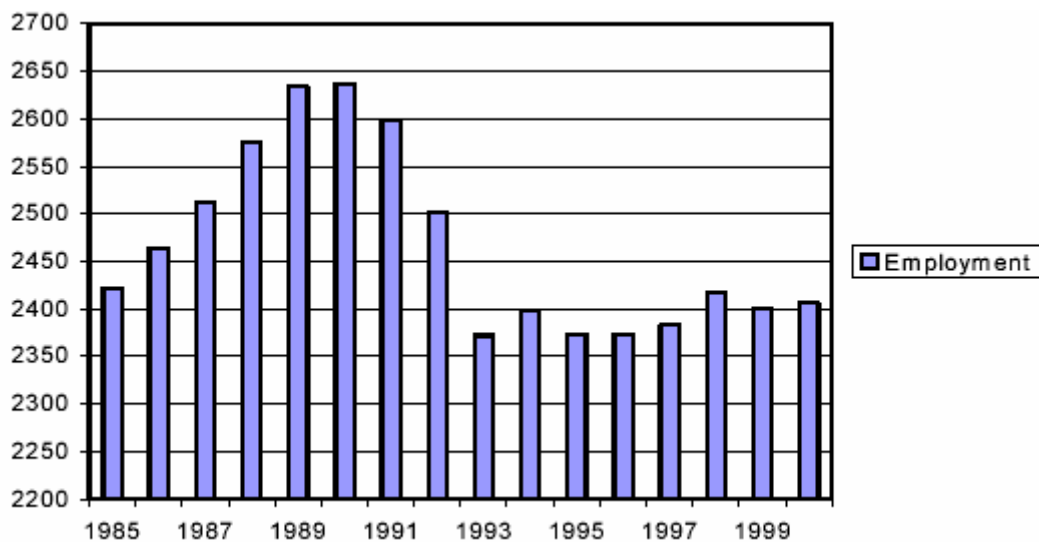


Figure 3-9. Number of employees in the service sector in Sweden (in 1000s)

Source: Energy efficiency in Sweden (2002)

3.3 National policies for energy efficiency

The push for energy efficiency has been aided by political will in promoting the measures through the implementation of a range of policies. The scope of policies implemented from 1998-2002 for energy efficiency is diverse and wide, but measures within the context of the commercial/tertiary sector are summarized in this section.⁵⁰ Such measures include reducing the use of electric boilers for district heating, substituting it with fuel firing.⁵¹

Measures promoting the efficient use of the electricity with governmental funds, through information transfer, education, procurements in technology and advisory committees providing services, was also actively implemented from 1998-2002. Table 3-1 summarizes these measures.

In 1998, a national program for energy efficiency was established, and while the progress in energy issues have been satisfactory, the district-heating program has yet to fulfill its goal of supplying 1.5TWh of district heating services.⁵² Currently, the deregulated prices for the use of electricity in heating, for private consumption has risen more than 20% since 1993 (0.60 SEK/kWh in 1993 to 0.727 SEK/kWh in 1999)⁵³. Likewise, the prices for oil products have risen significantly during 1998-2001 due to additional taxation, especially in the case of heating oil, where the increase has been at 25.8%.

⁵⁰ For detailed descriptions of existing measures in the commercial building sector of Sweden, please refer to the “Energy Efficiency in Sweden 1990-2000” report and information from the ODYSSEE and MURE databases. [Online]. Available: <http://www.odyssee-indicators.org/Publication/PDF/Swe-r01.pdf>

⁵¹ Energimyndigheten. (2002). *Energy efficiency in Sweden 1990-2000*. p. 12.

⁵² Energimyndigheten. (2002). *Energy efficiency in Sweden 1990-2000*. p. 13.

⁵³ Prices in Swedish öre per kWh as measured at net calorific value including taxes. Source: The Swedish National Energy Administration, Energy in Sweden.

Table 3-1. Synthesis of energy efficiency policy measures by the tertiary sector

Tertiary Sub Sector	Policy Field	Policy Title	Policy Type	Status/Date	Evaluation Impacts
Heating	Norms	Building Regulation	Legislative/ Normative	Last revision decided 1994	
Total Sector	Information/ Education	Information on Efficient Use of Energy	Information/ Education/Financial	Ongoing from 1991	
Total Sector	Financial	Research, Development, Demonstration	Financial	Ongoing from 1991	
Total Sector	Financial	Local Environmental Investment Programme	Financial	Ongoing from 1997	Reduction in the use of electricity and fossil fuels by 2.1TWh per annum equivalent to 1.6Mtons of CO ₂ savings.
Total Sector	Financial	Technology Procurement	Financial	Ongoing from 1989	Between -5% & -50% depending on Technology
Total Sector	Norms	Municipality Energy Planning Act	Legislative/ Normative	Decided in 1977	

Source: Energy efficiency in Sweden (2002)

3.4 Current methods of energy performance assessment

In Sweden, the prevailing trend in building energy performance assessment considers only the components of thermal energy flows, namely, the ventilation, transmission, internal solar heat gains and the heating system, given the cold-climatic conditions.⁵⁴ The current energy performance calculation methods have been in place since 1990 and are loosely based on the European Standard EN832 for the thermal performance in buildings. However, the electricity consumption component of energy performance is not regulated in Sweden.

These regulations only apply to new buildings, but there are no corresponding energy performance requirements, standards or assessments adjusted for existing buildings in Sweden, and neither do regulations exist for retrofits or extensions, therefore the status of regulation in this sector does not exist.⁵⁵ Currently, the performance requirements that apply to new buildings are proposed and highly recommended to be applied in the existing commercial building stock, but these requirements are not mandatory, and often much more difficult to achieve in existing buildings.⁵⁶

⁵⁴ European Commission (2003) *Energy Performance of Buildings. Calculation procedures used in European countries*. ENPER-TEBUC project. SAVE p. 7. http://butler.cc.tut.fi/~keranen/save/B1_laskenta/B1_final_report.pdf [2003, August 7].

⁵⁵ Thomsen, K. E. (2002). *Enquiry on Global Philosophy of the energy performance calculations*.

⁵⁶ Häggbom, Sune. Sunda Hus Rådgivning. (2003, August 25). Telephone interview.

Energy performance assessments are primarily based on building energy simulations software which model net energy consumption with respect to a modeled reference building, where $Q_{\text{energy consumed}} < Q_{\text{reference}}$, where no distinction is made in relation to thermal heat versus electricity consumption. The method of assessment is not standard, where the emphasis in the calculation lies in the results generated, regardless of the type or purpose to the software used.⁵⁷ In addition, the use of European Standards for energy performance calculations, developed and issued by the European Committee for Standardization (CEN), is not mandatory or commonly applied in Sweden, although the Standards can be used as an alternative, if desired. Given the vagueness of these current practices, the formulation of a framework methodology in integrating all these lacking aspects, in a formal established manner, based on existing standardized calculation methodologies is considered very useful.

For more detailed information on the current calculation procedures practiced, please refer to Appendix B, Current methods of energy performance assessment in Sweden.

⁵⁷ Häggbom, Sune. Sunda Hus Rådgivning. (2003, August 25). Telephone interview.

4. Review of existing tools and literature

This section provides a background review of the existing energy codes, requirements and methodologies in place that are currently used for the assessment of energy performance and efficiency in buildings. While many such methodologies do exist, each for varying aims and purposes, the emphasis here is largely on issues pertaining to building energy consumption for commercial buildings. In a similar manner, the review of common building energy modeling software is provided. It should be noted that the list covered in the review is not exhaustive.

This section also contains references to articles written by a number of authors concerning the issue of integrated energy performance in buildings and the corresponding codes and standards required for its implementation. The reviewed articles represent varying opinions from different regions but, nevertheless, provide the background research that this thesis uses in development of an integrated framework methodology for energy performance in buildings.

4.1 Existing building codes and regulations

The Swedish Building Regulations (BBR) lists the mandatory provisions and general recommendations in accordance to regulations of the Swedish Board of Housing, Building and Planning. It is legally binding and similarly found in the Code of Statutes of Boverket. The BBR contains building and design regulations for new buildings as well as for retrofits to existing buildings, for all aspects in buildings. It applies to both the residential and the commercial building stock in Sweden.

The primary review covered aspects of Sections 6 and 9, listing the regulations and recommendations for “Hygiene, health and the environment” and “Energy economy and heat retention” respectively. In relation to Section 6:2, the general aspects of air quality has been listed, and subsections on indoor air quality, ventilation, light and temperature was reviewed. It is found that the general indoor air quality is determined by the level of activity to be performed in the occupied zone; therefore, for office spaces, these requirements are stricter.⁵⁸ Ventilations requirements for ventilating systems require a specific quantity of air in order to provide a satisfactory and effective level of ventilation. One complies to this requirement when the air change in the zone is found to be not less than 40%.⁵⁹ Other requirements for continued air circulation in the zone has been clearly stated with specified rates of air flow.⁶⁰ Lighting regulations are largely related to satisfactory indoor environments, with the access to natural direct daylight, a specified minimum window area and satisfactory lighting conditions in rooms or part of room with human activity.⁶¹

The temperature regulations as listed in the BBR are stricter, as compared to the general recommendations listed in the previous subsections. This is understandable given the necessary standards for the thermal comfort of occupants, and for the appropriate design of

⁵⁸ BBR. Section 6:22. p. 75.

⁵⁹ Where the air change ratio requirement, of supply air to extract air, is stated to be not less than 0.4.

⁶⁰ BBR. Section 6:23. 76-77.

⁶¹ BBR. Section 6:31-6:32. p. 81.

heating, ventilation and air conditioning (HVAC) system capacities. As listed by the BBR, it is mandatory for habitable rooms in buildings to operate, at least, with the lowest bound for directional operative temperature (*set point temperature*) set at 18°C.⁶² It is of interest to note that this subsection similarly takes into the account the significance of thermal bridges, and requires the consideration of such negative effects. Compliance to heating standards is considered to be satisfied with the supply of heat from radiators, ceiling or under-floor heating system, so long as the temperature variance recorded within different points in an occupied room is not more than 5K.⁶³

Section 9 of the BBR, while more appropriate for review in this thesis, is less extensive than Section 6. The statutes listed are largely general recommendations, and special provisions are provided in many cases. The section addresses the energy requirements of a building, with respect to limited heat loss and the efficient use of electricity.⁶⁴ Nevertheless, the provisional wavering of standards is permitted if it can be “shown by special investigation (*trade-off calculations*) that the requirement for supplied energy for space heating, domestic hot water and heat recovery does not exceed the energy which would be needed if the requirements were complied with”.⁶⁵ The most significant requirement in this section would be the maximum limit of the average thermal transmittance values, U_m , as obtained by calculations presented in Subsection 9.2 for the building envelope. Similarly, It is of interest to note that a provision for control systems in commercial buildings is included in Subsection 9.222, where the call for the reduction in the rate of flow of outdoor air is included when the building, or part of which, is not in use.⁶⁶ This general recommendation reduction can be attained continuously, step-wise or in the form of intermittent operation. If the use of boilers is employed in the building, the boilers are required to have sufficient efficiency while in normal operation, and protection against heat losses should be factored into design considerations “as much as possible”.⁶⁷

Other features of energy economy with regards to the distribution of heat and the efficient use of heat and electricity were reviewed from Subsections 9.3 and 9.4 respectively. Specific requirements, for buildings that obtain heat from fossil fuels or from electricity to reduce the heat energy requirement by at least 50%, reflect favorably in the regulatory trend towards energy efficiency in buildings.⁶⁸ Similarly, “building service installations which require electrical energy shall be designed so that the power requirement is limited and energy is used efficiently” with regards to (i) ventilation systems, (ii) fixed lighting, (iii) electric heaters, and (iv) motors.⁶⁹

Since 1998, the Boverket has updated certain energy codes, thermal and insulative requirements based on the energy performance of buildings for both new and existing buildings, and while references are made to existing European Standards published by the

⁶² BBR. Section 6:41. p. 81.

⁶³ BBR. Section 6:41. p. 81.

⁶⁴ BBR. Section 9:1. p. 113.

⁶⁵ BBR. Section 9:1. p. 113.

⁶⁶ BBR. Section 9:222. p. 117.

⁶⁷ BBR. Section 9:231, 9:234. p. 118.

⁶⁸ BBR Section 9:3. p. 119.

⁶⁹ BBR Section 9:4. p. 119.

European Committee for Standardization (CEN), the direct application these standards are not made mandatory.⁷⁰

4.2 Standardized methodologies

4.2.1 European Standards

The European Standard EN832, approved by the European Committee for Standardization (CEN) on 1 July 1998, governs the thermal performance of residential buildings and lists specific procedures and methodologies for the calculation of energy for heating.⁷¹ The scope of the standard covers only residential buildings, and it contains extensive methodological calculations established in relation to:

1. The assessment of heat losses of a building when heated to a constant temperature.
2. The annual amount of heat required in maintaining specified set-point temperatures in a building.
3. The annual amount of energy required by building heating systems for space heating.

The application of the method can be for⁷²:

- Judging compliance with regulations, with energy targets;
- Optimizing building energy performance of planned buildings, by applying the method to several available options;
- Displaying the conventional level of energy performance in existing buildings.
- Assessing the potential of energy conservation measures on existing buildings, by the calculation of energy use with or without energy conservation measures; and,
- Predicting future energy resource needs, on different scales, by calculating the energy use of several buildings representative of the building stock.

The degree of assessment in the EN832 and the methodological steps presented is clearly defined, and currently, a similar standard, the EN ISO 13790 exists for the calculation of thermal performance in commercial buildings. It represents a complete and valid methodology as duly covered in the European Standard EN832, which covers the scope for all buildings.

The EN832 is more widely used, as compared to the EN ISO 13790 that was newly published in 2001. It outlines the procedures in assessing the thermal performance of buildings in relation to heat losses (at constant interval temperatures), heat gains, heat use and the annual heating load and use of the residential building. One can argue that this

⁷⁰ Jönsson, Peter. Boverket. (2003, August 11). Telephone interview.

⁷¹ European Standard EN832. (1998). ICS 91.140.10. Ref. No. EN 832:1998E.

⁷² European Standard EN832. (1998). ICS 91.140.10. Ref. No. EN 832:1998E. p. 3.

standard is detailed and robust enough to be directly applied to the calculation of heat use in commercial buildings, given that the distribution of heat consumption and thermal performance in a residential building is higher in proportion as compared to commercial buildings. Therefore, when applied directly on to commercial buildings, this ensures stricter compliance with a certain additional degree of conservativeness, making it more than adequate in current circumstances.

In general, what is lacking is, therefore, the appropriate use and application of the EN832 and EN ISO 13790 in mechanical and electrical installations by design engineers, and the push for legal compliance to the standards on a national level, in order for widespread application. As discussed, it is the current practice in Sweden that the use of these European Standards are not mandatory. Despite its detailed methodology, little is being applied and adhered to in building design, although certain parts of the standards have been adopted by Boverket as national requirements.⁷³

There are equivalent standards for the design of heating and cooling loads in a building, these standards, for example, the EN14335 for design efficiency and energy demand of heating systems, which is similar to the 1998-updated version of EN832, applies to all residential and non-residential, new and existing buildings.

4.2.2 Technical Committee Standards

In a similar fashion, the technical standard for calculation, TC 156, presents a simplified HVAC methodology for energy performance, where the cooling load calculation procedure is provided, and it integrates the ventilation system component into the procedure. The standard applies both to residential and non-residential buildings. It also includes calculation procedures for⁷⁴:

- The sizing and energy requirements of cooling systems for buildings,
- Air flow rates for ventilation and infiltration in non-domestic buildings,
- Energy losses in ventilation, infiltration and air conditioning systems.

The TC169 presents a harmonized standardization in energy consumption for lighting controls and natural lighting and is applicable for use in non-residential buildings such as commercial office buildings. Both the TC169 and TC156 can be applied together in order to calculate the optimum energy performance for cooling, ventilation and lighting system, and a working group under CEN is currently in the process of integrating these 2 standards.⁷⁵ The benefits in integrating calculation standards show that improvements to systems can reduce the energy consumption of a building up to a factor of 2.⁷⁶

⁷³ Jönsson, Peter. Boverket. (2003, August 11). Telephone interview.

⁷⁴ European Committee for Standardization. CEN. (2003). *Energy Performance Directive: Proposal for organizing the work inside CEN*. JWG-N117r. http://www.take-finland.com/tiedostot/JWGN177rev2-report_on_EPD.pdf [2003, August 6].

⁷⁵ Schumacher, M. (2003). *CEN Relation between energy performance in buildings to building automation, controls (BACS) and building management (BM) standardized by CEN/TC247*. European Committee for Standardization. http://www.enerbuild.net/docs/CEN-TC247_Workshop.ppt [2003, July 24].

⁷⁶ Fraunhofer Institut für Bauphysik (2003). *ENPER BBRI International Workshop, 19 May 2003*. <http://www.ibp.fhg.de/>

The development of standard TC247 for building automation, controls and building management represents a calculation method for energy management in buildings. It presents a standard list of “definitions, requirements, functionality and test methods of building automation products and systems, for the automatic control of building service installations and the primary integration measures”.⁷⁷ The scope of this standard ensures energy efficiency in the operations and management of building services for commercial buildings.

In summary, Table 4-1 summarizes the application of these methodologies.

Table 4-1. Existing calculation methodologies that can be used in implementing Directive 2002/91/EC

Criteria For:	Existing Methodologies to be used*
Building site and orientation	Already regulated in EN832 & EN ISO 13790
Thermal insulation	Already regulated in EN832 & EN ISO 13790
Heating loads	Already regulated in EN14335
Service hot water production	Already regulated in EN14335
Cooling loads	Not yet fully regulated, presented in TC156 (in cooperation with TC169)
Ventilations	Already regulated in EN14335 & TC 156 (with considerations for cooling loads) PrEN13779 for performance in non-residential buildings
Lighting systems	Already regulated in TC169
Building management	Already regulated in TC247

**) The technical committees at CEN are continuously conducting research on integrating standards for the application in Directive 2002/91/EC.*

Source: TNO Building and Construction Research Institute (2003) & CEN (2003)

4.3 Checklist assessment tools

4.3.1 BREEAM Assessment

The review of the Building Research Establishment Environmental Assessment Method (BREEAM)⁷⁸ for existing buildings provides an overview of an existing and established checklist methodology currently used for the environmental evaluation of a building. In this particular method, the simultaneous evaluation of heat and electricity consumption, and hence energy performance and/or efficiency, is included.

BREEAM is said to be the world's most widely used means of reviewing and improving the environmental performance of buildings, where “BREEAM for Offices” is most widely used for “reviewing and improving the environmental performance of office buildings”.⁷⁹ Developed in the United Kingdom by the Building Research Establishment (BRE) in the

⁷⁷ Schumacher, M. (2003).

⁷⁸ Building and Research Establishment. (2003). http://www.bre.co.uk/services/BREEAM_and_EcoHomes.html [2003, July 9].

⁷⁹ Building and Research Establishment. (2003). *BRE Building Assessment Method. BREEAM*. <http://products.bre.co.uk/breeam/offices.html> [2003, July 9].

1990s, it includes both a checklist assessment and a detailed methodology for application on both new and existing office buildings, regardless of occupancy durations or densities. In the scope for existing buildings, as with the focus in the thesis, the assessment method can be carried out on existing occupied office buildings, by applying the “Management and Operation BREEAM” section.

Within the management and operation section of the assessment method, energy performance issues such as heat and electricity efficiency are covered accordingly, and it is the review of these aspects that are of significance to the thesis.

In general, the assessment method, based largely on checklist assessment criteria, credits the setting of minimum requirements with regards to the energy and resultant CO₂ emissions of a building, as well as a commitment to annually-based reviews and reporting procedures for both internal and external purposes.⁸⁰ The 2 other specific areas of interest in this assessment method fall under the “Health and well-being” and “Energy” sections. In the “Health and well-being” section, factors pertaining towards indoor air quality are assessed and ranked. The criteria in the section includes considerations for mechanical and natural air ventilation systems, the use of daylight management, load control for temperature adjustments, and the operational compliance of other mechanical services in the building, for example (i) heating/cooling systems, (ii) ventilations/humidification systems, (iii) lighting systems, and (iv) district hot water systems.⁸¹

The “Energy” section of BREEAM focuses on both the heat and electricity consumption of an existing commercial office building, with the recommendation of the application of “sub-metering”⁸² for substantive energy uses within the building.⁸³ The assessment recommends audit procedures (performed every 3 years), prompt improvements based on the audits and monitoring using historical data. The assessment tool similarly favors maintenance records covering the calibration and operation for all heating and cooling system controls.

It is of interest to note that this assessment tool is not offered in its entirety except through licensed BREEAM assessor organizations and the checklist assessment reviewed is based on a pre-assessment checklist. The purported aim of this methodology lies in rating the assessed building, in order to compare similar commercial office buildings against a BREEAM performance rating score.

4.3.2 LEED system

The Leadership in Energy and Environmental Design (LEED) for Existing Buildings, version 2.0, is another existing energy performance methodology.⁸⁴ It is currently used extensively throughout the United States and is based on the original “LEED Green Building Rating System™ for Improving Building Performance through Upgrades and Operations”.

⁸⁰ BRE. (2003). *BREEAM Offices 2003*. p. 3. <http://products.bre.co.uk/breem/pdf/MOPredictionChecklist2003.pdf> [2003, July 9].

⁸¹ BRE. (2003). *BREEAM Offices 2003*. 4-5.

⁸² Sub-metering refers to the application of meters or counters at specified energy consumption points (power-points) within the building system in order to quantify the energy usage of particular building occupants.

⁸³ BRE. (2003). *BREEAM Offices 2003*. p. 6.

⁸⁴ US Green Building Council. (2003). *Leadership in Energy and Environmental Design: LEED rating system for existing buildings*. http://www.usgbc.org/LEED/existing/leed_existing.asp [2003, June 6].

Unlike the BREEAM pre-assessment checklist, LEED for Existing Buildings (LEED EB) is a “set of performance standards for the sustainable operation of existing buildings” which earns the “LEED 2.0” certification upon satisfactory compliance.⁸⁵ In general, the system addresses building operations and performance improvements. The focus area of this review is within the sections of energy efficiency performance and system upgrades towards the improvement of building energy, indoor air quality and lighting performance in relation to “green” performance standards.

The LEED EB system works in a similar manner to the BREEAM assessment, given that credits are awarded for compliance to certain performance standards, and the final score is tallied accordingly in a final scorecard. However, the public-version of this assessment standard is significantly more detailed than that of the BREEAM pre-assessment checklist.

In the “Energy and atmosphere” section, 3 prerequisites are to be satisfied before accreditation of the existing system can take place. These involve the verification and assurance that the “fundamental buildings elements and systems are designed, installed and calibrated to operate as intended” and for the establishment of a minimum energy performance for the base building systems.⁸⁶ Compliance to these prerequisites are listed within LEED EB with methodological procedures, and are benchmarked on existing requirements based on the United States Environmental Protection Agency (US EPA) Energy Star™ label and the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) 90.1-1999 system.

Issues pertaining to the optimization of energy performance focuses on the intent of “increasing levels of energy performance above the prerequisite standard to reduce use of non-renewable fuels and to reduce the environmental impacts associated with excessive energy use”, with regulated energy components including the HVAC systems, building envelope and lighting systems, as per defined by ASHRAE.⁸⁷ What is of interest is the unit of measure for performance - typically the energy metric, kWh of energy consumption per square meter of net building area - expressed in terms of the annual energy cost in US dollars in LEED EB. Requirements for compliance involve the provision of calculations showing that the actual energy efficiency and performance of the building exceeds those described by ASHRAE.⁸⁸

The “Indoor environmental quality” section focuses largely on the establishment of indoor environment conditions for the comfort of the occupant. It includes sections on the establishment of minimum indoor air quality performance and the provision of an adequate level of lighting, ventilation, temperature control, hazardous chemical control and carbon dioxide monitoring for occupant health and comfort.⁸⁹ While this may not affect the energy performance of a building directly, the gain of energy efficiency and low energy use in a building must not be achieved through a compromise of these standards, therefore, the review of the indoor environment is important in the assessment of energy performance in a building.

⁸⁵ US Green Building Council. (2002). *LEED EB v2.0*. p. 2.

⁸⁶ US Green Building Council. (2002). *LEED EB v2.0*. p. 17.

⁸⁷ US Green Building Council. (2002). *LEED EB v2.0*. p. 20.

⁸⁸ US Green Building Council. (2002). *LEED EB v2.0*. p. 20.

⁸⁹ US Green Building Council. (2002). *LEED EB v2.0*. p. 31.

4.4 Energy modeling software tools

4.4.1 Enorm 1000

The theoretical calculation method, Enorm, is the most common energy performance calculation tool currently being used on the total building stock in Sweden.⁹⁰ The corresponding energy calculation program, Enorm 1000 version 1.10, is therefore most frequently applied. It is used in the verification of energy performance of a building with respect to the standards stated according to the BBR, calculated for each day of the year. It is a steady-state program originally designed for use only in residential buildings, where building characteristics and parameters are entered into the program. It goes without saying that an adequate knowledge of building parameters is required for proper input, in order for the simulated results to be of meaningful value.

Despite this, designers have applied the use of the program extensively for both residential and commercial buildings, regardless of the resulting output. Based on literature examining the use of Enorm, the program is known to inaccurately calculate the energy performance of buildings with significant window areas or with significant heat storage capacities.⁹¹ In buildings with significant heat storage capacities, the validity of output results becomes complicated because the heat capacity of building materials in the building envelope may account towards the temporal storage of heat within the structure. While it is possible to factor in the heat capacity of surface building materials in energy calculations, the output generated suggests extensive reductions in the heating demand of the building, which is not true when compared to values obtained during actual building operations.⁹² This simulated 15-20% reduction in heat demand is most likely sourced to the steady state calculation procedures applied in Enorm, which disregards temperature fluctuations, heat accumulations in buildings materials and gains from solar radiation on the building's façade.⁹³

When applied to commercial buildings, these inconsistencies become significantly amplified, manifested when Enorm-generated energy demand figures are compared against actual building energy audits. Under these skewed conditions, variances up to -50% of audit figures are not impossible. In view of this deficiency, alternative dynamic calculation methods and programs should be used, in order to accurately investigate how input parameters affect energy consumption over time. One such program is the IDA Indoor Climate and Energy version 3.0, which simulates the energy performance of the whole building.⁹⁴ The use of this program in commercial buildings reduces the above-mentioned inconsistencies dramatically.

The real weakness of the Enorm program lies largely in its use and how results are being applied. Enorm was developed specifically for use in residential single-family homes for cross-comparative purposes, while its use and application today encompasses the absolute comparison in commercial buildings. Energy consumption and load patterns of commercial

⁹⁰ Hiller, C. (2003). *Sustainable energy use in houses: Will the energy use increase with time? A study of literature and computer simulations*. p. 66. <http://www.byfy.lth.se/Publikationer/CH-3041/CH-3041.pdf> [2003, June 6].

⁹¹ Hiller, C. (2003). *Sustainable energy use in houses*. p. 66.

⁹² Borg, M. (2001). *Environmental Assessment of Materials, Components and Buildings; Building specific considerations, open-loop recycling, variations in assessment results and the usage phase of buildings*. Kungl Tekniska Högskolan. p. 27. <http://www.lib.kth.se/Sammanfattningar/borg011023.pdf> [2003, June 6].

⁹³ Svensk Byggtjänst. (1996). *Enorm 1000 Manual*. Stockholm: AB Svensk Byggtjänst.

⁹⁴ Equa. (2002). *IDA Indoor Climate and Energy version 3*. <http://www.equa.se/eng.ice.html> [2003, June 6].

and residential buildings differ significantly, therefore, using the very same tool in both cases without applying normalizing adjustments or factors, undoubtedly leads to highly erroneous results.

4.4.2 ABB Ventac

ABB Ventac is another such energy modeling program for calculating the total energy consumption in a building. The use of the program will not reflect efficiencies, because the results are generic in nature and dependant on the input parameters. Although with reiterative testing, energy savings can be identified through parametric testing of certain variables within the building system.

It should be noted that there are many other such modeling software programs that facilitate the simulation of building energy consumption, such as VIP+ and IDA ICE. These programs each have their advantages and disadvantages, and are favored by different energy consultants. But it is important to state that their aim is generic, and that the results predicted do not differ significantly from other programs used, if used appropriately in the right context.

4.5 Literature review

In the review of academic research papers within the context of energy performance and efficiency in buildings, existing developed methodologies with similar aims were sought. Base definitions of energy efficiency and the energy performance of buildings were largely established by the respective papers, “What is an energy-efficient building?”⁹⁵ and “Rating the energy performance of buildings”⁹⁶ by Meier, Olofsson and Lamberts. Despite the varying claims of energy efficiency by developers, building owners and designers, these papers define the basic characteristics of an energy efficient building as:

1. Containing energy efficient technologies, operating as designed, in reducing energy use.
2. Supplying the required amenities and features expected for the standard use of the building, for at least 60 hours per week.
3. Operated in a manner to be efficient, which gives evidence of low energy use when compared to other similar buildings.

The distinction between the levels of assessment criteria in order to attain energy efficiency, determined by mandatory codes, prescriptive requirements and performance-based standards based on building design and function was clearly defined by Hui, Sam C. M. (2002), in order to support assessments in buildings.⁹⁷ This is because if expressed ambiguously, the criteria for which to base energy performance would be unclear and unsupported. This distinction has been likewise adopted throughout the thesis.

⁹⁵ Meier, A., et al. (2002). *What is an energy efficient building?*

⁹⁶ Meier, A., Lamberts, R., Olofsson, T. (2003). *Rating the energy performance of buildings*. [2003, May 3].

⁹⁷ Hui, S. C. M. (2002). *Environmental Sustainability Assessment of Buildings Using Requirements in Building Energy Codes*. Paper accepted for the Sustainable Building 2002 International Conference, 23-25 September 2002, Oslo, Norway. <http://arch.hku.hk/~cmhui/sb2002-cmhui.pdf> [2003, June 27].

A paper written on the energy performance criteria in the Hong Kong Building Environmental Assessment method (HK-BEAM), gives an excellent background on an assessment method for air-conditioned office buildings.⁹⁸ One can argue that the validity of the literature may not be applicable in relation to Sweden, but the approach of the analysis is applicable to this thesis. The efficient use of electricity in commercial office buildings forms a major part of the assessment, and the focus of the paper in this aspect is on the electricity consumption for air-conditioning and the lighting load. The assessment criteria and methods listed in these papers are accordingly revised and applied in the analysis sections of the thesis.

Most other papers on building energy efficiency reviewed discussed similar concerns relating to the thermal performance of the building envelope, including certain specific energy-intensive equipment, such as (i) the lighting, (ii) HVAC systems, (iii) other electrical appliances, (iv) lifts and escalators, and (v) water heating services.⁹⁹ The focus in most existing research lies on the practice of benchmarking, comparing or ranking the energy efficiency aspects in buildings, in relation to the meeting of design goals and the measurement of the “superiority” of a design against another.¹⁰⁰ Many of the papers reviewed have applied the use of energy simulation programs in order to verify their analyses and discussions, reflecting low-energy use and more efficient energy consumption.¹⁰¹ This supports the use of computer modeling software in verifying proposals.

Given the scope of these discussions, literature and existing research in relation to a common assessment methodology for the assessment of energy performance, and/or efficiency, is unfortunately very limited. The urgency for a standardized methodology has been extensively written about and expounded upon, as with the potential benefits to be reaped, reflected in EuroACE reports.¹⁰² However, there is a lack of literature published in relation to an actual energy performance assessment method, as called for by Directive 2002/91/EC. This thesis aims to bridge this academic gap, in proposing an integrated approach towards a clear and structured assessment of energy performance in existing office buildings. This proposed approach is presented with the use of existing tools available.

Additionally, it is of particular interest to note that the distinction between heat energy and electricity energy consumption in the review of existing literature is not at all times made clear. It is often assumed that analyses are carried out on final energy use, and that 1kW_eh of heat energy use is of the same practical value as 1kW_eh of electricity use. While the calorific values are identical, the monetary values are not. This practice skews the goal of efficient energy use, and is avoided in the analysis of this thesis, with the distinction made early in the thesis, and, as far as possible, throughout the analysis presented.

⁹⁸ Yik, F. W. H., Burnett, J., Jones, P., Lee, W. L. (1998).

⁹⁹ Hui, S. C. M. (2002). *Environmental Sustainability Assessment of Buildings Using Requirements in Building Energy Codes*.

¹⁰⁰ Meier, A., Lamberts, R., Olofsson, T. (2003). *Rating the energy performance of buildings*.

¹⁰¹ Bordass, B., Cohen, R., Standeven, M., Leaman, A. (2001). Assessing building performance in use3: energy performance of Probe buildings. *Building Research and Information Journal*. Issue 29 (2). 114-128. [2003, May 29].

¹⁰² EuroACE. (1998). *Assessment of potential for the saving of carbon dioxide emissions in the European building stock*. Submitted by CALEB Management Services. SAVE ENPER-TEBUC reports. http://www.euroace.org/reports/R_Caleb1.pdf [2003, May 29].

5. Analysis towards an integrated framework methodology

Based on the trends reported over the last decade, it is clear that energy efficiency of buildings in the commercial sector should be increased, and significant potential energy savings do exist. The goal of the analysis is to arrive at an integrated framework methodology where energy performance in commercial office space buildings can be identified, in order for energy efficiency to be implemented. This stated according to Directive 2002/91/EC.

The definition of an energy efficient building by Meier, Olofsson & Lamberts, as stated in Section 2.2 and in the literature review of Section 4.5, provides a clear reference point, and in the analysis of energy performance, the 3 listed criteria for an “energy-efficient” building cannot be ignored.

5.1 Aim of the methodology

The goal of this methodology is for the integration of energy performance aspects in relation to the whole building system, and the assessment according to established standardized calculation methodologies. As shown in the review of tools in Section 4, there are many existing detailed calculation methodologies used for the different system components in a commercial building, but these components and their tools are not being applied or integrated in a systematic manner for the implementation of energy efficiency in whole building systems. The pressing issue is that the law requires this application of the Directive to be developed and in force by 2006.

The aim of this Section is to arrive at an integrated framework methodology for identifying energy efficient aspects in commercial buildings, with the application of established standardized methodology, as called for in the Directive.

Therefore, this framework methodology aims to combine the different components of a building system in an integrated manner where existing codes and standards can be accordingly applied in order to renovate, refurbish or retrofit an existing commercial building in terms of enhanced energy performance. Based on such improvements, the application of a building performance certification system can rate the energy performance of these buildings, and issue energy efficient building certification if it applies. This is directly in compliance with Articles 3, 4, 6 and 7 of the Directive 2002/91/EC on the energy performance of buildings.

In Sweden, as stated, the current practice for refurbishments or energy enhancement in the existing building stock relies a great deal on energy simulation software, where an empirical trial-and-error method is used in extracting energy savings.¹⁰³ There is no standardized integrated approach in analyzing the energy performance of a building, which is required by the Directive. This methodology proposal therefore presents such an alternative, where the systematic approach towards energy efficiency in the existing building stock can be assessed, and thereafter certified.

¹⁰³ European Commission (2003) ENPER-TEBUC project.

The analysis of such a methodology is motivated by the fact that it is not within the scope of this thesis to formulate and develop a calculation methodology with detailed heat and energy equations, as with the European Standard EN832. Instead, it is to utilize existing established methodologies, and integrate its application with respect to commercial buildings, for the assessment of energy performance and the identification of energy efficient aspects. The proposed integrated methodology distinguishes between the 2 areas of energy consumption - heat energy and electricity energy.

5.2 Determining what to measure in buildings

There are numerous building component systems in an operating commercial building and all are highly complex yet interrelated. Furthermore, the process of determining which energy intensive aspects to consider in buildings is highly case-specific and dependent on the occupant usage patterns. Nevertheless, the 2 aforementioned areas of energy consumption: heat and electricity, falls principally under a few categories of end-use consumption. These categories are:

1. Primary usage service systems: HVAC systems, lightning, etc.
2. Secondary use systems: Lifts, escalators and other optional energy-intensive building service equipment.
3. Individual user systems: Mainly personal office electrical equipment such as personal computers, printers, copiers, etc.

The following subsections cover these categories, listing the quantitative and qualitative aspects deemed important by different reviewed methodologies, opinions from various authors, and most importantly, what the Directive requires. Finally, a narrowed set of building aspects is presented, with a clear decision on which aspects are considered in an integrated framework and its justification.

5.2.1 According to the literature review

Based on the aspects defined by Meier, Olofsson and Lamberts, an energy efficient building must contain these 3 aspects:

- §1. It should contain energy efficient technologies, operating as designed, in reducing energy use.
- §2. It must supply the required amenities and features expected for the standard use of the building, for at least 60 hours per week.
- §3. It must be operated in a manner to be efficient, which gives evidence of low energy use when compared to other similar buildings

Therefore, in relation to energy performance, the determination of which aspects to measure and improve covers these concerns. A trade-off between comfort levels and energy performance exists, and it is important to state distinctly that low energy consumption figures should not be achieved through reducing the standard level of comfort, where the provision

of the standard indoor air quality conditions must be fully satisfied.¹⁰⁴ Energy performance enhancements through such means can never, and should never, contribute to efficiency goals. Therefore, based on what have been reviewed in building codes and standards, it is assumed that compliance to these standards is fully satisfied.

In reference to the electricity consumption of commercial buildings for office use, Yik, Burnett, Jones and Lee (1997) have identified HVAC systems, lighting, plumbing and lift systems to contribute most significantly.¹⁰⁵ The paper discusses that while heat energy consumption is by no means insignificant, electricity consumption from such buildings weigh far heavier when compared, especially when converted into primary energy.¹⁰⁶ Therefore, due to the dominant use of electricity in the commercial building sector, this aspect cannot be ignored.

The methodologies reviewed clearly distinguish between the aspects of heat and electricity energy consumption. Table 5-1 summarizes this and indicates the aspects that were considered in each reviewed methodology.

Table 5-1. Identified aspects in existing energy performance methodologies

Reviewed Methodology	Identified Aspects:	
	Heat consumption	Electricity consumption
European Standards EN832/EN ISO 13790	Energy input for heating, Energy consumption from other appliances, Recovered energy, Heat losses, Technical losses.	N.A.
LEED for Existing Building system (v 2.0)	Building envelopes, HVAC systems, Recovery systems, Humidity control systems.	Cooling (refrigerating) systems, Lighting systems, Ventilation fan systems, Safety systems, Building automation controls, Service hot water systems.
BREEAM Offices 2003	HVAC systems, DHW systems, Humidification systems.	Cooling systems, Lightning systems, Ventilation fan systems, Computer rooms, Catering facilities, Others (miscellaneous).

Source: BREEAM Offices (2003), EN 832 (1998) & LEED EB (2002).

5.2.2 According to the energy consumption patterns

Based on the percentile figures of final energy use presented in Section 3.2, it is obvious that the most significant energy-intensive features of a commercial office space building should be analyzed. Therefore, it is most likely that an integration of these aspects into a framework methodology will result in increased benefits for building energy performance. There is, nevertheless, the concern between the distinctions of final energy use, in terms of heat energy, expressed in kW_th, or electricity consumption, kW_eh. This is not always clear from

¹⁰⁴ Bevington, P. L. (1984). Measuring energy performance. *Journal of Property Management*. Vol. 49, Issue 2. p. 31.

¹⁰⁵ It should be noted that while this paper refers to the conditions of the commercial building stock in Hong Kong, there are several generalities that can be drawn from the research and applied accordingly to the building stock in Sweden.

¹⁰⁶ Yik, F. W. H., Burnett, J., Jones, P., Lee, W. L. (1997). Energy performance criteria in the Hong Kong Building Assessment Method. p. 208.

the data reviewed on the type of consumption for each end-use component. It is important that these 2 aspects are studied in order to arrive at a complete and valid methodology, but given that electricity consumption has a greater primary energy conversion value and environmental impact than heat consumption, the emphasis would be largely on electricity consumption, as shown in Figure 3-5.

5.2.3 According to the aspects listed in the Annex of Directive 2002/91/EC

The consideration of specific aspects, related to building energy performance, listed in the Directive cannot be ignored. Article 3 of the Directive 2002/91/EC clearly states that the adoption of a methodology should be based on “the general framework as set out in the Annex” of the Directive, while “taking into account standards or norms applied in Member State legislation”. This framework listed in the Annex of the Directive, is shown in Box 5-1.

ANNEX	
General framework for the calculation of energy performance of buildings (Article 3)	
1.	The methodology of calculation of energy performances of buildings shall include at least the following aspects: <ul style="list-style-type: none">(a) thermal characteristics of the building (shell and internal partitions, etc.). These characteristics may also include air-tightness;(b) heating installation and hot water supply, including their insulation characteristics;(c) air-conditioning installation;(d) ventilation;(e) built-in lighting installation (mainly the non-residential sector);(f) position and orientation of buildings, including outdoor climate;(g) passive solar systems and solar protection;(h) natural ventilation;(i) indoor climatic conditions, including the designed indoor climate.
2.	The positive influence of the following aspects shall, where relevant in this calculation, be taken into account: <ul style="list-style-type: none">(a) active solar systems and other heating and electricity systems based on renewable energy sources;(b) electricity produced by CHP;(c) district or block heating and cooling systems;(d) natural lighting.
3.	For the purpose of this calculation buildings should be adequately classified into categories such as: <ul style="list-style-type: none">(a) single-family houses of different types;(b) apartment blocks;(c) offices;(d) education buildings;(e) hospitals;(f) hotels and restaurants;(g) sports facilities;(h) wholesale and retail trade services buildings;(i) other types of energy-consuming buildings.

Box 5-1. The general framework for the calculation of energy performance in buildings (Article 3) as listed in the Annex of Directive 2002/91/EC

Source: Official Journal of the European Communities (2002)

Parts 1 and 2 of this framework are significant, but the emphasis for this thesis is largely on Part 1. This is because Part 2 of the Annex in the Directive relates mostly in considerations for new buildings, taken into account before the commencement of construction. On the other hand, Article 6 states that for any existing building with a useful floor area above 1000m² undergoing major renovations; that the subsequent energy performance of either the whole or renovated section, must be upgraded in order to comply with both Articles 3 and 4, with the “objective of improving the overall energy performance of the building”. Therefore, in order for the proposed methodology to remain valid, it is crucial that the listed aspects in Part 1 are considered in the analysis of developing such a methodology.

5.2.4 Other qualitative aspects

Non-quantifiable variations do exist within the same category of building, even when sample pools are derived from the same climatic conditions. Such variations may include differences in building aspect ratios leading to varying factors of heat loss coefficients.¹⁰⁷ Therefore, a description of qualitative features of the building should be included alongside the quantification process when assessing energy performance. This provides a general qualitative description of the building and an indication of the aspect ratio, window use ratio, etc, before any methodology is performed. As far possible, the data collected should be normalized; this includes accounting for outdoor weather patterns and varying occupancy patterns covering the same time period, if necessary.¹⁰⁸ Such variances are accounted for when the “kWh/kaph”, “kWh/degree-day” energy metrics, shown in Table 2-2, are applied.

Similarly, the “adequate” level of indoor air quality conditions and level of comfort are difficult to assess, and for this reason, monitoring indoor air quality levels when assessing energy performance is crucial.¹⁰⁹ Such evaluations are carried out by qualified surveyors, through interview surveys with building occupants or physical inspections of the building.

In such qualitative assessments, physical inspections will, without doubt, be necessary for the evaluation of the ideal operation of equipment, maintenance and quality of services provided by the building. Energy efficiency is often not effectively employed in buildings because of the incorrect use and lack of maintenance of equipment. Most importantly, such inspections should verify that the aspects of indoor air quality, as listed in the BBR, are not compromised.

5.2.5 Combining the quantitative and qualitative aspects

In determining the aspects that should be included in the methodology, the decision is based on the aspects discussed in Sections 5.2.1-5.2.4, namely, (i) the aspects which are considered by existing methodologies, (ii) the aspects which reflect the most intensive use of energy in building energy consumption, (iii) the detailed aspects called for by the Directive that should be considered, and, (iv) non-quantifiable aspects of buildings, which can influence energy performance and should be accounted for.

¹⁰⁷ Cole, R. J., Larsson, N. (2002). *Green building challenge: Environmental performance indicators*. p. 3.

¹⁰⁸ National Renewable Energy Laboratory (2002). *Protocol for monitoring and reporting commercial building energy performance. High Performance Buildings: Measurement and documentation projects*. p. 2.
http://www.eere.energy.gov/buildings/highperformance/performance_metrics/pdfs/bldgenergyperf_protocol.pdf [2003, July 17].

¹⁰⁹ Bevington, P. L. (1984). *Measuring energy performance*. p. 31.

Assuming that qualitative aspects should be considered in all cases, then the common list of aspects, similarly shown in Figure 5-1, is found to be:

1. The building envelope;
2. Lighting systems;
3. HVAC systems;
4. Electrical equipment;
5. Lifts and escalators;
6. Service water heating

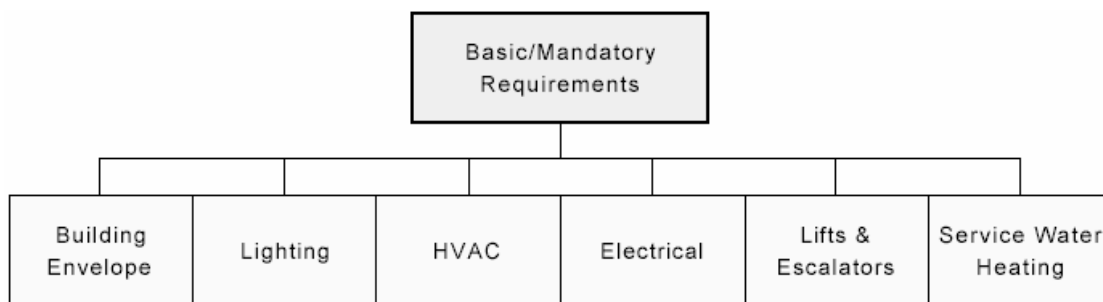


Figure 5-1. Major aspects considered for building energy performance

Source: Hui, S. C. M. (2002), revised

The building envelope cannot be neglected because it concerns issues related to heat losses, thermal bridges and other thermal transfer properties.¹¹⁰ The improvement of the thermal performance of a building can significantly alter the loads imposed on HVAC systems and the annual heat consumption of the building. Quantifiable factors that determine this heat transfer are¹¹¹:

1. The temperature differential between indoor and outdoor temperatures, ΔT ,
2. The area of exposed building surfaces, A ,
3. Other heat transfer properties, for example, the U-value¹¹² of a building,
4. The thermal storage capacity of the building.

Additionally, the qualitative features of the building envelope as discussed previously, can be taken into account with this aspect. It is imperative that non-quantifiable features, such as the

¹¹⁰ European Standard EN832. (1998). ICS 91.140.10. Ref. No. EN 832:1998E.

¹¹¹ Hui, S. C. M. (2003). <http://arch.hku.hk/teaching/SBT99/SBT99-01/sld032.htm> [2003, May 29].

¹¹² The U-value of a building measures the rate of heat loss through a building. It is determined by the total amount of heat loss, in Watts, divided by the total surface area of the medium material, in m^2 , per degree-change on either side of the material, ΔT in degrees centigrade.

building aspect ratio and other architectural features, are not disregarded when considering the energy performance and efficiency of a building. This is often the case when quantitative studies are performed on buildings. Such features may influence the thermal performance of a building significantly, either negatively or positively. Therefore, the inclusion of this aspect has 2-fold purpose of assessing both the quantitative and qualitative features of the physical building.

Likewise, justification for the inclusion of lightning, HVAC, electrical, lifts and service water systems in the methodology is supported by the repeated emphasis on these features in existing methodologies. HVAC systems are the single most energy-intensive feature of building service systems, where the systems are critical for the provision of occupant comfort, health and safety.¹¹³ This is similarly reflected in Figure 3-5, where the components of HVAC, lighting, electrical office equipment and elevators constitute almost the total electricity consumption in a building. In addition, interactions between the building envelope, lighting and HVAC systems, also determine significant consequences if inadequately considered.

It is important to note that these energy-intensive aspects interact with each other and consume mainly electricity energy. Therefore, there is not only a need to reduce energy consumption, but also to increase the efficiency of building service systems in an integrated manner in order to realize the sizeable potential identified.¹¹⁴ These 6 aspects may not cover every aspect of energy consumption in a commercial building. However, given the method of determining the aspects, it is assumed that the decision is deemed sufficiently adequate.

These aspects can be categorized by considering the type of energy consumption and the different kind of primary, secondary or user-dependant systems, as shown in Table 5-2. This facilitates the subsequent quantification and assessment of each heat or electricity consumption component, which will be covered in the following sections. It is reflected in Table 5-2, that the type of energy used in office buildings is predominantly electricity.

Table 5-2. Identified significant aspects in energy performance assessments

System	Type of Energy Consumption	
	Heat energy	Electricity
Primary system	Building envelope heat losses	Air-conditioning load of HVAC systems
	Heating demand of HVAC systems from district heating sources	Ventilation fans of HVAC systems - largely fans in air handling units (AHU)
		Lighting systems
	Service water heating (may or may not be purely supplied by electricity)	
Secondary systems	--	Lifts and escalators
Final-user system	--	Electrical appliances
		(Largely consisting of computers, servers and other Information & Communications Technology)

¹¹³ Hui, S. C. M. (2003). <http://arch.hku.hk/teaching/SBT99/SBT99-01/sld044.htm> [2003, May 29].

¹¹⁴ Energimyndigheten. (2002). *Energy in Sweden 2002*. p. 26.

5.3 Determining how to assess the aspects of energy performance

Based on the aspects identified from the previous section, this section analyzes the general quantification of these 6 listed aspects, as according to the nature of their energy consumption, as listed in Table 5-2. The main aim of this section is to quantify energy performance through the use of indicators presented in Table 2-2, and standard established methodologies that are already in use. When applied, these indicators and methodologies provide individual building component assessments of energy performance in a building.

In general, the most commonly used index for final energy (heat and electricity) consumption is in terms of kWh/m² of the *net* building area, where the annual final energy consumption is summed. However, in Sweden, heat and electricity consumption is not made distinct in tabulation methods. In such cases, the nature of energy consumed must be made distinct; otherwise these cumulative figures become questionable.

5.3.1 Heat consumption

This subsection discusses the aspects of the heating component of HVAC systems and the thermal characteristics of the building envelope. In existing buildings, the heat may be supplied by electric heaters, boilers using fuels, or by the use of district heating networks. It should be noted that if the use of electric heaters were employed in such buildings, the nature of the energy consumption would fall under the electricity consumption of the building. In Sweden, the practice of using electric heaters is generally discouraged, if the option of more energy-efficient systems exists, such as district heating.¹¹⁵

Annual heat consumption of a building

The annual heat consumption is measured in terms of kWh/m², and it refers to the annual sum of heat used for space heating within the total heated floor area of a building. This is the most commonly used indicator to indicate a building's heat use through the HVAC systems. It also can be normalized with the use of a reference climate, reflected in time-series data for the average temperature required for the particular building sector.¹¹⁶

Quantifiable range of energy use and performance for heating

The existing methodologies presented in the European Standard EN832 and EN ISO 13790 defines the detailed quantification for the thermal performance and heat transfer of buildings. Buildings in Sweden are bound to comply with the Standard, as with all other Member States, but this is rarely practiced and compliance is voluntary.

For calculation procedures, please refer to the Quantitative Analysis section of Appendix C, Assessment of energy performance in the identified aspects: Thermal heat performance.

The issues pertaining to the indoor air quality are difficult to establish, and that trade-offs between comfort levels and energy efficiency factors will always exist. This is typical for developed countries, such as Sweden, given the higher standards of living. Nevertheless,

¹¹⁵ Sweden has since prohibited the use of direct electric heating for residential uses (ENPER-TEBUC SAVE, 2003, p. 58).

¹¹⁶ Asia Pacific Energy Research Center. (2002). *Energy efficiency indicators and potential energy savings in APEC economies: A study of energy efficiency and savings in APEC economies*. p. 31. <http://www.ieej.or.jp/aperc/2002pdf/EEI2002V2.pdf> [2003, July 11].

regardless of the level of indoor air quality provided, it is crucial that the building component performance complies with the minimum level of requirements for health and safety, as stated by Boverket in the BBR code. At the same time, the maximum heating loads required, as defined by the performance-based European Standard EN832, EN ISO 13790 and EN 14335 for the energy efficiency of heating systems, would determine the upper design cap.

In this manner, the 2 boundary points define a clear and suitable range of energy consumption in acceptable indoor environment conditions. The flexibility of trade-offs made within this range, for energy efficiency and varying levels of comfort is, thereafter, included in both the European Standards and Swedish national requirements.

5.3.2 Electricity consumption

Based on identified aspects of energy consumption as listed in Table 5-2, this section provides a discussion into the application of existing methodologies which can be used to assess the electricity efficiency of the systems. These refer to the electricity consuming aspects of the (i) HVAC system, (ii) lighting systems, (iii) service water heating systems, (iv) lifts and escalators, and, (v) electrical appliances used.

Annual electricity consumption of a building

The annual electricity consumption is measured in terms of kWh/m², and it refers to the annual sum of electricity used within the total used floor area of a building. Often times, this is normalized for with the use of a “per occupant” component, which in turn reflects the annual electricity consumption of a building per occupant, per square meter.

This consumption figure could be further divided, segregated into the electricity consumption component of¹¹⁷:

- Electricity consumption per capita for lighting and electrical appliances.
- Electricity consumption of services, based on the identified aspects, per occupant.
- Electricity consumption per occupant, per net unit floor area, per unit of value-added in service, office-space commercial buildings.

While the indoor air quality and environment conditions often are not reflected from the use of these indicators, it is assumed that the minimum requirements for occupant comfort are satisfied and adequately provided for.

Assessment of electricity use and performance

The technical facet of the calculation methodology will not be covered in this thesis, but there are established methodologies that contain calculation procedures based on the evaluation of the performance and electricity efficiency of a building. These existing methodologies have been covered in the review of tools in Section 4 of the thesis.

The following suggests the use of applicable tools in order to assess each aspect:

¹¹⁷ Asia Pacific Energy Research Center. (2002). *Energy efficiency indicators and potential energy savings in APEC economies*. p. 31.

1. HVAC systems:

The electricity-intensive component of the HVAC system consists of the ventilation system and the cooling load required by the building.¹¹⁸ The minimum requirements on cooling loads are defined by set-point temperatures as established in national codes. However, on the national level, no mandatory standardized energy performance calculation for cooling loads has been established. Nevertheless, calculation procedures for the energy performance of the cooling load and ventilation systems exists, and is presented in the European Standard TC156, as reviewed in Section 4. For additional calculation procedures for HVAC system cooling loads, please refer to the Quantitative Analysis section of Appendix C, Assessment of energy performance in the identified aspects: Performance of electricity consumption.

The LEED methodology has considered the calculation of energy performance, minimum energy performance and features for optimizing energy performance in a commercial building, which are general guidelines that can be adopted.¹¹⁹

“In principle, existing buildings could be more accurately assessed on the basis of metered consumption” with the use of sub-meter measurement devices.¹²⁰ The practice of metering presents a simple method of measuring the total electricity consumption and performance of any particular service system.

The application of such methodologies, for HVAC systems, could be adopted for the calculation of energy performance, and ranked to assess efficiency if required.

2. Lighting systems:

High efficiency fluorescent tubes and electronic ballasts can provide adequate levels of illumination while reducing power consumption by about 40%.¹²¹ Technical codes have stated that the provision of 300 lux is deemed adequate.¹²² The use of daylight management has been promoted in the Directive and TC169 provides the calculation of performance in lighting. TC169 and the assessment of the building envelope can be integrally applied in order to incorporate the use of daylight. Additionally, this can be applied with TC156 in the combined performance evaluation of lighting, ventilation and cooling loads.

There are additional references for energy efficient lighting defined by the ASHRAE organization, the Energy StarTM¹²³ label and the LEED environmental assessment guidelines

¹¹⁸ The component of heating load of HVAC systems may be provided by the use of electric heaters, although this is highly discouraged. Determination of the heating load can be similarly determined by the use of EN832, EN14335 and EN ISO 14335, although the energy carrier mode would be electricity, instead of heat.

¹¹⁹ US Energy Star. (2003). http://www.energystar.gov/index.cfm?c=products.pr_index [2003, June 17].

¹²⁰ Yik, F. W. H., Burnett, J., Jones, P., Lee, W. L. (1998). p. 210.

¹²¹ Yik, F. W. H., Burnett, J., Jones, P., Lee, W. L. (1998). p. 212.

¹²² Bartenbach, C., Klingler, M. (1994). Daylight Management and Integrated Artificial Lighting. In the *European Directory of Energy Efficient Building 1994*. England: James & James Science Publishers. p.112.

¹²³ US Energy Star. (2003). *Compact fluorescent light bulbs*. http://www.energystar.gov/index.cfm?c=cfls.pr_cfls [2003, June 17].

for existing buildings, with other general recommendations and performance calculations for optimization.¹²⁴

3. Service water heating systems & Lifts and escalators:

In a similar fashion, extensive references in the EN 14335 and LEED methodologies point to established energy calculation methods defined by CEN for service water heating systems, and, ASHRAE¹²⁵, for lift and escalator systems with energy efficiency considerations as listed by the Energy Star™ label scale. In addition, the LEED system presents an assessment of energy efficiency using a benchmarking scale. The LEED EB reference guide also provides options for energy conservation measures, energy efficiency technologies and resources for assisting retrofits and renovations. These present flexible options for energy efficiency improvements in existing commercial buildings.

It is important to note that service water heating systems can similarly be provided by district heating services, with a higher overall efficiency level. In Sweden, this can be supplied through the local district-heating network, and this is considered to be an efficient system.

4. Electrical appliances:

This particular component of energy efficiency has increased significantly over the past decade. This is contributed by the significant increase in the amount of electrical appliances used per building occupant. There is a large variety of electrical appliances, and the LEED methodology refers to the Energy Star™ label in order to assess energy efficiency for each type of appliance.¹²⁶ Since 2001, the EU has adopted the US Energy Star™ system for energy efficiency in office equipment, but the initiative has not made mandatory in Member States.¹²⁷

Alternatively, the energy performance of appliances could be benchmarked against best practices. This method of benchmarking “corresponds to the lowest specific consumption of appliances available on the market”, based on average-sized appliance and “not to the smallest appliance available on the market, with a non-negligible market share”.¹²⁸ The individual energy efficiency of each appliance is emphasized in this particular aspect, and there is significant potential for enhanced performance in this area, given the available technology and the relative ease of replacing such appliances.

It is of interest to note that in Sweden, a national labeling program for household appliances has been in force since 1993.¹²⁹ This program, however, does not apply to appliances used for commercial purposes.

¹²⁴ US Green Building Council. (2002). *LEED EB v2.0*. p. 20.

¹²⁵ IESNA 90.1-1999.

¹²⁶ US Energy Star. (2003). *Office equipment*. http://www.energystar.gov/index.cfm?c=ofc equip.pr_office_equipment ; *Supplementary load reductions*. <http://estar7.energystar.gov/ia/business/SupplementalLoad.pdf> [2003, June 17].

¹²⁷ European Union. (2003). *The European Energy Star Programme*. <http://europa.eu.int/comm/energy/en/ener-star-prog.html> [2003, June 17].

¹²⁸ ODYSSEE (2003). *Definition of ODYSSEE indicators*. p. 62. <http://www.odyssee-indicators.org/Publication/PDF/def-ind.pdf> [2003, June 17].

¹²⁹ Energimyndigheten. (2002). *Energy efficiency in Sweden 1990-2000*.

5.4 Determining how to apply aspects in an integrated method

5.4.1 Analysis of a qualitative methodology

The formulation of a qualitative methodology is essential given the significance of its influence on building energy performance, and hence, efficiency. There is a spectrum of non-quantifiable aspects that has not been primarily addressed by any existing calculation methodology. Nevertheless, certain aspects have been listed in the Annex of Directive 2002/91/EC, which may be of interest to chart.

It is important to first begin the methodology with a descriptive report of the building. This may include the type of building considered, its use and the category of the building. In this thesis, the scope is narrowed to commercial buildings used for offices, but these may include buildings with composite purposes. For example, certain commercial buildings contain a singular office block for office use, or, a tower in a composite building, which is cordoned for office use.¹³⁰ It is crucial to make such distinctions clear before a quantitative methodology is adopted, as energy performance of such varying buildings will reflect differently and these differences must be substantiated.

In summary, the method of qualitatively assessing the energy performance and efficiency of a building should include the following procedures and aspects shown in Figure 5-2 and Table 5-3, respectively. For a full existing qualitative description of the qualitative aspects of a building, according to the US Department of Energy, National Renewable Energy Laboratory, please refer to the section on Qualitative aspects in Appendix C.

As seen in Figure 5-2, the qualitative assessment of the energy performance and efficiency of a building is important, because if the building still performs in an unexpected manner, after the quantitative assessment, then some qualitative aspect might be influencing the performance of the building. Therefore, there is a need to review the qualitative properties of the building to justify the variances reflected, and provide supporting explanations to the corresponding performance and efficiency.

¹³⁰ Yik, F. W. H., Burnett, J., Jones, P., Lee, W. L. (1998). p. 207.

Table 5-3. A simple example of a building description survey

Name of Building	--
Type of Building	Commercial/Residential/Public/etc
Use Type	Building Activity: Office use/Apartment blocks/Education buildings/Hospitals/etc
Description of Building	<ol style="list-style-type: none"> 1. Year constructed & major renovation years (refurbishment/retrofits) 2. Gross Building Area & Total <i>Net</i> Heated Area 3. Single use/Composite use - Providing a description of the composite use 4. Number of climate zones - Air-conditioned/Naturally ventilated zones 5. Number of floors - Description of air conditioning of each floor 6. Ownership occupancy - In percentage of total net building floor area
Position & Orientation of Building	<ol style="list-style-type: none"> 1. City/State, or, Location in degrees latitude and longitude 2. North-South orientation
Climate zone	Temperate cold-climate/Severely cold-Climate
Building aspect ratio	--
Window-to-floor-area ratio	--
Description of occupancy densities	<ol style="list-style-type: none"> 1. Total floor area vacant for more than 3 months 2. Number of employees within the main shift 3. Description of the main shift - Operating hours

Source: NREL (2002)

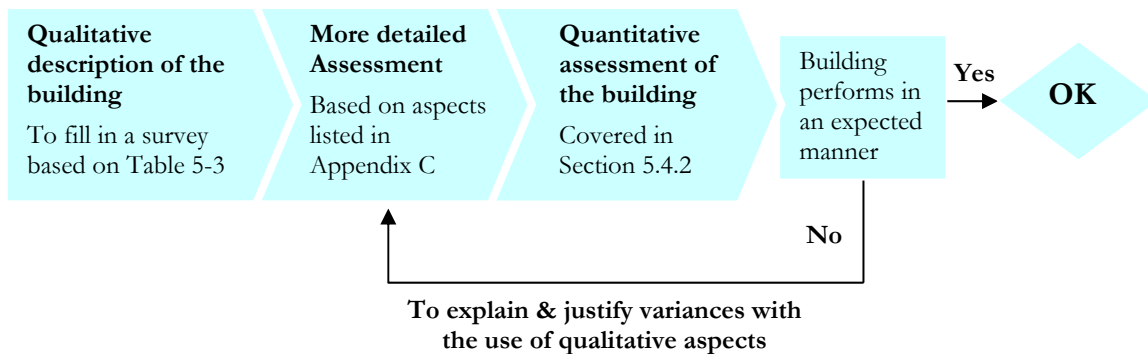


Figure 5-2. Qualitative methodology for energy performance assessment in buildings

For example, if the building orientation and aspect ratio is such that it induces the existing building to demand a significant amount of cooling load in summer, and the building performance does not improve after quantifying the potential of energy savings, then it is very likely that some qualitative aspect, not reflected in the quantitative analysis, is contributing to the result as such. This aspect can be identified within the qualitative analysis.

5.4.2 Analysis of a quantitative methodology

The analysis of building energy performance and efficiency should stem from an integrated procedure that assesses the 6 identified aspects discussed in Section 5.2. By simultaneously assessing the performance of each component with the ideal of efficiency, within the context of the whole building system, a valid integrated methodology can be developed. Research has shown that an integrated approach increases the energy performance of whole building systems by up to a factor of 2.¹³¹ Figure 5-3 shows the existing mandatory standards, prescriptive requirements and performance-based results that are required and applied, when analyzing the building system as a whole.

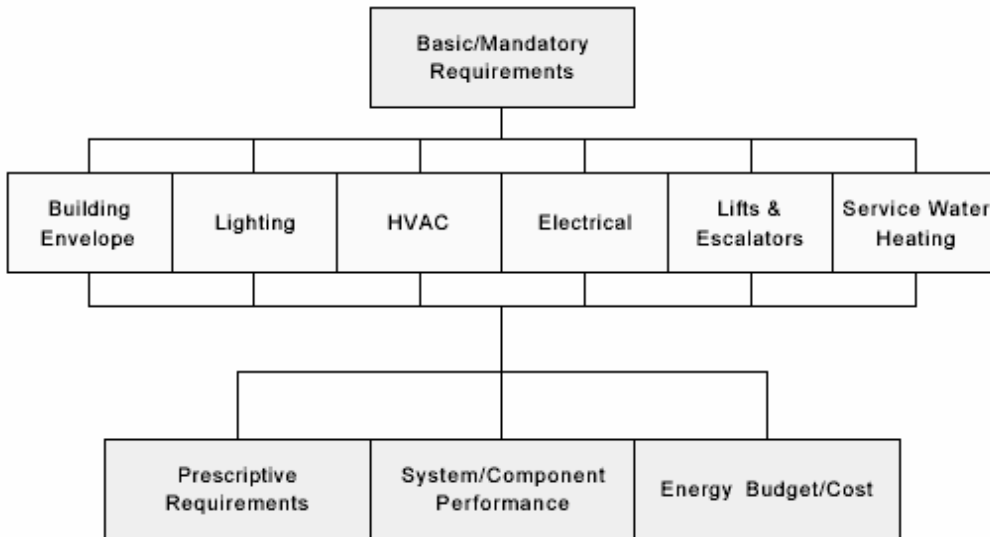


Figure 5-3. Major areas and compliance options for building energy codes

Source: Hui, S. C. M. (2002)

The first level of basic and mandatory requirements, as seen in Figure 5-3, contains “fundamental issues” where compliance within the 6 identified aspects is essential.¹³² These requirements determine the minimum performance and operation of the 6 systems, where the satisfaction of the lower bound of performance must be ensured for occupant health and comfort. Issues covered in these requirements are largely safety features, for indoor air quality and environmental conditions, such as minimum ventilation requirements, the minimum amount of lighting to be supplied and indoor set-point temperatures.

The upper bound of energy performance required for energy efficiency can be described by additional prescriptive requirements, system/component performance standards, or evaluated with the use of an energy budget. Prescriptive requirements may pertain to individual aspects of the building system, for example, a prescribed minimum requirement on insulation levels for the building envelope for optimal building energy performance.¹³³ Such requirements influence building efficiency by prescribing certain standards to be complied with, but their positive effects are largely indirect in nature when addressing energy efficiency

¹³¹ Fraunhofer Institut für Bauphysik (2003). *ENPER BBRI International Workshop 19 May 2003*.

¹³² Hui, S. C. M. (2002). *Environmental Sustainability Assessment of Buildings Using Requirements in Building Energy Codes*. p. 3.

¹³³ Hui, S. C. M. (2002). *Environmental Sustainability Assessment of Buildings Using Requirements in Building Energy Codes*. p. 3.

issues. Alternatively, system and component performance requirements allow for a degree of freedom in choosing the most appropriate system, while experiencing certain “trade-offs” in order to attain efficient performance for the whole building system.¹³⁴ These requirements do not describe design caps on individual systems, but places certain performance caps with respect to aggregated systems.

In a similar fashion, the energy budgeting alternative proves to be the most flexible of all the types of compliance requirements, through the evaluation and assessment of energy consumption of the whole building system. The only requirement here is for the basic layer of mandatory requirements to be satisfied. This method is more complicated and often facilitated by the use of computer energy simulation programs.

Therefore, the goal of energy assessments in commercial buildings lies within this lower and upper boundary for energy performance in buildings. In Sweden, existing energy codes determine the basic mandatory requirements of building energy performance.¹³⁵ These well-established and detailed codes were introduced in the 1960s, and since then, detailed construction standards have been largely replaced by performance requirements. This trend has been reflected in the 1988 revision of building standards, which “introduced a building performance standard instead of requiring insulation for certain building components”, and again in January 1994, for harmonization with EU regulations as stipulated by the Directive 89/106/EEC for construction products.¹³⁶

The procedures for assessing compliance with such basic codes and performance standards do exist and are well documented, and “the use of such existing methods may serve as a simplified benchmark in assessing enhanced energy performance”.¹³⁷ In a graphical explanation of this concept, Figure 5-4 shows the simplified process of evaluation.

¹³⁴ Hui, S. C. M. (2002). *Environmental Sustainability Assessment of Buildings Using Requirements in Building Energy Codes*. p. 4.

¹³⁵ Energimyndigheten. (2002). *Energy efficiency in Sweden 1990-2000*.

¹³⁶ Energimyndigheten. (2002). *Energy efficiency in Sweden 1990-2000*.

¹³⁷ Hui, S. C. M. (2000). Building energy efficiency standards in Hong Kong and mainland China. In the *2000 ACEEE Summer Study on Energy Efficiency in Buildings, 20-25 August 2000, Pacific Grove, California*.
<http://arch.hku.hk/~cmhui/aceee590a.pdf> [2003, May 29].

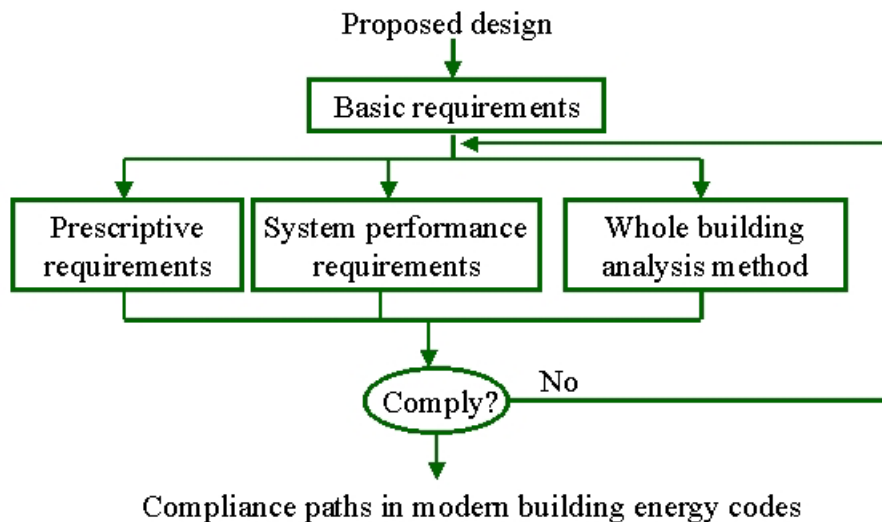


Figure 5-4. Building energy standards and energy performance

Source: Hui, S. C. M. (2003)

The assessment of thermal and electricity consumption performance of a building may be divided into¹³⁸:

1. The analysis of each individual component, as defined by prescriptive and performance standards for individual equipment/appliances, or,
2. The analysis in the relation to the total building performance in an integrated manner.

The former assessment method has previously been evaluated in Section 5.3, with supporting efficiency assessment methods that are based on existing and established standards. The latter assessment method, however, includes the evaluation of the 6 identified aspects together, and is more complicated in nature. This performance assessment method is typically determined by the building energy consumption value of kWh/m² per year, or a building energy budget. The method of assessment and evaluation of the 6 aspects can be integrated into a singular methodology diagram, with the use of established CEN standards, as shown in Figure 5-5.

¹³⁸ Hui, S. C. M. (2003). *Assessment methods*. <http://arch.hku.hk/teaching/SBT99/SBT99-08/sld030.htm> [2003, May 29].

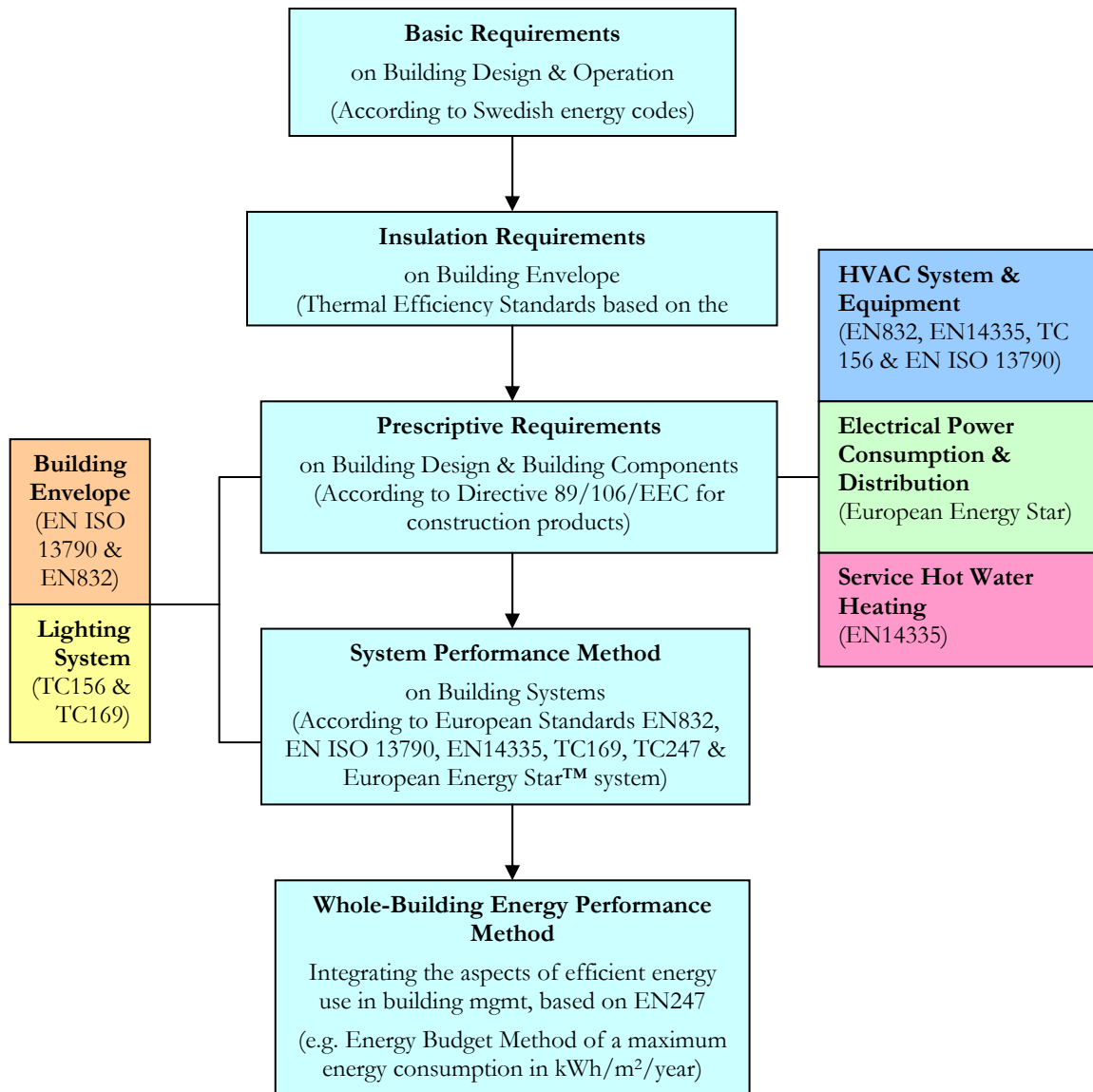


Figure 5-5. An integrated framework methodology satisfying requirements and standards of energy performance

Source: Hui, S. C. M. (2003), revised

Figure 5-5 presents how commercial buildings can be assessed in terms of energy performance and efficiency standards, with the integration of existing requirements, standards, and existing calculation methodologies. For existing buildings, the basic mandatory requirements would have been satisfied, and assessment may commence from the evaluation of (improved) insulation requirements, according to calculations from the BBR. Due to the sheer extent and cost-prohibitive nature of amendments to the building envelope, it is often the case that prescriptive requirements on other building components and service systems are assessed first instead.¹³⁹

¹³⁹ Hui, S. C. M. (2003). *Energy efficiency standards for building design*. <http://arch.hku.hk/~cmhui/teach/65747-Xc.htm> [2003, May 29].

As seen, these factors all point towards the enhanced energy performance of the whole building system. Where the use of TC247 for energy efficient building automation, controls and building management applies when managing efficient building systems. When crystallized into a specific final energy consumption value, in terms of kWh/m² per year, this creates an energy efficient building. This is main aim of integrating basic codes, prescriptive requirements and performance-based standards listed by the CEN, in order to achieve energy efficient performance in buildings.

Additional regulations within the scope of these 6 aspects may include:¹⁴⁰

- Standards for the testing of energy efficiency in building products and building materials,
- Standards for testing efficiency in electric appliances and equipment,
- National codes and policies regarding energy efficiency management.

It is important to note that the energy performance and efficiency issues in buildings are not limited only to the technical building design. Energy consumption trends, as discussed in Section 3, have shown that increases in energy use is also dependent on the preference and behavior of building occupants, through the provision of extra building service systems and increasing use of electrical appliances. This also contributes significantly to the energy performance of a building.

5.5 Determining aspects of maximum benefits

The previous section focused on energy performance assessments in a building, according to a combination of established codes, requirements, and standards. In this section, the focus is shifted from assessing the energy performance of a commercial building, to the identification of energy efficient aspects, which provide the maximum benefits, enhancing the general building performance.

In a simplified analysis, it is evident that leverage points in obtaining energy efficiency in a building can be identified with an evaluation of which aspect is:

- Most energy-intensive, terms of primary energy use kWh/m² per year.
- Easy to change - Non disruptive and cost-effective.
- Verified with applied research and supporting parametric studies conducted with energy stimulations modeling. This supports the current practice of energy performance evaluation in Sweden with the use of reference building models, as stated in Section 3.4.

There are additional requirements in order to determine which aspect should be identified for improvement within the complex energy-intensive systems of a commercial building. For example, the decision between improving building insulation, or, refurbishing the HVAC

¹⁴⁰ Hui, S. C. M. (2003). *Energy efficiency standards for building design*.

systems of the building. In order to determine the aspect to be improved, the following features are identified by Hui, S. C. M:¹⁴¹

1. The improvement assessment must be “understandable and acceptable by building professionals and the general public”.
2. Given the physically limiting nature of existing buildings, the identified aspect must be “practical and cost-effective to implement”.

This point reflects the concerns listed in Article 6, regarding existing buildings, of the Directive 2002/91/EC, whereby “energy performance is upgraded” in so far as it is “technically functionally and economically feasible”.¹⁴²

3. Assessments for improvements must similarly be based on “technically sound” and established knowledge, based on “local research and analyses”.
4. The assessment must have “clear objectives and good considerations of local conditions”.
5. Improvements must be facilitated by “efficient mechanism for implementation, capacity building and market stimulation”.

Given the preliminary stage of development in assessing energy performance and aspects that provide maximum efficiency benefits, it is inevitable that the single most influential determinant for developers will be the cost-effectiveness of such improvement assessments. Refurbishments or retrofitting would be cost-dependant and case-specific in nature. While the scope of this thesis does not focus on determining the cost-effectiveness of such improvements, it will nevertheless be an important factor for improving the efficiency of buildings, given the flexibility in performance-based standards.

A performance-based approach for enhanced energy performance in buildings, rather than the prescriptive nature of codes, stimulates innovation, reduces costs and increases flexibility, all according to the developer’s decision on the value of trade-offs incurred.¹⁴³ It is important to note that although a degree of flexibility is allowed in determining aspects of maximum benefits, but compliance to minimum standards with respect to indoor air quality and standard provision of amenities should never be compromised.¹⁴⁴

With renovations and retrofits to building service systems, it is not unusual that renovated commercial buildings fare very well based on final-energy tabulations and comparisons, but in general perform relatively worse when the final energy consumption is converted into primary energy figures.¹⁴⁵ This is anticipated given the increasing percentage of electricity use in office buildings, with the declining importance, and percentage of heat energy used, in

¹⁴¹ Hui, S. C. M. (2002). *Environmental Sustainability Assessment of Buildings Using Requirements in Building Energy Codes*. p. 5.

¹⁴² Directive 2002/91/EC of 16 December 2002. Article 6 p. 68.

¹⁴³ Hui, S. C. M. (2002). *Environmental Sustainability Assessment of Buildings using Requirements in Building Energy Codes*.

¹⁴⁴ Meier, A., et al. (2002). *What is an energy efficient building?*

¹⁴⁵ Meier, A., Adalberth, K., Busching, S., Elmroth, A., Haltrecht, D., Mroz, T., Pettersen, T. D., Virtanen, M., Yoshino, H. (1999). *Indicators of energy efficiency in cold-climate buildings: Results from a BCS expert working group*. <http://eetd.lbl.gov/EA/Buildings/ALAN/indicators99/index.html> [2003, July, 7].

space heating even for buildings located in severely cold climates. Converted into primary energy, the energy consumption of electricity in offices is increasing exponentially. Therefore, it is obvious that more efficient use of office electrical appliances is required. Changing office equipment that turn off to sleep mode, when not in use, saves a significant portion of electricity in commercial buildings.¹⁴⁶ Such replacements are not complicated, and do not involve major disruptions to building use schedules.

It is important to note that in Sweden, the use of district heating for space heating requirements ensures sufficient efficiency in the heating component of HVAC systems. The use of district heating in commercial buildings, as seen Section 3, has been an increasing trend. Therefore, the traditional focus of energy efficiency in space heating equipment should not be the focus point now. Instead, significant leverage points for enhanced energy performance can be obtained in issues concerning the energy efficiency of electrical appliances and the sizing of other electricity-intensive building service equipment in an integrated manner.

Introducing another angle, research has shown that “existing building technology, daily user patterns, user behaviors, and administrative practices all play a major role in energy use”, it is imperative that all these components are integrated into the assessment of an energy performance methodology, and for the identification of maximum benefits.¹⁴⁷ The occupancy patterns in buildings are unique and an individual approach for each assessed building is required. Because of the significant correlations, it is important that these qualitative aspects are integrated and reflected in the methodology. While this aspect is not specifically included in this thesis, influencing and altering user patterns may yield significant benefits, and prove most cost-effective, but it is nevertheless an aspect with high inertia, and changes in behavioral patterns are not always guaranteed.

5.6 Summary of the methodology

In summary of the analyses and discussions covered in this section, Figure 5-6 presents the general flow of analysis. As seen, the qualitative and quantitative aspects of energy consumption are first distinguished and assessed in terms of energy performance, with respect to existing basic mandatory codes, prescriptive requirements, performance-based standards and methodologies. Based on the assessment of energy performance, energy efficiency can be implemented with the identification of certain aspects that should be improved. This leads to the attainment an energy efficient building system. If the building does not perform as expected, then additional quantitative and qualitative assessments should be conducted in order to explain the variances and ultimately improve the energy performance of the building.

As discussed, the assessment of energy efficiency is obtained within a range, as seen from Figure 5-7, with codes, standards and requirements determining the upper and lower boundaries of energy performance. Based on the range presented, it would the developer's

¹⁴⁶ Roth, K., Goldstein, F., Kleinman, J. (2002). *Impact of Information and Communications Technology on the energy system*. Arthur D. Little, Inc. & International Energy Agency. <http://www.worldenergyoutlook.org/weo/papers/ictfeb02/Roth.pdf> [2003, May 5].

¹⁴⁷ Mrozowski, T., Lawrence, D., Tavanapong, S., Malhotra, K. (2000). *Executive summary. Development of an Energy Assessment Methodology for University Academic Buildings: Case study of the Natural Resources Building, Michigan State University*. Energy Subcommittee of the University committee for a Sustainable Campus and the Power and Water Department, Physical Plant. p. 7. http://www.ecofoot.msu.edu/files/pdfs/report_nat_bldg.pdf [2003, July, 7].

decision to determine the specific aspects of the building or its systems that could be improved for energy performance enhancement, while maintaining cost-effectiveness.¹⁴⁸ This range is incorporated into the iterative decision-making process of developing and improving building design, as shown in lower section of Figure 5-7.

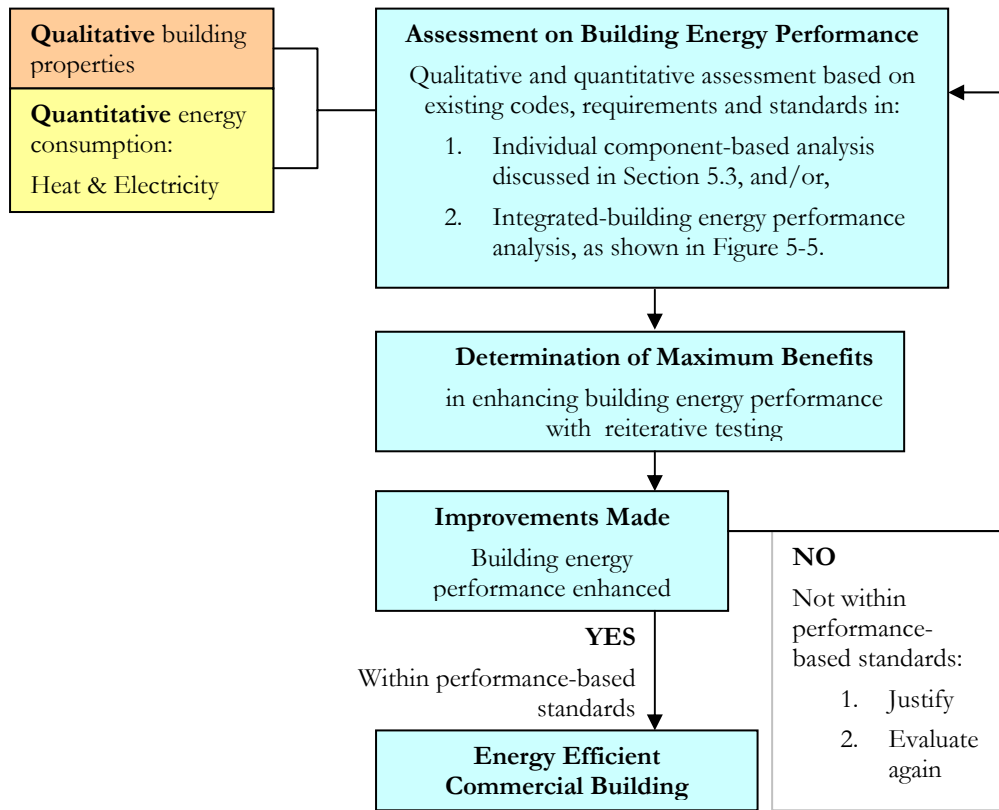


Figure 5-6. Summarized qualitative and quantitative analysis of energy efficiency in office buildings

¹⁴⁸ Mrozowski, T., Lawrence, D., Tavanapong, S., Malhotra, K. (2000). p. 10.

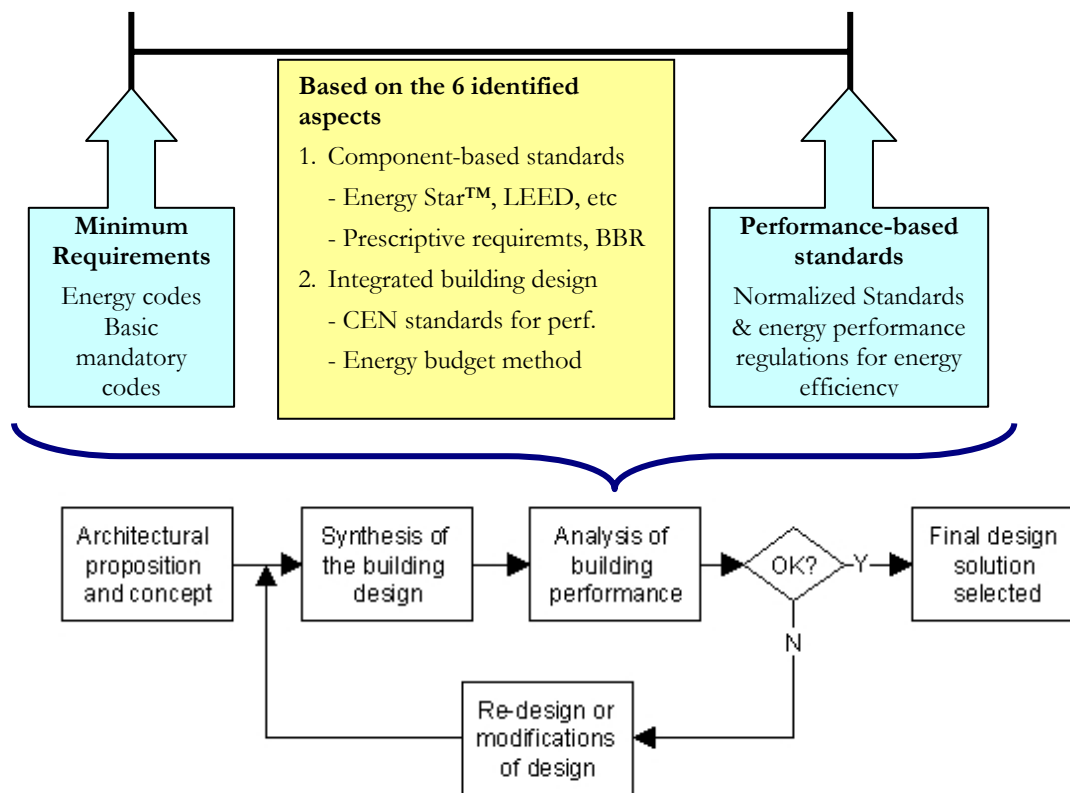


Figure 5-7. Range of energy performance in commercial buildings within the decision-making process

Source: Hui, S. C. M. (2003), revised

5.7 Limitations

There are, however, limitations to the methodology described in this section. Commercial buildings are complex systems, and very rarely can a singular methodology cover similar significant aspects in each building, therefore it is important to include a qualitative assessment. It should be reiterated that each building is unique and should be determined with an individual approach. Given the wide spectrum of buildings within a single category, it is also highly unlikely for every possible building component to be prescribed into one methodology.

While the issue of the cost-benefit analysis of such energy efficient improvements in the existing commercial building stock was raised, it was not been considered in this assessment. It is, itself, an avenue for continuing research in assessing energy efficiency measures from an economic and financial point of view. Likewise, in the assessment of maximum benefits, the discussion did not include certain benefits to owners, occupants and communities, where the “soft” benefit issues of high-performance buildings were not considered.

There is a spectrum of approaches applicable in order to develop a methodology for the assessment of energy performance in buildings. Other evaluations may be based on a whole building life cycle approach (LCA) and/or a life cycle cost (LCC) approach.¹⁴⁹ The avenue

¹⁴⁹ Cole, R. J., Larsson, N. (2002). *Green building challenge environmental performance indicators*.

taken for this thesis has not covered these aspects, which are in themselves, significant and valid approaches in assessing performance. The main purpose of the thesis is to utilize existing mandatory codes, established standards and existing methodologies applicable, for the purpose of energy performance assessment. Therefore, on hindsight, no “new” methodology or calculation method has been proposed, but rather, the combination of existing information is presented in an integrated manner in order to comply with aspects of the Directive.

This methodology does not put into effect the adoption of every article listed in the Directive, because it is only developed with respect to existing office buildings, and the scope of implementation in this category of buildings is less vigorous as compared to new buildings. Nevertheless, it does provide a structured direction for the integrated application of specific performance-based European Standards in other categories of buildings, when assessing building energy performance. This is applied with the supporting structure of existing energy codes, basic mandatory and prescriptive requirements. It should be stated that this methodology represents only one possible approach, where other approaches may be just as justified and valid.

6. Verification and certification

This section focuses on the verification of the framework methodology presented in Section 5, where the analysis lies in the assessment of energy performance of a commercial building based on codes, prescriptive requirements and CEN performance standards. The issue of energy performance certification is addressed similarly, with a discussion of how energy performance certification schemes can be addressed in relation to the Directive, and based on the current developments in Sweden.

6.1 Verification

6.1.1 Boundaries of the analysis

The estimation of building energy performance with simulations is determined by the chosen building design parameters, as discussed in Section 5. These parameters constitute the main design features of the building envelope and the installation equipment that should be tested. As discussed, the influence of climatic conditions has a significant impact on building energy consumption values, in relation to the HVAC service systems of the commercial building. Based on these 2 sources of input, suitable indoor environmental conditions that conform to minimum codes, performance standards, and the maximum total energy consumption, can be determined by the simulation program. The boundaries of building energy simulation are seen in Figure 6-1.

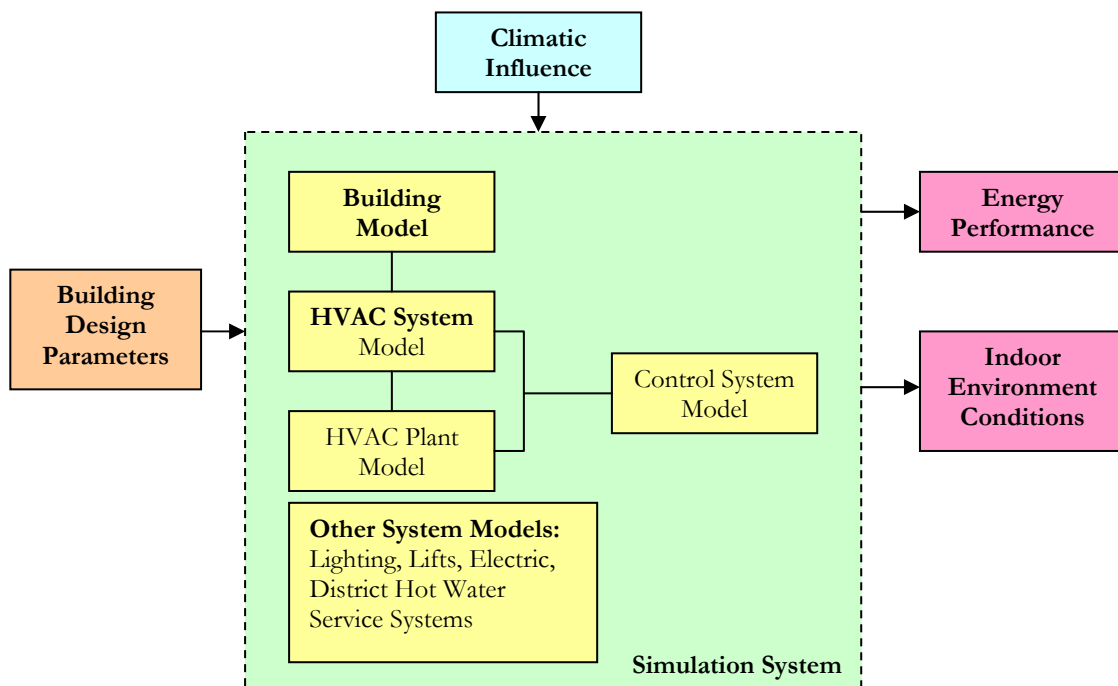


Figure 6-1. Major elements and boundaries of the building energy simulation

Source: Hui, S. C. M. (2003), revised

The information obtained at the end of the simulation will provide data on the final energy consumption figures based on the equipment and performance defined, with comfortable

indoor conditions, within an acceptable range of energy consumption.¹⁵⁰ This procedure optimizes the energy efficiency of the building service systems and may be reiterated for the best permutation of design parameters in terms of reduced final energy consumption in the simulated commercial building. However, it should be stated that this model only refers to energy efficiency in technical design, because simulations do not reflect variances from operation, maintenance and use patterns. Therefore, in practice, it is inevitable that variances arise due to the inaccurate assumptions of the “standard” use and operation of the building.

6.1.2 Verification analysis

The proposed procedure of iterative testing to verify the framework methodology is as shown in Figure 6-2. This approach should be conducted by experienced consultants, and it proves to be a useful tool in predicting the total building energy consumption, and for enhancing performance in a particular building.

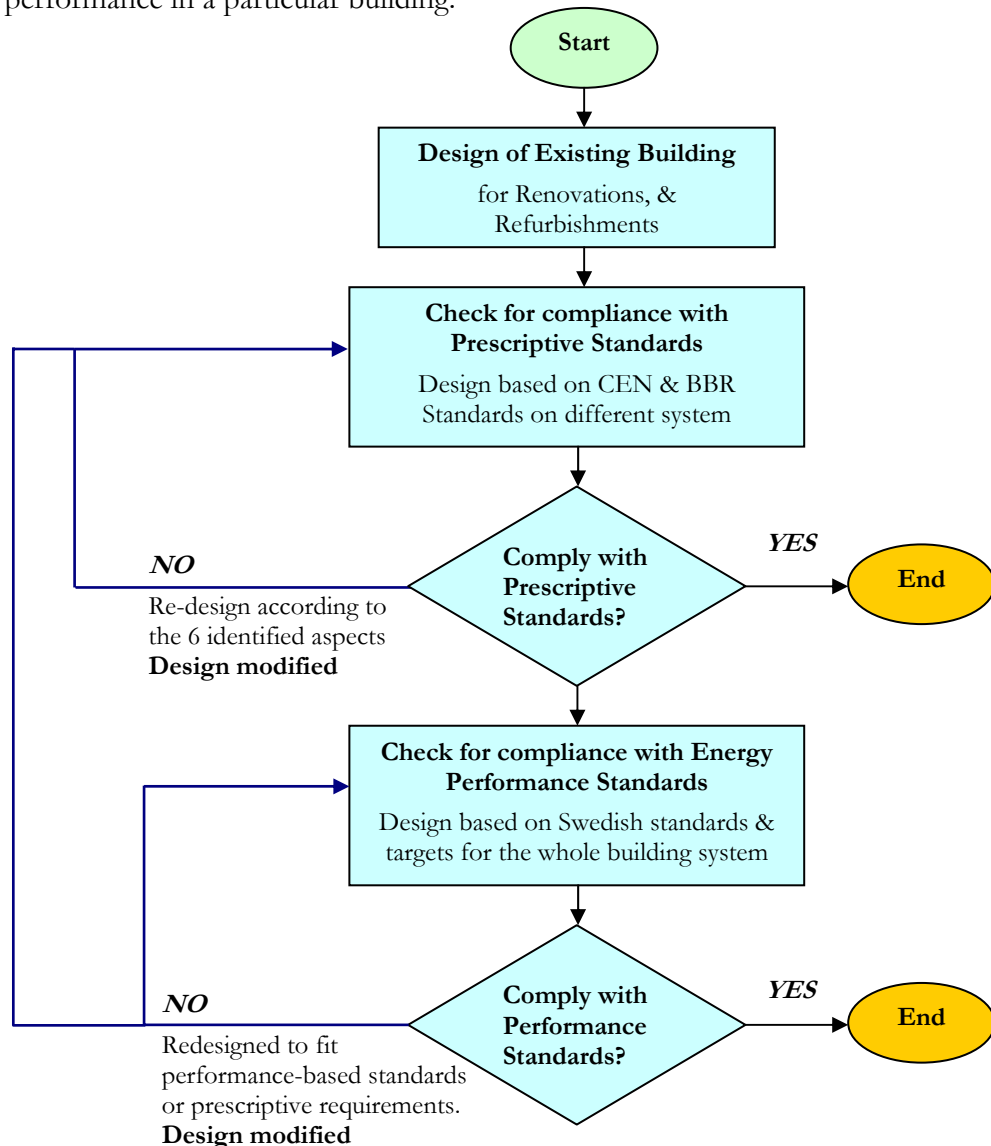


Figure 6-2. Verification process

¹⁵⁰ Hui, S. C. M. (2003). <http://arch.hku.hk/~cmhui/teach/65256-01/sld028.htm> [2003, May 29].

Source: Chou, S. K. (2001), revised

Industry-based energy consultants should use and develop this procedure after the Swedish national authority has determined the necessary building energy performance standards required. This could be facilitated by the use of common building energy simulation programs such as Enorm, IDA ICE v3 or ABB Ventac. The simulations should be carried out in compliance with these standards, where the final design solution selected should conform to the established CEN standards, and/or, energy performance standards. This thesis does not involve conducting the iterative testing in order to obtain the most energy-efficient combination of energy-intensive equipment, as presented in Figure 6-2, because no supporting information from the energy performance of buildings based on CEN design procedures is currently available for comparison.¹⁵¹

Nevertheless, corresponding information obtained from parallel case studies, based on similar procedures presented in Figure 6-1 and 6-2, conducted within the UK provide results that will very likely apply in the context of Sweden.¹⁵² Figure 6-3 presents the generalized results of energy performance in existing office buildings when targets, codes, prescriptive requirements and CEN standards are applied. It is assumed that given a similar approach, the averaged results in Sweden will be verified in the same manner.

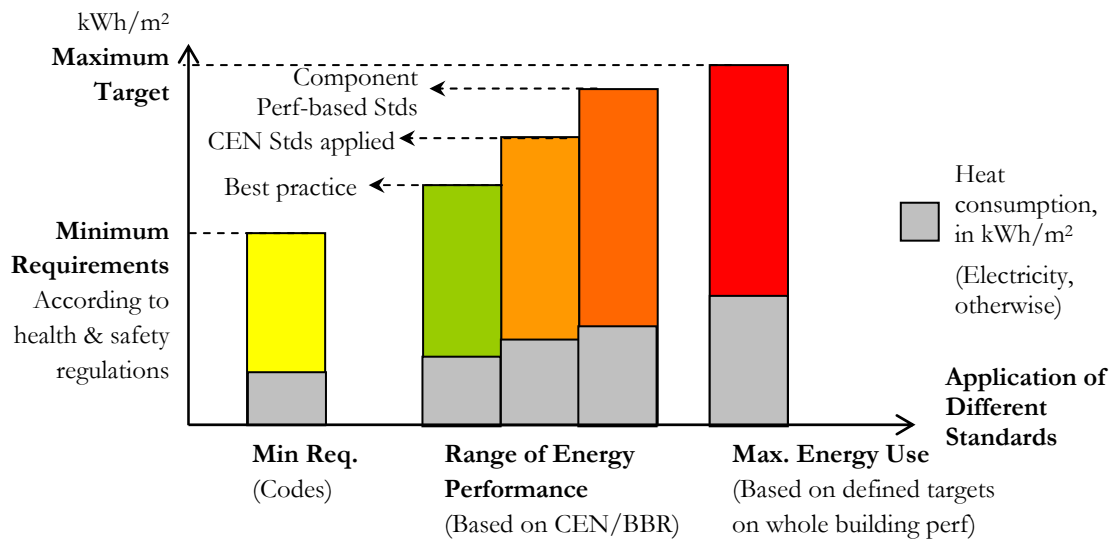


Figure 6-3. Range of energy performance when standards are applied in existing office buildings

Source: Adapted from Lowe, R. (2001), ESRU (2003), revised

The current energy consumption of existing office buildings in Sweden ranges from 140kWh/m², for buildings built after 1986, and 240kWh/m², for buildings built before

¹⁵¹ The practice of applying CEN standards in design is not practiced in Sweden, and although no supporting information can be found, similar studies have been conducted in several UK reports. It is the opinion that the results of these studies can be estimated to reflect results when applied within Sweden. The best approximation found, based on a Swedish case study, was the Hagaporten, reviewed in Appendix D, although the analysis differs significantly from the approach presented here.

¹⁵² Her Majesty Customs and Excise. (2001). *Energy Performance Indicators kWh/m²*. <http://www.hmce.gov.uk/about/reports/sustain2.gif>; Argonne National Laboratory. (2000). *Purchased Energy Consumption*. http://hem.dis.anl.gov/eehem/picts/9609p32_2.gif [2003, June 10].

1986.¹⁵³ Based on the Boverket target of 200kWh/m² in final energy consumption for existing office buildings by 2005, the use of both prescriptive and performance-based standards in refurbishments and renovations will limit total building energy consumption to a value less than this target, as verified by supporting studies. Therefore, the use of prescriptive requirements and standardized codes limits the range of energy use even further than the requirements specified by the Boverket. In the current practice, this range of energy consumption is determined through the expertise of the designing engineer, but the evaluation is assessed in a less structured manner. This is because the nature of assessing energy performance through simulations is very subjective and highly case-specific, with results varying significantly even within the same category of buildings.

There are limitations in this analysis, mainly from the lack of supporting results within the Swedish context. If obtained, it will clearly verify the methodology proposed by reflecting specific reduced energy consumption values from the application of different standards. Nevertheless, the results were generalized from supporting reports and studies made by several UK organizations, and assumed to apply likewise in Sweden. Therefore, the aim of this approach is to show that the use of CEN standards and performance-based standards, within an integrated approach, will contribute to enhanced energy-efficient performance, reducing total final energy consumption. This is reflected by the reduction of the upper bound of total annual energy consumption, per square meter, in buildings, when CEN standards are applied. Consequently, with the range of applicable building energy use narrowed, the certification of the efficient use of energy in an office building can be better defined.

6.2 Variance analysis

There are limitations, nonetheless, in the use of computer modeling programs. Building designers may employ very advanced calculations and robust simulations to ensure the energy performance of buildings, but this is not reflected when the building is operated and in use. This section provides a discussion into the variances that are often observed between actual energy consumption and simulated models, and assesses the possible cause. This section shows that guaranteeing an adequate energy efficient technical design is only one of many facets in ensuring that the building performs in an energy efficient manner.

Building energy simulation programs reflect, in theory, an expected result according to defined parameters. But it is important to note that actual building performance data obtained from energy audits may differ up to $\pm 20\%$ of what was modeled. If the model is developed poorly, the difference may be even more pronounced.

Extensive experience and accurate input parameters are required in order to create a simulation model that approximates the actual building. The accuracy of the model will depend on the sensitivity of the building design parameters defined. More often than not, the practice of substituting unknown data with “default” values raise questions to the validity and accuracy of the absolute results. The simulated results may be meaningful for comparative

¹⁵³ Boverket (2003).

purposes, but the incorrect use of simulation programs may, in some cases, predict up to an absolute -50% of energy use, when compared to actual building energy consumption data.¹⁵⁴

Therefore, the sources causing the variance between the modeled and actual performance must be analyzed, in order for models to estimate the energy performance of a building accurately. Besides inaccuracies in the input parameters, these differences can be explained by several non-quantifiable factors from (i) particular facility management practices, and/or, (ii) inefficiencies in occupancy behavioral patterns. A discussion into some of these distorting factors is provided below:

- User occupancy pattern - The energy consumption of a building is affected not only by its design, but also by the manner the equipment is used. In this case, the impact of the building facilities management department and the behavior of the occupant will be significant. Therefore, unless energy efficient equipment is maintained and operated as they are designed, the benefits of energy efficiency will not be evident.¹⁵⁵ For example, energy efficient heating systems will remain inefficient if left in operation through the whole weekend. Therefore, it is important for building facility managers to develop energy efficient management practices in order to exploit the full benefits from an energy-enhanced building.
- Workmanship quality control - It is not unusual for the quality of workmanship to differ in standards, and such variances could very well contribute to the difference between actual results and simulated data. This can, however, be reduced with the application of quality control in the design and construction phase, and with proper commissioning of system components and the whole building system after the renovation/refurbishment work.¹⁵⁶ Quality can be controlled through the use of quality assurance labels in commissioning contracts, or through the certification of performance.
- Inconsistencies in climate - Building energy audits rely on the measurements of temperature, indoor environment conditions and the operating equipment in buildings. Nevertheless, inconsistencies in any one of these areas could contribute to inaccurate input parameters, even if the data is collected in a standardized structured manner. For example, a sudden deviance in climatic factors on several of the days in which data is collected will induce a larger spread of input data than normal. This may contribute to inaccuracies in the building simulation study. Correcting this may require the collection of more input data when climatic conditions differ, or, the collection of data only on days with “typical climate”.

Any permutation of these listed factors will contribute to significant distortions of the generated results from the simulation program. Figure 6-4 presents this variation graphically.

It is important to state that the aim of energy simulations is not to obtain the absolute prediction of energy performance in a modeled building, but rather to arrive at results that

¹⁵⁴ This refers to the situation where the building energy simulation program, Enorm 1000, is used in commercial building applications, when its design is primarily applicable only to dwellings slated for residential purposes.

¹⁵⁵ Meier, A., et al. (2002). *What is an energy efficient building?*

¹⁵⁶ Stum, K. (2000). *Commissioning in energy performance contracts*. Portland Energy Conservation. http://ateam.lbl.gov/mv/docs/Espc_and_Cx_OrigLongVer.pdf [2003, July 9].

can be used with a certain degree of accuracy, and validity. Only when simulated results are reasonably accurate ($\pm 20\%$) and valid, can the simulated figures be used for the qualitative and quantitative analysis as presented in Section 5.6, its verification as discussed in Section 6.1, and for application in a corresponding building energy certification scheme, which will be discussed in Section 6.3.

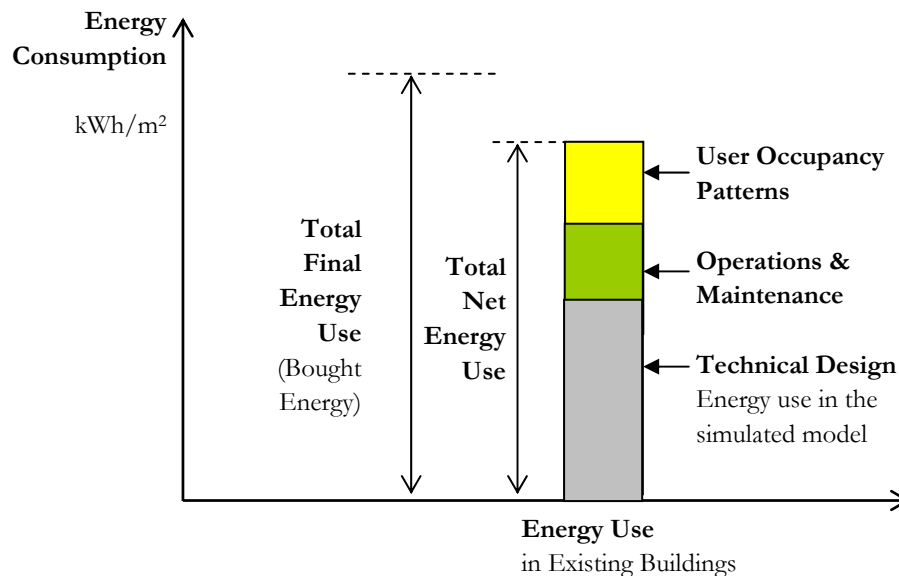


Figure 6-4. Variation of energy performance from different facets

Source: Svenska Miljöinstitutet (2002), revised

Additionally, other subjective measures can be employed to correct the range of variance. Such recommended measures may, amongst others, include:

1. Educating and training building occupants in the energy efficient operation of equipment and energy saving behavior, in addition to providing incentives for change, for example, transferring energy savings to office tenant.
2. Establishing a budget energy accounting system or environmental management system for the building facility management team, in order to ensure control and continuous improvement in the maintenance and operation of the building.
3. Similar energy management procedures made compulsory to the tenants could limit inefficiencies in the energy consumption from occupancy patterns.
4. Installing sub-meters that measure energy consumption at occupant consumption points, allowing for an accurate identification of energy inefficient behavioral patterns.

The limitations involved with computer simulation results must be understood, before the results are used because perfect accuracy will most likely never be obtained. Therefore, it is recommended that the generalities drawn from the simulation exercise are used to *verify* design parameters calculated based on structured design procedures from codes, prescriptive requirements and other performance-based standards, as shown in Figure 6-2, instead of the

direct use of simulation results for design purposes.¹⁵⁷ As iterated, extensive experience is required to use simulation software in an accurate manner, and even then, it is still fraught with subjectively.

6.3 Certification schemes

Based on the narrowed range of energy performance discussed in Section 6.1, bounded by performance-based standards on building components and CEN standards, as seen in Figure 6-3, and by the current best available practice, different certification rating systems can be applied. This section provides a discussion into the different energy performance certification methods that can be applied in relation to the presented integrated methodology and the Directive.

6.3.1 Existing tools

The review of the BREEAM, LEEDS and Energy Star™ certification procedures show that energy performance can be assessed and accredited based on the award of “points”, or through the practice of benchmarking, on a scale of 1-100.¹⁵⁸ These tools measure the environmental performance of buildings, which covers a wider scope than the building energy performance. Nevertheless, the application of the methods used in certification can be adopted for certifying the energy performance in existing buildings. The main advantage of these tools is that they offer normalized systems that allow for the relative and absolute comparisons of energy performance between similar buildings.

However, the practice of benchmarking is limited by the current performance of the existing building stock. Very often, even if the best energy-performing 25% of the existing building stock, with the lowest total energy (heat and electricity distinction considered) consumption, is certified, it may not reflect efficient performance because of general inefficiencies throughout the total building stock. Therefore, this statistical approach is not recommended, although it is very commonly practiced.

The use of commercial tools similar to the BREEAM and LEED system can be applied for energy performance certification schemes, as according to the Directive, but a separate point-system criteria based on accrediting compliance with CEN and performance-based standards must be developed. It should be sensitive enough to reflect different grades of compliance, in order for the certification rating to be valid and relevant. This could be facilitated by the use of a simulation model-based method of benchmarking that reflects energy efficiency in a well-defined manner.¹⁵⁹

This method is called “hybrid” benchmarking; where the use of CEN standards and modeling software is employed simultaneously. The simulation model should be based on the computer testing procedure shown in Figure 6-2. “Hybrid” benchmarking presents a valid approach “for estimating the minimum of energy required to meet a set of basic functional requirements”, defined by the minimum conditions for indoor environmental

¹⁵⁷ Thormark, C., Thuvander, L. (2002). Experiences Related to Data in Building Research. In Chalmers Institute of Technology. *MISTRA – Sustainable building: Experiences from a cross-disciplinary research programme*, p. 96. Gothenburg: Chalmers University of Technology.

¹⁵⁸ Hoggard, J. (2000). Shoot for the Star. Energy Planning Network™. *Engineered Systems*, January 2000. [2003, July 20].

¹⁵⁹ Meier, A., Lamberts, R., Olofsson, T. (2003). *Rating the energy performance of buildings*. p. 2.

conditions.¹⁶⁰ This ensures that only the best energy performance is certified, regardless of the quality of the existing building stock assessed.

Based on this hybrid approach, and from the procedure seen in Figure 6-2 and 6-3, a “Best 25%” strategy of energy performance certification, with a minimum final annual energy consumption from simulated “best practices”, is proposed. An example of determining a “best practice” application within an integrated approach is shown in Figure 6-5. The determination of the current best practice would require more than compliance with performance-based requirements and CEN standards, and would very likely require the integrated approach towards energy use, in order to reduce energy consumption significantly.

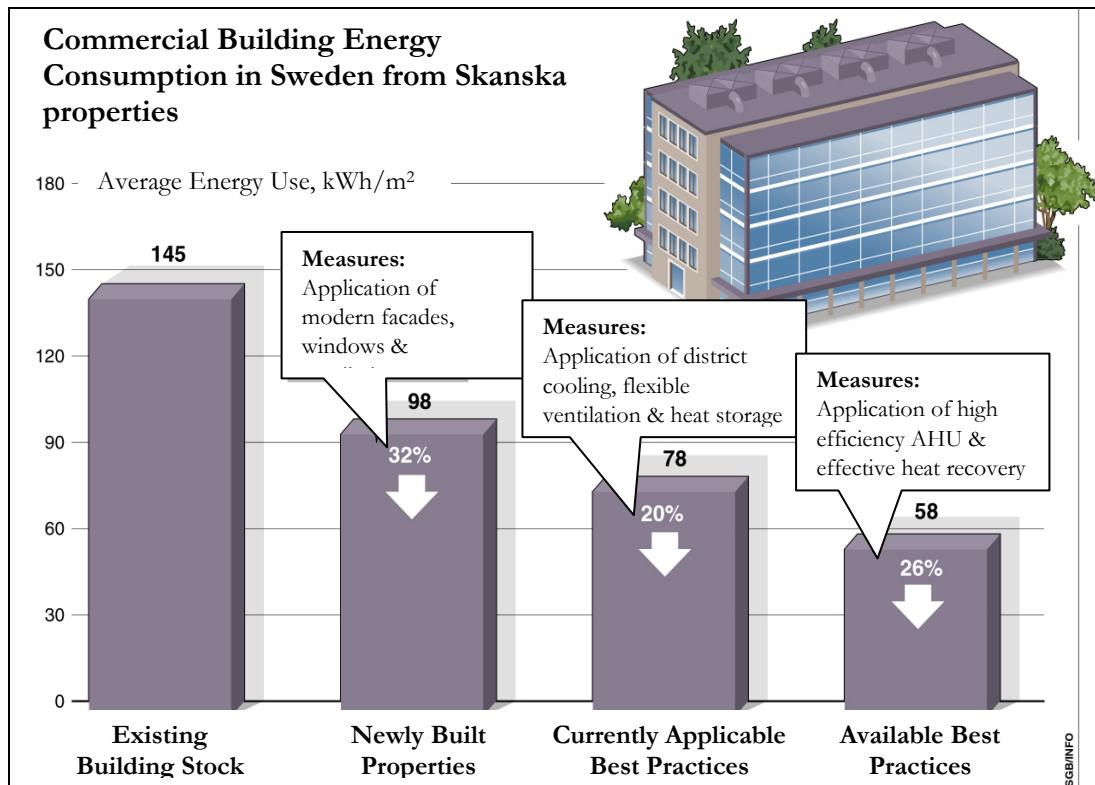


Figure 6-5. Energy use in Skanska commercial properties in Sweden

Source: Skanska (2003)

It should be noted that this discussion pertains only to existing office buildings, and the definition of “best practices” for energy performance in buildings should be categorized by building type and age, with figures corrected for the local climatic conditions. This is important for countries such as Sweden, with a wide range of climatic conditions.

6.3.2 Current developments in Sweden

Based on the minimum and maximum current energy use currently in Sweden, a statistical certification approach has been developed by Sweden.¹⁶¹ The developed energy performance labeling certificate distinguishes the building type, date of completion in construction, and

¹⁶⁰ Meier, A., Lamberts, R., Olofsson, T. (2003). *Rating the energy performance of buildings*. p. 2.

¹⁶¹ EnergiledarGruppen Nätverk Sverige. (2003) <http://www.energiledargruppen.com> [2003, July 29].

the temperature zone it is located in. The defined temperature zones of Sweden in the use of this current certification system are seen in Figure 6-6.

Certification is based on the segmentation of each type of building, and the total building stock is divided into 4 grades of energy performance. This is seen in Figure 6-7. The certification program is in its third year of use, and has been voluntarily applied in selected buildings. An example of the certificate is presented in Figure 6-8.

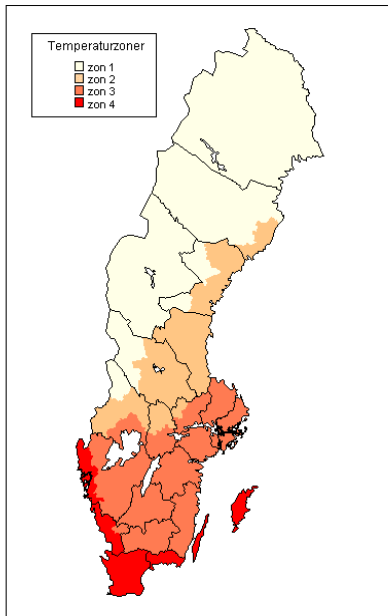


Figure 6-6. The 4 defined temperature zones in Sweden

Source: EnergiledarGruppen (2003)

However, one limitation is that this type of certification is dependent on the overall energy efficiency of the total building stock, and the rate of improvement in the energy efficiency of the building stock is not expected to be significant as compared to the hybrid labeling scheme described in Section 6.3.1. Although it is currently in use, recommendations can be made to improve the certification system, based on the analysis presented. Improvements in defining the suitable range for certified energy efficient performance of buildings can be assessed as shown in Figure 6-9.

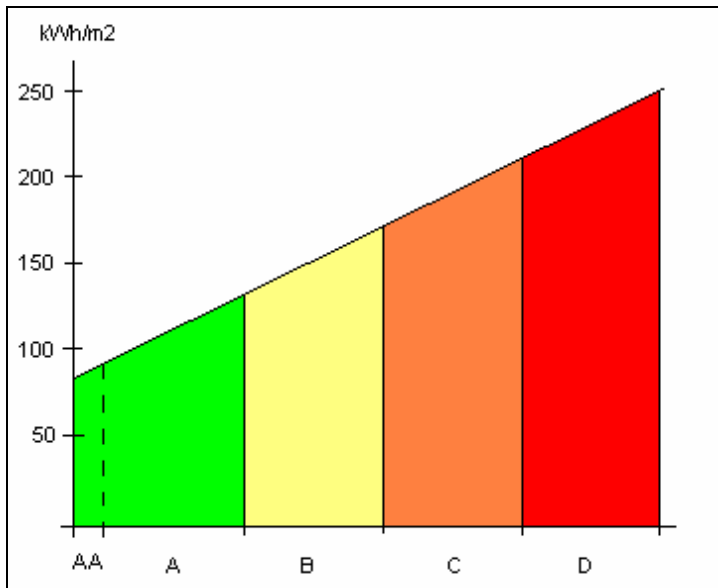


Figure 6-7. Classification method of the certification scheme based on energy performance

Source: EnergiledarGruppen (2003)

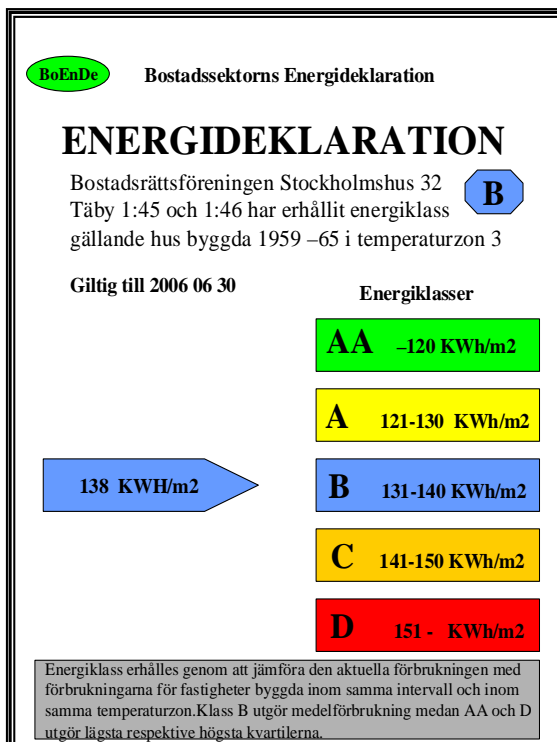


Figure 6-8. An example of the energy performance certificate

Source: EnergiledarGruppen (2003)

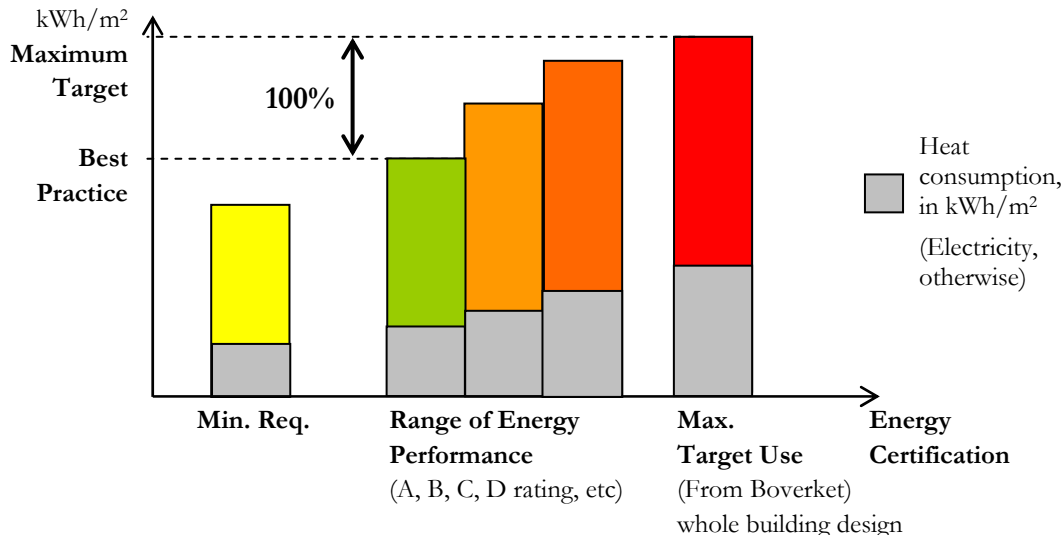


Figure 6-9. Improved certificate based on the hybrid approach

In Figure 6-9, the 100% spread of values used for certification purposes is based instead on the reduced range presented in Section 6.1. As with EnergiledarGruppen’s current certification grading, this energy consumption range, in terms of kWh/m², could be similarly segmented into quarters (25%). The significant difference in this method is that the certification system is no longer dependant on the level of energy efficiency of the existing building stock, but based on the targets for energy performance instead. This is bounded by best available practices and the target maximum energy use determined by Boverket. Therefore, the drive for energy performance is induced from policy measures and the process of attaining an energy efficient building stock is hastened significantly.

It is important to state that although the current EnergiledarGruppen certification system is revised every few years in order to enforce a stricter grading system, but its main approach of certification is still based on the statistics of the existing building stock, which is less effective.

It is interesting to note that the energy performance of buildings that conform with CEN standards and other prescriptive requirements, will fall within the 100% range of energy performance, shown in Figure 6-9. Nevertheless, it is highly unlikely that a building will be certified with a label simply because it complies with CEN standards. This is because certification from mere compliance of standards does not reflect enhanced energy performance nor does it provide the industry with additional incentives for efficiency improvements.

Additionally, it is important to take note that, in certification ratings, the qualitative assessment of a building, as discussed in Section 5.4, is not neglected. As stated, depending on the descriptive nature of each building, certain qualitative features may be too subtle to be reflected in a quantitative assessment, but may nevertheless contribute to significant impacts on the energy performance of the building. Therefore, a summary of the qualitative assessment of the building, according to the “building description survey” as shown in Appendix C, may be posted together with such an energy performance label.

While the aim is to quantify and verify energy performance with certification, it is important to note that a holistic and comprehensive view is required when certifying energy

performance. Figure 6-10 represents this holistic view and Section 7 will address the other elements required for stakeholder involvement, transparency and other identified issues.

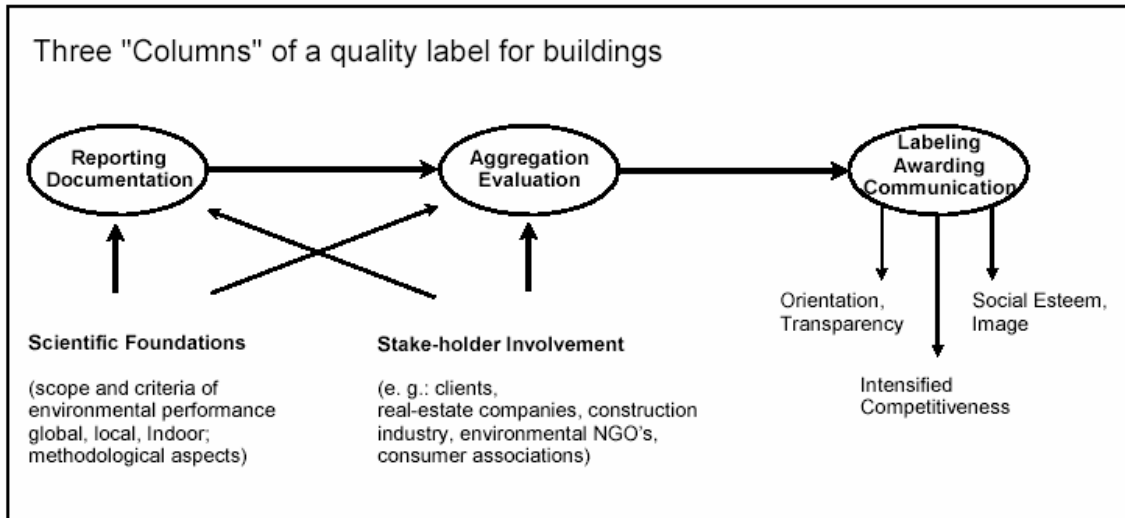


Figure 6-10. The main elements of a quality label for buildings

Source: Blum et al, (1998) & OECD (2001)

7. Future development and implications of the Directive

Within the 15 Member States of the European Union a total of 160 million buildings are currently in use, and the Directive 2002/91/EC on the energy performance of buildings has been, to date, called “the greatest step change in energy in buildings”.¹⁶² There is, without doubt, a multitude of challenges facing the Member States’ adoption of the Directive, concerning and affecting a large group of actors. These challenges and the implications of which can be divided into the requirements for:¹⁶³

1. Scientific-technical aspects concerning building energy performance standardizations, as duly covered in the earlier sections of this thesis, and,
2. Policy aspects and administrative issues that concern the legislation behind the building energy performance legislation, which will be covered in this section.

The specific challenges facing these 2 aspects are differentiated as shown in Figure 7-1.

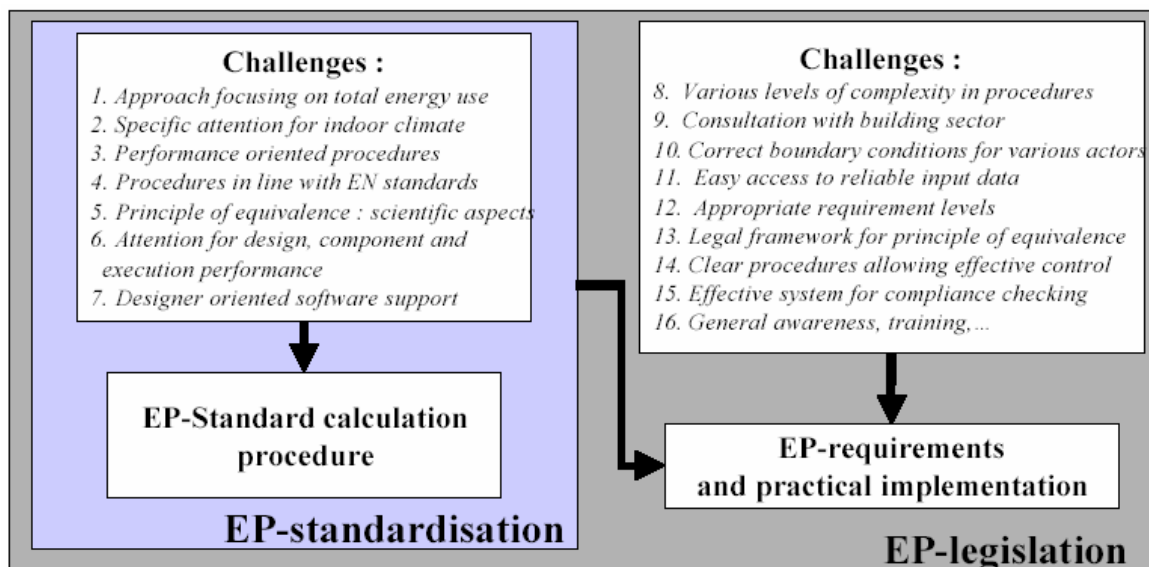


Figure 7-1. Challenges and implications for an EP approach and interaction between EP standardization and legislation

Source: Wouters, P., Heijmans, N., Porrez, P., Van Orshoven, D., Vandaele, L. (2002).

Such challenges are formidable, and it is of interest to note that the original estimate for the potential of total CO₂ emissions reductions with energy efficiency in new buildings was a value of 450 million tons for the EU.¹⁶⁴ The second estimate based on the European Climate

¹⁶² Warren, A. (2002). Directive should be the greatest step change in energy in buildings. *Energy in Buildings & Industry*, July/August 2002. [2003, May 29].

¹⁶³ Wouters, P., Heijmans, N., Porrez, J., Van Orshoven, D., Vandaele, L. (2002). Innovative concepts and energy performance regulations. In the *ENPER-TEBUC Conference, Athens March 6, 2002*. p. 3. http://www.spitia.gr/greek/meleti_efarmogi/bioclimate/sinedria/energy_performance_regulations/6_PW.pdf [2003, June 30].

¹⁶⁴ EuroACE. (1998). *Assessment of potential for the saving of carbon dioxide emissions in the European building stock*. Submitted by CALEB Management Services.

Change Programme, however, concluded that the value would be closer to 45 million tons of CO₂ savings, while many advisers skeptical about the real benefits of the Directive have projected even lower estimates of 4.5 million tons of CO₂ mitigation.¹⁶⁵ This section focuses on the legislative implications, administrative challenges and the future developments that may occur from the enforcement of this single most important Directive in the building and construction sector.

7.1 EU level

The Directive was adopted very swiftly with the whole process, from the very first draft to adoption by the Council, stretching over 2 years.¹⁶⁶ One justification was because the bulk of implementing the Articles listed in Directive 2002/91/EC is left to the subsidiaries, at a national level of legislation. Therefore, in view of this situation, the most important element of the Directive for the European Union lies within the context of harmonizing the yet-to-be-defined energy performance calculation methodology, requirements and certification schemes. Although several normalized standards do exist and have been published as European Standards, their application in Member States is limited. Therefore, there is a need to use these existing standards, in an integrated manner.¹⁶⁷

The European Commission has been active in assisting Member State authorities and organizations in these energy performance issues, providing support tools for “the rapid take-off of the Directive”, and integrating previous efforts into a program called “Intelligent Energy - Europe Programme (2003-2006)”.¹⁶⁸ Present and future governance roles, policies and incentives provided at this level are presented in Figure 7-2, where the spectrum of information-based strategies to Directive-driven legislature can be, and are currently, employed in facilitating the adoption of the Directive.

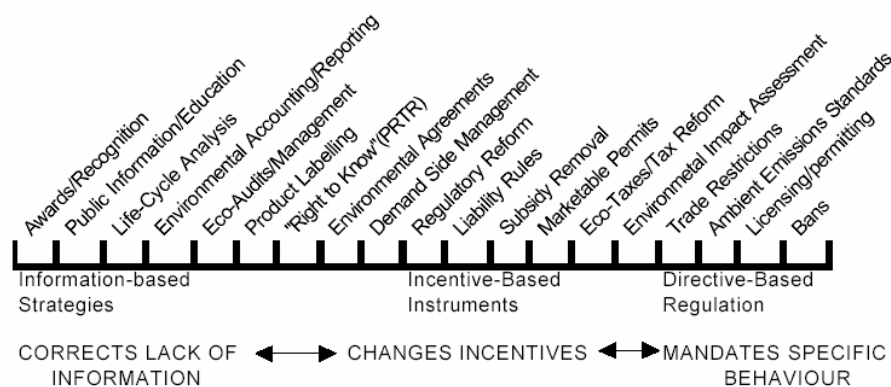


Figure 7-2. Potential instruments in facilitating building energy performance regulations

Source: David, H. (2002)

¹⁶⁵ Warren, A. (2002). Directive should be the greatest step change in energy in buildings.

¹⁶⁶ Bowie, R., Jahn, A. (2003). The new Directive on the Energy Performance of Buildings - Moving closer to Kyoto. *Energie Verwertungsagentur*, 2/2003, ISSN 1026-339X, p. 4. <http://www.eva.wsr.ac.at/publ/pdf/en2-03.pdf> [2003, July 29].

¹⁶⁷ Bowie, R., Jahn, A. (2003). The new Directive on the Energy Performance of Buildings - Moving closer to Kyoto. p. 4.

¹⁶⁸ European Union (2002). *Intelligent Energy for Europe: The Commission proposes a new energy action program*. IP/02/524. Brussels. http://europa.eu.int/rapid/start/cgi/guesten.ksh?p_action=getfile=gf&doc=IP/02/524|0|RAPID&lg=EN&type=PDF [2003, June 9].

Most existing literature argue that the single most critical aspect that should be made consistent in energy performance regulations for enhanced energy performance and efficiency in buildings, at the EU level, is the climate.¹⁶⁹ Harmonizing energy performance standards should be defined by climatic conditions of the region and accordingly adapted into the national, and/or, regional setting. This task is not without challenges, given the complexities and heterogeneous nature of buildings, there is “a whole range of innovative systems that are at present not covered by the so-called Energy Performance Regulation (EPR) procedures and/or treated in a uniform way throughout the European Member States”.¹⁷⁰

Nevertheless, in a positive move towards the Directive 2002/91/EC, the EU has adopted the Energy Star™ labeling system for energy efficient office equipment within the EU.¹⁷¹ The Agreement has been officially signed on 19th December 2000, and published in the Official Journal of the EU in the Council Decision 2003/269/EC on the 8th of April 2003, “concerning the conclusion on behalf of the Community of the Agreement between the Government of the USA and the EC on the coordination of energy efficient labeling programs for office equipment”.¹⁷²

7.2 Regional/National level

The success of this Directive hinges on the “ambitious and proper transposition of the Directive into national legislation”.¹⁷³ Therefore, the implementation of the Directive on a national level will lie heavily on the principle of equivalence.¹⁷⁴ As previously stated, the most significant determinant for consistent energy performance regulations is the climate.

This is important for countries such as Sweden, with a broad range of climatic conditions from the North in Norrland to the milder conditions of Skåne. These should be adjusted according to regional energy performance requirements and standards, with the energy performance requirement “expressed as a function of the local climate”.¹⁷⁵ The existing level of implementation of the tertiary sector in Sweden is offered through a package of incentives and policies, as seen in Table 3-1.

While the hope is that the impact of the Directive can be materialized as soon as possible, many Member States, and the European Parliament itself, have admitted that the operational date of the Directive might be a year too early.¹⁷⁶ In comparing the energy efficiency measures adopted by other regional EU Member States, the percentage change in Sweden

¹⁶⁹ Weber, C., Dicke, N. (2002). *Climatic Conditions, Legislative Context and Economic Efficiency: The Europeans challenge for energy performance regulation*. Universität Stuttgart. Institut für Energiewirtschaft und Rationelle Energieanwendung (IER). http://www.spitia.gr/greek/meleti_efarmogi/bioclimate/sinedria/energy_performance_regulations/9_CW.pdf [2003, July 29].

¹⁷⁰ Wouters, P., Heijmans, N., Porrez, P., Van Orshoven, D., Vandaele, L. (2002). p. 4.

¹⁷¹ Environment Daily. (2001). *EU finally adopts Energy Star ecolabel*. 18/12/01. <http://www.climnet.org/news/Dec2001.htm> [2003, June 20].

¹⁷² Council Decision 2003/269/EC of 8 April 2003.

¹⁷³ Bowie, R., Jahn, A. (2003). *The new Directive on the Energy Performance of Buildings - Moving closer to Kyoto*. p.4.

¹⁷⁴ Wouters, P., Heijmans, N., Porrez, P., Van Orshoven, D., Vandaele, L. (2002). p. 3.

¹⁷⁵ Weber, C., Dicke, N. (2002). *Climatic Conditions, Legislative Context and Economic Efficiency*.

¹⁷⁶ Warren, A. (2002). *Directive should be the greatest step change in energy in buildings*.

has not been significant, as seen in Figure 7-3. Nevertheless, one can argue that CO₂ emissions in Sweden are already at a very low level, and that the energy performance and efficiency of the existing building stock fares reasonably well, as compared to other EU Member States.

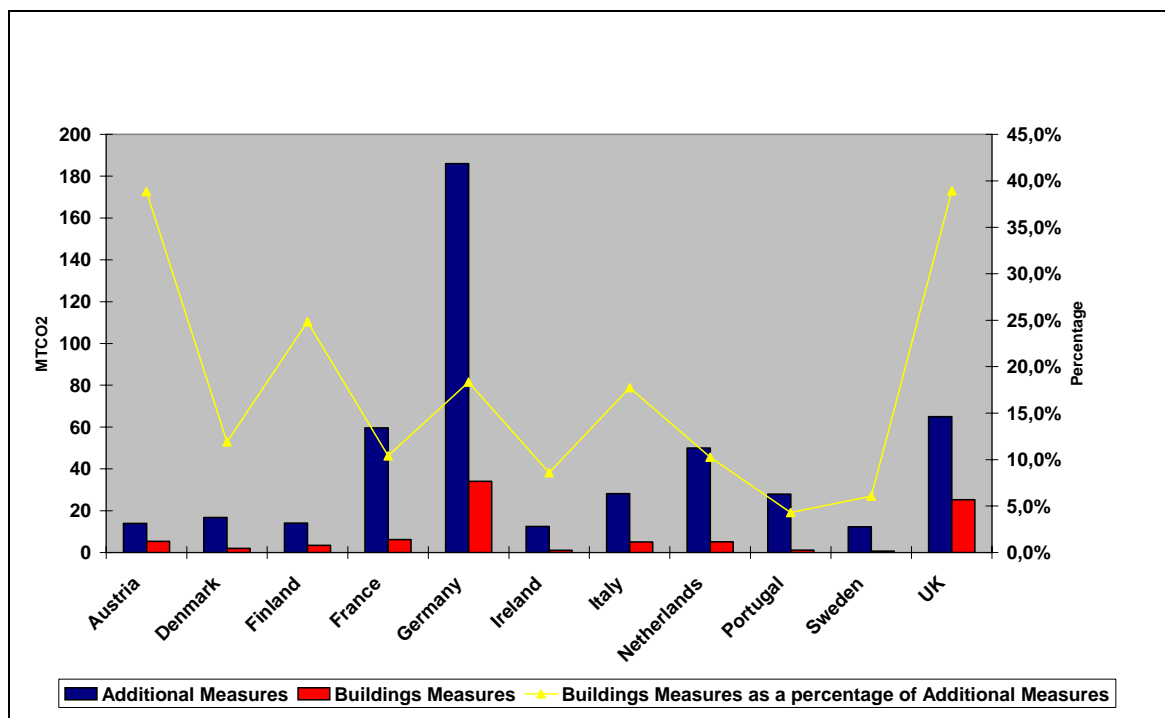


Figure 7-3. EU Member States energy efficiency improvements in buildings, as a proportion of additional measures proposed under UNFCCC Third Communications

Source: EuroACE (2002)

The energy performance standards and regulation proposed by each national body should be in accordance to well-established and existing standards, and integrated into a complete and valid framework that covers the energy-intensive components of a building, as presented in Section 5.4. The national body in Sweden, therefore, has to implement either (i) National standards, or, (ii) adopt existing European Standards that are already established; and these standards have to be made mandatory for compliance with the Directive. Currently, energy performance calculations and standards in Sweden only define the *net* annual energy use in the building, controlling it within a particular reference value, where $Q_{\text{actual}} < Q_{\text{ref}}$, and unlike the “*final* annual energy use” this does not take losses into account.¹⁷⁷ Nonetheless, Table 7-1 shows the energy efficiency targets set by the Boverket in existing efforts to limit the net energy consumption in the commercial office building stock.

It should also be noted that the Swedish national body is responsible for defining and regulating the respective boundaries for different actors in the building and construction industry.¹⁷⁸ Additionally, it is the role of the Government to include the involvement of

¹⁷⁷ Thomsen, K. E. (2002). *Enquiry on Global Responsibility of the energy performance calculation procedures*. p.13.

¹⁷⁸ Santamouris, M., Geros, V. (2002). General philosophy of an energy performance regulation. Group Building Environmental Studies, University of Athens, Physics Department. In the *ENPER-TEBUC Conference, Athens March 6, 2002*, p. 4.

industry and stakeholders in the establishment of such standards, with collaborative working groups in all concerned sectors. This stimulates stakeholder motivation in for the successful adoption of the Directive.

Table 7-1. Target energy use of final energy in office buildings per annum

Office Buildings	Type	Total, kWh/m ²
Today	Existing building*	140-240
	New building	140
2005	Existing building	200
	New building	120
2025	Existing building	100
	New building	70

*) Where the lower bound figure refers to buildings built after 1986, and the upper bound for buildings built before 1986

Source: Boverket (2003)

A significant challenge faced by national regulative boards with respect to the Directive involves the issue of innovation. National authorities are faced with a paradox, whereby regulations and performance standards must be strictly enforceable, while flexible enough in encouraging the open-platform for innovation in the building and construction industry. This could be integrated into the regulatory framework through the use of the principle of equivalence as discussed previously, where proof of compliance can be substantiated through some specified legal framework.¹⁷⁹

In summary, “the Government of Sweden should maintain the high level of activity in promoting energy efficiency in buildings, giving particular attention to the economic potential for improvements in the use of electricity”.¹⁸⁰ While the debate on the cost-effectiveness of improvements is left untouched in this thesis, it can be generally stated that the scope of efficiency for electricity consumption is largely untapped, and economic potential is often an efficient driving force propelling the industry into action. It is important to note that in Sweden, as with many other EU Member States, energy-rating schemes do exist but are only voluntarily employed in new residential buildings. Commercial buildings are not assessed in the same manner, and the new regulations are expected to cover this significant area.

Similarly, given that existing regulations do not cover the scope of existing buildings, the successful improvement of the total building stock relies on political will in extending such regulations to both new and existing buildings.

http://www.spitia.gr/greek/meleti_efarmogi/bioclimate/sinedria/energy_performance_regulations/2_MS.pdf [2003, June 30].

¹⁷⁹ Santamouris, M., Geros, V. (2002). General philosophy of an energy performance regulation. p. 3.

¹⁸⁰ Energimyndigheten. (2002). *Energy efficiency in Sweden 1990-2000*. p. 5.

7.3 Industry level

The scope of influence of Directive 2002/91/EC is significant, with a wide-spectrum of actors and stakeholders within the industry involved. The Directive's impact on the industry is largely focused on accelerating the diffusion process of energy-efficient technologies, where the advantage is that these technologies already exist.¹⁸¹ As stated in Section 7.2, legislation and the significant potential cost savings from energy enhancement assist this diffusion. While the Directive focuses largely on efficient performance in the operation and use phase of existing buildings, the implications nevertheless concern all the stakeholders in the life cycle of a building. This includes building design and product development, the 50-80 year maintenance and operative life span of a building and end-of-life management of building materials, where "the whole building process from inception to handover, will be affected by the requirement to produce an easily managed, energy efficient building".¹⁸²

Given the far-reaching implications to each actor involved (investors, building designers, contractors, architects, owners, administration), it is important that regulations and standards affecting each actor and building sector are clear, and the boundary conditions for each actor affected by the Directive must likewise be made explicit.¹⁸³ This is a formidable challenge given that the Directive does not provide instructions or guidelines on how to achieve this, and for the actors themselves to prove compliance. However the Directive 89/106/EEC, on the approximation of laws, regulations and administrative provisions for the Member States relating to construction products, does provide a background in relation to the essential requirements for energy economy and heat retention in buildings.¹⁸⁴ There, it states that the industry's compliance with identified components listed in the European Standards and Codes of Practice issued by the CEN would have been satisfactory, for the essential requirements.¹⁸⁵ Therefore, the aim of a performance-enhanced building stock can be achieved by the industry through various step-wise performance improvements, with the increasing application of CEN performance-based standards, as opposed to mere compliance with prescriptive codes.¹⁸⁶ This integrated target-based approach has been discussed in Sections 5 and 6.

It would suit the industry well if specific target actors were to adopt a performance-based approach and integrate energy efficient technologies as early as possible, in order to develop a competitive advantage.¹⁸⁷ The key actors that stand to gain from rapidly adopting this may include, *inter alia*:

- Design engineers designing building structures and installation equipment.
- Building facility management departments involved in the operation of the building.

¹⁸¹ Bowie, R., Jahn, A. (2003). The new Directive on the Energy Performance of Buildings - Moving closer to Kyoto. p. 7.

¹⁸² National Building Specification. (2003). Saving electricity. *NBS Journal May 2003, Issue 02*. p. 9.
<http://www.thenbs.com/Archive/pdfs/NBSJournal02.pdf> [2003, June 20].

¹⁸³ Santamouris, M., Geros, V. (2002). General philosophy of an energy performance regulation. p. 2.

¹⁸⁴ Council Directive 89/106/EEC of 21 December 1988.

¹⁸⁵ Sustainable Design International Ltd. (2003). *Directive 89/106/EEC: A step backwards for barrier-free design?*
<http://www.sustainable-design.ie/arch/disa.htm> [2003, June 20].

¹⁸⁶ Santamouris, M., Geros, V. (2002). General philosophy of an energy performance regulation. p. 4.

¹⁸⁷ Bowie, R., Jahn, A. (2003). The new Directive on the Energy Performance of Buildings - Moving closer to Kyoto. p. 4.

- Energy consultants contracted for renovations and retrofits.

The implications for the building and construction industry are, therefore, to transparently comply with the integration of:

1. Prescriptive requirements based on the Directive 89/106/EEC and standardized codes, which are based on individual components, for the product development of efficient construction products and equipment.
2. New performance-based standards, as defined in the EN ISO 13790 or EN 14335, in order to integrate energy efficient technology into whole building systems.

But, the significant debate for the industry is the impact of the Directive 2002/91/EC in context to existing buildings and the incremental cost of such energy efficient measures for the industry.¹⁸⁸ The effects of improvements to existing buildings are bound to be less cost-effective as compared to new buildings. Nevertheless, it is found when existing buildings are refurbished, under the specification whereby the payback period is 8 years or less, “the net investment cost per ton of CO₂ saved through building energy efficiency is in fact negative”, and additional benefits include the creation of up to “3.4 million job-years in the EU, between 2000 and 2010”.¹⁸⁹

The building and construction industry in Sweden has come under the present energy performance regulations since 1990, and although nothing has been amended nor are changes foreseen, amendments to current procedures should be announced in compliance with the Directive and in force by 2006.¹⁹⁰ The inclusion for possibilities of trade-offs in energy performance have been incorporated in the existing performance standards, and the industry in Sweden should tap this potential in determining a more energy efficient building. Therefore, the challenge presented to the industry in Sweden, as with the rest of the Member States, would involve the decision-making process in assessing the trade-offs when considering the total energy performance of a building, and the need to ensure satisfactory flexibility within the built-in service equipment, if future adjustments are to be added.

In terms of energy performance certification in existing commercial buildings, this will introduce efficiency in supply-side management in the industry when the demand for energy efficient buildings increases. Building operators will then have to apply stricter energy management procedures for energy efficient maintenance, in order to maintain property value.

7.4 Consumer level

For the consumer, the Directive ensures that when relocating to another building, one obtains information on how energy efficient the building is and supporting guidance on how

¹⁸⁸ Wilberforce, R. (2000). Furthering understanding - and spreading the practice of energy efficiency in buildings. Pilkington PLC & EuroACE. *International Glass Review, Issue 3, 2000*, p. 29. <http://www.internationalglassreview.com/glass/2000/issuethree/Wilberforce.pdf> [2003, June 29].

¹⁸⁹ Wilberforce, R. (2000). Furthering understanding. p. 29.

¹⁹⁰ Thomsen, K. E. (2002). *Enquiry on Global Philosophy of the energy performance calculations*. 5, 9.

it can be improved.¹⁹¹ This induces the property market to assign value to energy efficient buildings, acting as a driving force for the enhancement of energy performance in the total building stock. The influence of Directive 2002/91/EC is, therefore, expected to have an impact on the property market in both the supply and demand of new and existing energy efficient property, when it enters into force.

There are also additional implications for the consumer, given that energy performance is highly dependant on occupancy and behavioral patterns. Therefore, as an employee in a refurbished commercial building, one has to ensure that the energy saving criteria is adhered to.¹⁹² This is because; regardless of how well the building can be refurbished and designed to perform, the actual building performance is reflected negatively if space heating and other electrical equipment are left constantly on, even during vacation periods or the weekends. Therefore, it is important for energy efficient buildings to be used and operated in the manner that they are designed for in order for enhanced energy performance to be evident. With this in consideration, a secondary certification scheme or environmental management system has been recommended, based on the metered energy readings from the yearly energy audit of a building.¹⁹³

With the need for a change in excessive user patterns, it is found that sub-metering energy use in the tenant space is effective in reducing inefficiencies and the waste of electricity in occupancy patterns. This is understood, given that energy performance can be translated into cost savings for the building tenant, or occupant. Therefore, consumers that previously had no incentive to save electricity or heat are induced to behave in an energy-conscious manner. It can be noted that changes in energy consumption patterns in building occupants can be accelerated and made more even distinct when economic incentives are applied or when taxes for excessive energy consumption are directly transferred to the consumer or tenant, in relation to building energy use.

In general, the adoption of energy efficiency in the commercial building sector is “typically more attractive than the domestic sector” because of the more significant cost-effectiveness and extensive savings potential for the consumers (tenants and building owners).¹⁹⁴ The use of policy instruments can also influence the adoption of energy efficient measures in existing commercial buildings on the consumer level, such policies include:

- Capital subsidy programmes¹⁹⁵ - Such programmes for building owners are currently applied to existing residential buildings in the EU, but will prove to be similarly effective and beneficial when applied to existing commercial buildings.
- Energy audit programmes¹⁹⁶ - These information-based programmes provide building owners with technical and financial assistance for upgrading the energy efficiency of

¹⁹¹ Warren, A. (2001). *European Directive, start of something big?* EuroACE.
http://www.styrax.com/demons/EuroACE/doclib/Documents/998408954.815/F%3a%5cEuroace%5csource_docs%5carticles%5cWarren_05-2001.pdf [2003, May 29].

¹⁹² Warren, A. (2001). *European Directive, start of something big?*

¹⁹³ Defra UK. (2003). *Analysis of UK responses to the proposed EC Directive on the energy performance of buildings - Summary.*
<http://www.defra.gov.uk/environment/consult/ec-ee/response/index.htm> [2003, June 18].

¹⁹⁴ EuroACE (1999). *Caleb II - The cost implications of CO₂ savings from European buildings.* p. 21.

¹⁹⁵ Organisation for Economic Co-operation and Development. (2003). *Environmentally Sustainable Buildings: Challenges and policies.* Paris: OECD Publications Service. p. 36.

existing buildings, together with recommendations for specific energy efficient measures. This is widely applied in the Netherlands, under the “Energy Performance Advice Programme”.

For building owners, the economic potentials in increasing efficiency in energy use will increase in importance, with rising maintenance bills and electricity costs. In Sweden, the effect of this would be significant, given the increasing cost of electricity because of reduced electricity production with the subsequent closure of nuclear power and stagnation in the expansion of hydropower.

7.5 Future scenarios

The previous sections have focused on the analysis into the implications and challenges faced by the different stakeholders from the adoption the Directive 200/91/EC and the type of framework methodology discussed in Section 5.4. This section aims to provide a discussion into the different future scenarios that may occur with assistance from the Directive, and how these scenarios of energy consumption reduction from commercial buildings, can be related to CO₂ mitigation commitments as ratified by the Kyoto Protocol.

One can argue that the total final energy consumption from the building sector within the EU consists of both residential and commercial buildings, and that the residential building stock consumes up to two-thirds of the total energy use, with commercial building stock contributing to the rest. Nevertheless, scenario planning within this scope is important because of the significantly increased rate of energy consumption within the commercial sector. This is due to the rapid shift from the industrial to service sector, as compared to the lower rate of increase from the residential sector in Sweden.¹⁹⁷

Given the variations in climatic conditions in Sweden, energy consumption is highly dependant on climatic fluctuations. Therefore, it is important to state that scenario forecasting must be adjusted for climatic variations. Some reports have also normalized the future scenarios with respect to “structural changes in the composition of the Gross Domestic Product (GDP)”.¹⁹⁸

The short-term scenario forecasting projects the energy consumption of the commercial, residential and service sector in Sweden till the year 2010. It should be noted that although the commercial sector is key area that should be analyzed, specific values from this sector cannot be always obtained and, therefore, is approximately derived from the combined sector.

In the EU, the European Commission has assumed 1.6% as the rate of annual improvement in energy intensity, but statistics have shown that this rate of improvement is still slower than the rate of GDP growth, which imply that significantly more reductions in CO₂ emissions is required because of the imbalance.¹⁹⁹ In complying with the Kyoto Protocol for CO₂

¹⁹⁶ OECD. (2003). *Environmentally Sustainable Buildings*. p. 37.

¹⁹⁷ OECD. International Energy Agency. (2000). *Energy Policies of IEA Countries: Sweden 2000 Review*. Paris: OECD Publications Service.

¹⁹⁸ OECD IEA. (2000). *Energy Policies of IEA Countries: Sweden 2000 Review*. p. 41.

¹⁹⁹ Wilberforce, R. (2000). *Furthering understanding*. p. 28.

emissions reduction based on reference values from 1990, this means that a further -18% in current reductions is required.²⁰⁰ The collective effect is as shown in Figure 7-4, with the difference between the “1990-1995” trend and “conventional wisdom” line representing the additional 18% reduction required.

Therefore, from actual EU trends reflected in the 1990-1995 period, it is understood that the overall energy intensity improvement is only improving at a much lower rate of 0.6%, where a doubling of CO₂ current savings is needed in order to achieve the Kyoto target for the EU.²⁰¹ Hence, if net energy intensities increase annually, the reality of attaining the Kyoto target will become even more distant, therefore, this emphasizes the impedance of reducing the rate of increase in electricity use in the commercial sector. Similar projections from scenarios predicted by EuroACE reflect approximately comparable figures, as seen in Figure 7-5, with the “Business -as-Usual” (BAU) model versus the target goal.

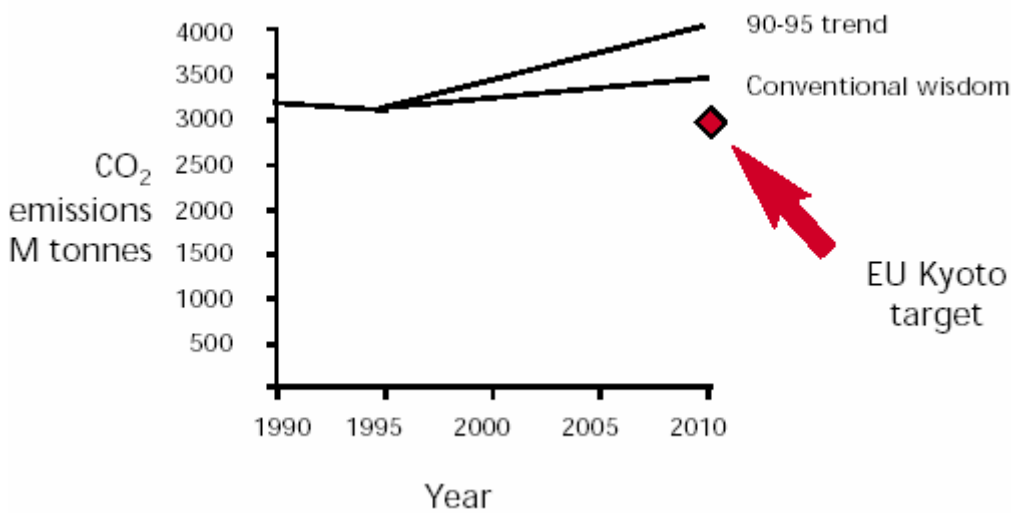


Figure 7-4. EU CO₂ emissions based on conventional wisdom and 1990-1995 trend

Source: Wilberforce, R. (2000)

²⁰⁰ Wilberforce, R. (2000). Furthering understanding. p. 28.

²⁰¹ Wilberforce, R. (2000). Furthering understanding. p. 28.

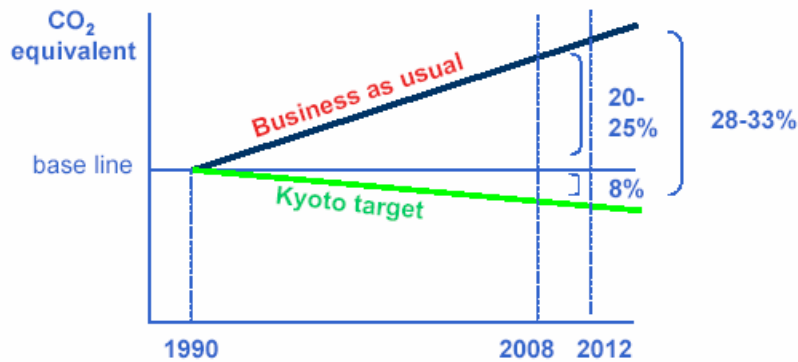


Figure 7-5. The real target for energy efficiency in buildings within the EU

Source: EuroACE (2000)

It is true that obligations to the Kyoto Protocol by individual Member States will not be completely fulfilled by improvements in the commercial and service sectors, but it is nevertheless an important aspect contributing significantly towards attaining the goal. Based on collected efforts focused on improving the energy performance of the European building stock, it is estimated that the total potential of CO₂ reduction in this sector alone can satisfy 20-25% of Kyoto commitments.²⁰² Therefore, within Europe’s building sector, the debate is that the necessary skills, standardized methodologies, energy efficient technology and products are already in place in order for the EU to meet its Kyoto climate change commitments.

In Sweden, the final energy consumption in the provision of services by the commercial sector increased by 1.1% per year from 1983 to 1996, where temperature-correction has been taken into account, but the fact that the increase in electricity intensity increased by 2% within the period is of more interest.²⁰³ Although Sweden is not required to reduce emission levels but allowed a 4% increase from 1990 levels up to 2010, it has imposed a further 4% CO₂ reduction on itself to 96% of 1990 CO₂ levels.²⁰⁴

When these figures are translated into tons of CO₂ equivalent, it is projected that “the total GHG emission in Sweden for 2008 is equivalent to 74 million tons of CO₂”, therefore, an 8.3% (6.1 million tons of CO₂ equivalent) reduction is required during the Kyoto period in order to satisfy national commitments.²⁰⁵ The potential of energy and CO₂ savings from energy efficiency within the commercial building sector can contribute to a significant portion of the total reduction commitment. More importantly, it is projected that this contribution can be pursued in a cost-effective fashion, in the existing commercial building stock.

²⁰² EuroACE (2002). *EuroACE Press Release: Brussels*. New studies show how EU can reduce CO₂ emissions by 12.5 per cent, save money and create 3.4 million job years of work. http://www.styrax.com/demons/EuroACE/doclib/Documents/998315285.087/F:%5Ceuroace%5Csource_docs%5Cr02.htm [2003, June 25].

²⁰³ OECD. IEA. (2000). *Energy Policies of IEA Countries: Sweden 2000 Review*. p. 44.

²⁰⁴ International Emissions Trading Association. (2001). *Meeting the Kyoto Protocol Commitments*. http://www.ietat.org/Documents/New_Documents/StatusonDomesticTradingSchemes_GeirHoybe.htm [2003, June 20].

²⁰⁵ IETA. (2001). *Meeting the Kyoto Protocol Commitments*.

A positive contribution is seen from the increase in the application of district heating networks in commercial buildings, as according to Directive 2002/91/EC. The total expected increase in the use of district heating is estimated to be 4.4TWh from the period of 1997-2010, where “it is assumed that district heating will be installed, supplying about 80% of heating requirements, in newly-built apartment buildings and commercial buildings”.²⁰⁶ In this positive scenario alone, as opposed to the use of electricity-intensive heaters or less efficient boilers for space heating purposes, up to 0.5 million tons of CO₂ emissions can be saved. This singular measure contributes to over 8% of the total required reduction.

In projections to the year 2010, the projected growth in final energy consumption for general service buildings is assumed to be 1.1-1.2% per year.²⁰⁷ This assumption, based from NUTEK, the Swedish National Board for Industrial and Technical Development, is the same as the estimated economic growth in Sweden. The projection is extended long-term to the year 2020, where NUTEK predicts that the increase in final energy consumption in the commercial sector will be up to +38% from 1991 figures.²⁰⁸

Nevertheless, in a positive scenario, the reduced energy consumption, in terms of reduced kW used per utility served, can be attained through the combination of efficient lighting, ventilation systems and office appliances. Given that the integrated benefits of the energy performance standards and Directive is evident by 2020, Table 7-2 presents the projection of a possible future scenario in Sweden, based on 1993* reference values.

The cumulative measures for existing office buildings reflected in Table 7-2, if attained, will contribute to an emissions reduction of more than 0.4 million tons of CO₂ per year, with respect to the year 1991. This value contributes to an additional 7% of the total CO₂ reduction commitments annually.

Table 7-2. Projected electricity demand for appliances in service buildings, in TWh per annum

Service Buildings	1991	2020
Lighting	6	2.4
Ventilation	2.5	2.0
Office Machines	1	0.2
Cooling	0.6	0.2
Food Storage	1.2	1.2
Pumps	0.5	0.6
Cooking	1	1.0
Not Specified	3.9	2.3
Sum	16.7	9.8

**) Source for base year 1993: NUTEK (1995) “Scenarier over energisystems utveckling åren 2005, 2020”*

Source: Fritsche, U. R., Cames, M., Lücking, G. (1998).

²⁰⁶ Energimyndighet. (2002). *Energy in Sweden: The climate report 2001*. p. 210. Eskilstuna: Statens Energimyndigheten.

²⁰⁷ Fritsche, U. R., Cames, M., Lücking, G. (1998). *A New Energy Policy for Sweden: Options and implications of a nuclear phase out*. Technical report. Öko-Institut. p. 22. <http://www.oeko.de/bereiche/energie/documents/sweden-lang.pdf> [2003, July 29].

²⁰⁸ Fritsche, U. R., Cames, M., Lücking, G. (1998). *A New Energy Policy for Sweden*. p. 22.

It is important to note that the development of building standards and labeling schemes are important drivers for an energy efficient building stock, and that the development and integration of future technologies may be based on innovation.²⁰⁹ Future technologies in specific building components and integrated development within the building system may include, amongst others:²¹⁰

1. Roof, floor and wall insulation
2. Energy efficient lighting systems and lighting system controls
3. Window glazing
4. HVAC systems and plant controls

The future scenario of energy efficiencies will depend largely on assumptions on the future price of electricity. In the long term, from the year 2020 and beyond, final energy use and the consumption of electricity is expected to be more demand-elastic as compared to short-term scenarios. It is noted that the success in implementing an energy-efficient building stock is a gradual process influenced not only by legislation and design factors, but also by the manner buildings are maintained, operated and used. Therefore, given these numerous facets, the success of which is uncertain and may only be evident in the long term.

²⁰⁹ Jakob, M., Madlener, R. (2003). *Exploring Experience Curves for the Building Envelope: An investigation for Switzerland for 1970-2020*. Centre for Energy Policy and Economics. Swiss Federal Institutes of Technology. CEPE Working Paper Nr. 22. http://www.sace.ch/downloads/SAEE2003/Martin_Reinhard_ppt.pdf [2003, June 5].

²¹⁰ EuroACE (2000). *Energy Efficiency in Buildings: The way for the EU to meet its Kyoto Commitments*. http://www.styrax.com/demons/EuroACE/doclib/Documents/998315285.087/F:%5Ceuroace%5Csource_docs%5Cr02.htm [2003, June 25].

8. Conclusions and recommendations

This thesis has analyzed the impact of Directive 2002/91/EC according to the content listed in Articles 3, 4, 6 and 7 of the Directive, with respect to the existing commercial building stock in Sweden. This final section provides the conclusions and implications found, based on the 3 main articles called for in the Directive:

1. The formulation of a methodology for the calculation of energy performance of buildings.
2. The setting of minimum energy performance requirements with respect to existing commercial office buildings, with adequate consideration for indoor environment conditions.
3. The establishment of a building energy performance certificate scheme.

8.1 Conclusions

There is an urgent need for buildings to decrease the total amount of energy consumed. It is seen that, within the EU, up to 40% of the total final energy consumption and CO₂ emissions comes from buildings. In Sweden, the final energy use in buildings consumes a similar corresponding value, with the commercial sector reflecting worrying trends of increasing electricity consumption per unit area of space. The increase in this sector is contributed by the significant increase in energy consumed by service systems in office buildings for occupant comfort and the increased use of electrical office equipment. Therefore, if Kyoto Protocol commitments are to be fulfilled, Sweden, as well as other EU Member States, must improve the energy efficiency in this sector. Directive 2002/91/EC addresses these issues, and by January 2006, national standards must be established in order for it to be enforced.

8.1.1 The need for a standard methodology and minimum energy performance requirements

In response to the need for establishing methods for consistent and reliable information on building energy performance, this thesis has shown that standardized information on calculation procedures and the assessment of energy performance do exist, in the form of:

1. Mandatory requirements prescribed for health and safety reasons, and performance-based standards established by the Boverket,
2. Normalized CEN standards and TC calculation methodologies, and,
3. Commercial checklist assessment tools, such as the UK BREEAM, or the US-based LEED system of performance certification.

But in spite of this, it is found that the compliance to such available information is not made mandatory especially in the case of the CEN standards, and other computational methods for calculating energy performance are employed instead. These computer-based methods are not incorrect, but in order to comply with the Articles of the Directive, some

standardized methodology must be developed by each Member State, and in Sweden, this has not been implemented for the all aspects listed in the Annex of the Directive. Therefore, the proposal of an integrated quantitative and qualitative analysis of commercial buildings was put forward in this thesis, addressing the areas found lacking. This qualitative and quantitative approach towards each component of analysis, arriving at its integration, is as shown in Table 8-1.

Table 8-1. Comparing the qualitative and quantitative analysis presented

	Qualitative Analysis	Quantitative Analysis
Procedure	Aim: To provide an overview on the non-quantifiable aspects of a building that influence energy performance in a building.	Aim: To provide quantifiable procedures that assesses the energy performance of a building and its systems, in an integrated approach.
Reviewing literature	Reviewing non-quantifiable aspects of a building that may influence building energy consumption. Qualitative aspects are listed based on a review of existing literature.	Reviewing the existing national energy codes, established CEN methodologies, environment assessment tools, etc. Reviewing energy intensive-aspects in a building from different approaches.
Analysis	Description of qualitative aspects based on the “Building Description Survey” shown in Table 5-3, and presented in Appendix C: Qualitative aspects.	Current energy performance assessment procedure in Sweden reviewed, where computer modeling is conducted w.r.t a reference model. $[Q_{actual} < Q_{reference}]$ The use of component-based performance standards for heat and electricity consumption, and integrated for whole building performance.
Methodology proposal	The proposal of a qualitative methodology to explain the variance if a building performs unexpectedly. Presented in Figure 5-2.	The proposal of an integrated quantitative framework where existing codes, methodologies and standards are applied. The framework methodology is presented in Figure 5-5, where a range of minimum requirements and performance-based standards is shown in Figure 5-7. Discussion into identifying improvements.
Verification	Not verified. Sensitivity of the proposed methodology relies on the specifics provided in the “Building Description Survey”.	Verified with the use of computer simulation tools in re-iterative testing on a reference model, as is the current practice in Sweden. Methodology proposal verified based on parallel studies conducted in UK, with assumptions on the general applicability in Sweden.
Integration	The summary of these qualitative and quantitative components of the analysis is presented in Figures 5-6 and 5-7. The approach of reiterating the procedure, within the range of minimum requirements, prescriptive requirements and performance-based standards, aims for the building energy performance to comply within this energy efficient range There are limitations to the approach listed, given the wide range of office building types; therefore, assessing every single building component in one methodology is not possible.	

In the qualitative analysis, the reliability of the approach presented relies on the accuracy of the description of the building described. On the other hand, in the quantitative analysis, it is of the general opinion that there is a need to apply existing methodologies, particularly in the

sections that are found to be lacking, as required by the Directive. This thesis, therefore, employed the use of such existing standardized methodologies in the formulation of an integrated framework in assessing the energy performance, and for identifying improvements to existing commercial buildings. It should be noted that no new calculation method was presented, but rather, an integrated approach was proposed with the formulation of a framework methodology.

In adopting the Articles in the Directive, and answering the first research question, it is shown that when an integrated qualitative and quantitative approach is presented, with the supporting use of existing codes, methodologies and standards, the energy performance and efficiency of an existing commercial building can be assessed in a transparent, structured manner. These codes and existing calculation methodologies contribute to a range of energy consumption figures, where an energy efficient building will comply with if performance-based CEN standards are applied. As additionally discussed, certain aspects can be identified for the maximum benefits, when using the approach of the framework methodology in the iterative manner, with this specified range of energy consumption.

In light of the limited time frame available for implementing the Directive, to develop a new calculation methodology based on the requirements of Directive 2002/91/EC may not be feasible. Such a methodology, if created, would be less established and provides no additional benefit because they are not normalized with other standards. Existing standards prepared by CEN, on the other hand, have been developed for the purpose of normalizing differing procedures, and when adjusted in relation to the climatic conditions, they present valid, and comprehensive calculation methods. Therefore, it is concluded that the adoption and use of these codes and standards in an integrated manner, in Swedish national building standards, will facilitate significant energy savings when analyzing the whole building system.

8.1.2 Verification and certification

Verifying the procedure for assessing the integrated energy performance of a building is crucial because this reflects how well it reduces the energy use in an evaluated office building. In verifying the proposed framework methodology, the approach of using building energy simulations program for the verification of designed parameters was presented, and it was concluded that the results of such verification is assumed to be very similar to parallel case studies conducted in the UK.

While the main limitations are that these generalities are not based on exact results obtained in Sweden, it nevertheless does show that when CEN standards, prescriptive requirements and performance-based standards are applied, that the range of energy consumption is narrowed, and it is from this ideal range that energy efficient performance can be certified.

As compared to the existing certification scheme based on current quality of the energy performance of the statistical building stock, the certification scheme proposed in the thesis is based on the narrowed range of energy consumption from buildings, as proposed by the framework methodology. This narrowed range, bounded by best available practices, and the maximum target energy consumption of office buildings determined by Boverket, should be split into quarters, with certification labeling based on the current developments conducted by the EnergiledarGruppen. In doing so, the benefits of an assessment method, based on the proposed integrated framework methodology, could be extended to the existing commercial building stock through this corresponding certification system.

It is concluded that when referring to building energy simulations, one should always be aware of the limitations of energy modeling software in reflecting exact behavior. This is because actual energy performance in a building is determined by the 3 combined factors shown in Figure 8-1. Therefore, the designer should keep in mind that energy efficiency in technical design is only one aspect of a building that is performing in an energy efficient manner.

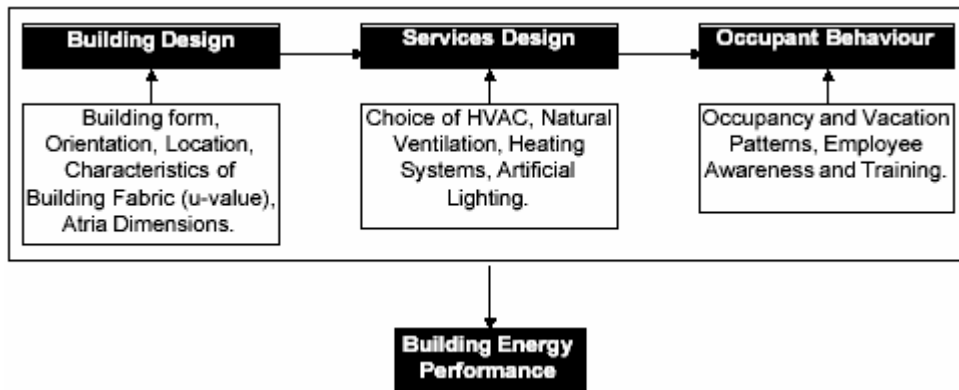


Figure 8-1. Integrating the components of building energy efficiency

Source: Adapted from Baker²¹¹ 1998, Horsley, A., France, C., Quatermass, B. (2000). p. 2.

Conclusions from this section show that building management practices and occupant patterns have an equally significant impact on building energy performance. Therefore, in analyzing the energy efficient performance in buildings, it is important that these aspects are integrated in the analysis. While the effects of measures, such as building management training and education for energy efficient occupancy behavior, are often too subtle to be specifically quantified, the negative impacts of neglecting these 2 significant aspects will be costly.

8.1.3 Implications and future development

The total amount of energy consumed by buildings, first researched and tabulated in 1999 and presented in the CALEB I report by the EuroACE organization, caused alarm to parties of the EU.²¹² Coupled with the pressure of satisfying Kyoto Protocol commitments, and the need to achieve this within reasonable payback periods with a positive net benefit, the drive for the implementation of Directive 2002/91/EC is understandable. The Directive presents very ambitious plans for a traditionally conservative industry, affecting a multitude of stakeholders, resulting in formidable challenges in order for the total 450 million tons of CO₂ mitigation potential to be exploited. The challenges faced by this Directive affect not only the technical standardization issues as discussed, but includes facets of policy implementation, as seen in Figure 7-1. These 2 types of challenges affect stakeholders in the building and construction industry differently, each affected by interrelated implications, as summarized in Figure 8-2.

²¹¹ Baker, N., Steemers, K. (1998) *The LT Method 2.0. An Energy Design Tool for Non-Domestic Buildings*. Cambridge: Cambridge Architectural Research.

²¹² Warren, A. (2001). *European Directive, start of something big?*

This thesis has shown that a discussion on these 4 different levels answer the different implications faced by each general type of stakeholder, based on different corresponding focus issues. Therefore, because of the interrelations, it is important that the process of standardization and legislation is developed with input from the concerned parties, in order for the successful implementation of the Directive. In addition to this, demand and supply issues in the property market will be significantly affected from the required energy performance certification, where both building owner and consuming tenant must operate in an energy efficient manner in order to ascribe value to the building.



Figure 8-2. Implications for different stakeholders and corresponding effects

In analyzing future scenarios, it remains crucial that the drive towards energy efficiency is continued, especially in the consumption of electricity within the commercial sector, if commitments to the Kyoto Protocol are to be fulfilled. Higher than expected increases in energy consumption will only drive targets further away. Therefore, standards and policies aimed at reducing electricity consumption must be adopted for any significant improvements to be projected in the future.

The solution is, hence, to attain energy savings through the integrated assessment of energy-intensive systems. In a positive scenario, it is found that up to 15% of Sweden's commitments to the Kyoto Protocol can be achieved within the existing office buildings, through the application of:

1. An 80% increase in the use of district heating, and
2. An integrated approach in the design and use of electricity in electrical building systems.

In an overview based on previous and present articles published in the Official Journal of the European Union, one can observe and conclude that there has been a build up of different decisions related to energy efficiency issues within the building sector, and that the political will behind this trend is encouraging. Besides Directive 2002/91/EC for energy performance in buildings, the increasing trend is seen from:

1. Directive 89/106/EEC in Annex I for energy economy and heat retention in relation to construction products,
2. The SAVE project of Directive 93/76/EEC in limiting CO₂ emissions from improving energy efficiency, by calling for the energy certification of buildings
3. Decision 2003/269/EC on the adoption of the Energy Star™ system for energy efficiency labeling in office equipment.

The CEN is actively continuing the work with aims of attaining a standard methodology for an integrated approach to energy performance, in adoption of the Directive. Working groups within the Technical Committee have started integrative efforts in merging existing standards for a performance-based approach, and completion of the work is expected before 2006.

In conclusion, the benefits of energy efficiency within the commercial building sector can be viewed as potential “low-hanging fruits”.²¹³ The argument in this thesis presents how this potential can be realized through available codes, standards and methods in an integrated approach, which links energy performance and efficiency issues. The hidden double-dividend benefit from this (i) reduces wastage from inefficient energy use thereby conserving the environment through the reduced “environmental and social costs of energy use”, and (ii) provides significant savings in utility bills in the process. This upgrading process creates employment, reduces reliance on foreign energy imports, contributes to Kyoto Protocol commitments, promotes technology advancements and stimulates innovation. The Directive 2002/91/EC may be called the singular “greatest step change in energy in buildings”, but the benefits waiting to be realized are similarly extensive.

8.2 Recommendations

The recommendations presented in this thesis, based on compliance with Directive 2002/91/EC, are as follows:

1. The increased use of normalized standards is needed for compliance with the Directive. There is a need to analyze the energy consumption based on a range of values. Therefore, the application of prescriptive requirements, bounded by existing minimum energy codes defined by health and safety rules, current best practices and

²¹³ United Nations Development Program. (2000). *World Energy Assessment: Energy and the challenge of sustainability*. Table 6.3. <http://www.undp.org/seed/eap/activities/wea/drafts-frame.html> [2003, May 29].

maximum performance-based standards can be used in order to attain an energy efficient range, as seen in Figure 8-3.

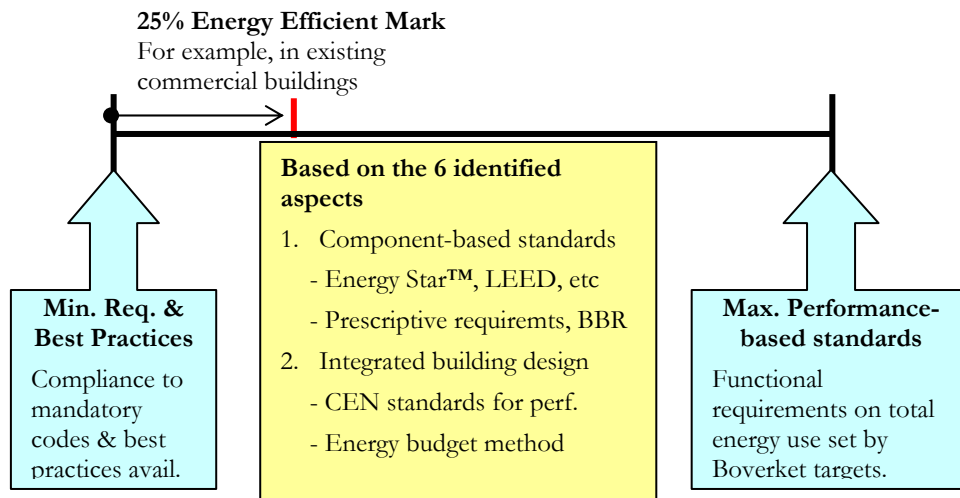


Figure 8-3. Identifying the efficient range for energy consumption in buildings

2. Such prescriptive and performance-based standards published by the CEN are widely accepted, but its application is not well established in Sweden. The use of such calculation procedures should be adopted in the integrated framework methodology as shown in Figure 5-5, with applications in the following areas:

Building envelope performance:	EN832 & EN ISO 13790
HVAC systems:	EN832, EN ISO 13790 & TC156
Service hot water systems:	EN14335
Lighting systems:	TC169
Building Automation and Controls:	TC247

When calculated in an integrated manner, the tabulated energy savings may be up to 2 times more than when each system component is assessed individually.

3. In preparing for the Directive, it is recommended that the Boverket adopts the mandatory use of these standards, and for the industry to familiarize itself with and apply these standards when refurbishing commercial buildings
4. It is also important to consider the non-quantifiable aspects of a building in a qualitative assessment before quantification is commenced. This should be provided by a qualitative description that supports the quantitative assessment of energy performance, in the form of a “building description survey” provided in Appendix C.
5. The use of building energy simulation programs, such as Enorm, IDA ICE v3, and ABB Ventac, for energy performance assessments, as is the current practice in Sweden, is not flawed but relies significantly on the experience and expertise of the designer. This is highly subjective, and not always presented in a clearly defined

manner. Therefore, the application of existing European Standards and calculation procedures makes this process more transparent, while verifying simulation results, and the experience gained from the current practice is not lost or discredited.

6. It is also important to note that while designing to reduce the energy consumption of buildings, the heat and electricity consumption must be reflected clearly. Attaining a lower annual net or final energy consumption, with a much higher proportion of electricity use is not beneficial. It is recommended that conversions of final heat and electricity use to primary energy use reflect energy savings more transparently.
7. It is recommended that a energy performance certificate based on the best available practices and energy use targets set by the Housing authorities is adopted instead of the current statistical approach applied by the EnergiledarGruppen. The proposed hybrid approach of obtaining a suitable range of energy consumption in a building, in kWh/m², with heat and electricity use made distinct, will base the energy performance certification on real efficiencies, rather than the quality of the existing building stock.
8. The success of implementing the Articles listed in Directive 2002/91/EC involves not only the transparent nature of energy performance assessment, but also the integrated effort by industry, authorities, and other stakeholders. Therefore, it is recommended that the national legislative bodies welcome dialogue and communication between all affected parties when formulating the necessary requirements.

8.3 Limitations

The analyses of this thesis have focused mainly on the technical and policy issues required in Sweden in order for compliance with the Directive. Given the constraints with this scope, not all issues have been covered in this thesis. The other facets of the analysis that have not been duly covered include the economic and financial considerations of the Directive.

Given the specified scope, this thesis only covers the energy consumption component of a building, which is different when an environmental approach is adopted. In an environmental approach, the significant environmental impacts of land use, water consumption, waste streams, hazardous waste production, occupant health and well-being, amongst others, are assessed. Therefore, when adopting a life-cycle approach in assessing the overall performance of a building, all these aspects should be considered. It should be noted that the energy performance of a building is only one aspect of the total performance of a building.

It is important to understand that there are many different interpretations to the Directive 2002/91/EC, with different opinions on how the Directive should be satisfied. This thesis presents just 1 such approach with the use of existing standards to aid compliance. The integrated approach presented is called a “framework” because the list of energy-intensive aspects listed is not exhaustive, and neither are energy consumption patterns similar in all commercial office buildings. Therefore, given these limitations, a general framework has been presented, based on several of the common aspects in a Swedish commercial office building.

8.4 Avenues for future research

Given the constraints and discussion into the limitations of this thesis in Section 8.3, and given the diverse implications of this thesis, there are several avenues for continuing research for each concerned stakeholder. Such avenues for future studies may include considerations on different levels:

Economical/Financial Level: The economic and financial assessments of refurbishments in existing buildings, where payback periods and net benefits of improvement are tabulated.

Policy Level: An analysis based on effective economic instruments and policy creation by the national Government in inducing energy efficient design for developers, energy efficient operation and maintenance for facility management teams, and energy-conscious behavior in building occupants.

Regional Level of Applicability: Developing certification schemes that are standardized for EU-wide comparison, and calibrated for absolute and relative comparisons between all types of buildings.

Additional Scope for Academic Research: The scope of future research may be extended to include residential buildings, which constitute up to two-thirds of the total building stock in the EU. Likewise, the research into the scope of new buildings, where up to 90% of savings can be identified when the design of building installations is included from the pre-construction phase. Energy performance in context with the Directive within this scope is easier to design for, more cost-effective, and an assessment of “alternative energy systems”, such as the application of Renewable Energy technologies (RET), may be included.

Additional Interests for the Industry: In this thesis, only the operation and maintenance phase of an existing commercial office building is analyzed for energy performance. A life-cycled analysis (LCA) and life-cycle cost (LCC) approach would further extend the scope for research into a “cradle-to-grave” approach, assessing specific building materials from the extraction of the resource to its disposal, for the lowest environmental impact cost. This avenue of additional interest promotes extended producer responsibility within the industry.

Regardless of the research approach, interpretation or the challenges faced by Sweden and the other Member States, or the angle of continuing research, the implications of the Directive 2002/91/EC are to be enforced by 2006, with a maximum 3 years of allowance, and by then Sweden must have laws regulating energy performance in buildings. Given the existing tools, methodologies and standards already in place, and the cost-effective nature of refurbishments to the existing building stock; the measures to reduce energy consumption and the effects of climate change currently exists, and more so at a net benefit. Therefore, the impending Directive, the integrated framework methodology and the implications presented in this thesis aims to attain an energy-efficient existing building stock. This Directive should not be viewed as a crisis but it represents great opportunity.

A pessimist sees the difficulty in every opportunity; an optimist sees the opportunity in every difficulty.
--Sir Winston Churchill

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When written in Chinese, the word “crisis” is composed of two characters. One represents danger, and the other represents opportunity.

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Abbreviations

AHU	Air Handling Unit
BBR	Swedish Building Regulations
CEN	European Committee for Standardization
CO ₂	Carbon Dioxide
EC	European Commission
EEC	European Economic Community
ENPER	Energy Performance Regulation for Buildings and Model Code Development
EPA	Environmental Protection Agency
EPR	Energy Performance Regulation
EU	European Union
EuroACE	European Alliance of Companies for Energy Efficiency in Buildings
GDP	Gross Domestic Product
GHG	Green House Gas
HVAC	Heating, Ventilation and Air Conditioning
LCA	Life Cycle Analysis
LCC	Life Cycle Costs
NUTEK	Närings- och Teknikutvecklingsverket [Swedish National Board for Industrial and Technical Development]
RES	Renewable Energy Sources
RET	Renewable Energy Technologies
SAVE	Specific Actions for Vigorous Energy Efficiency
TC	Technical Committee of the European Committee for Standardization (CEN)
TEBUC	Towards a European Building Code
UK	United Kingdom
US	United States of America

Appendices

Appendix A. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings

Appendix B. Current Methods of Energy Performance Assessment in Sweden

Appendix C. Building Assessment Information and Data

Qualitative Aspects: Building description survey

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Appendix A. Directive 2002/91/EC of the European parliament and of the council of 16 December 2002 on the energy performance of buildings

4.1.2003



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DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on the energy performance of buildings

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Having regard to the Treaty establishing the European Community, and in particular Article 175(1) thereof,

Having regard to the proposal from the Commission ⁽¹⁾,

Having regard to the opinion of the Economic and Social Committee ⁽²⁾,

Having regard to the opinion of the Committee of the Regions ⁽³⁾,

Acting in accordance with the procedure laid down in Article 251 of the Treaty ⁽⁴⁾,

Whereas:

- (1) Article 6 of the Treaty requires environmental protection requirements to be integrated into the definition and implementation of Community policies and actions.
- (2) The natural resources, to the prudent and rational utilisation of which Article 174 of the Treaty refers, include oil products, natural gas and solid fuels, which are essential sources of energy but also the leading sources of carbon dioxide emissions.
- (3) Increased energy efficiency constitutes an important part of the package of policies and measures needed to comply with the Kyoto Protocol and should appear in any policy package to meet further commitments.
- (4) Demand management of energy is an important tool enabling the Community to influence the global energy market and hence the security of energy supply in the medium and long term.
- (5) In its conclusions of 30 May 2000 and of 5 December 2000, the Council endorsed the Commission's action plan on energy efficiency and requested specific measures in the building sector.
- (6) The residential and tertiary sector, the major part of which is buildings, accounts for more than 40 % of final energy consumption in the Community and is expanding, a trend which is bound to increase its energy consumption and hence also its carbon dioxide emissions.

(7) Council Directive 93/76/EEC of 13 September 1993 to limit carbon dioxide emissions by improving energy efficiency (SAVE) ⁽⁵⁾, which requires Member States to develop, implement and report on programmes in the field of energy efficiency in the building sector, is now starting to show some important benefits. However, a complementary legal instrument is needed to lay down more concrete actions with a view to achieving the great unrealised potential for energy savings and reducing the large differences between Member States' results in this sector.

(8) Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products ⁽⁶⁾ requires construction works and their heating, cooling and ventilation installations to be designed and built in such a way that the amount of energy required in use will be low, having regard to the climatic conditions of the location and the occupants.

(9) The measures further to improve the energy performance of buildings should take into account climatic and local conditions as well as indoor climate environment and cost-effectiveness. They should not contravene other essential requirements concerning buildings such as accessibility, prudence and the intended use of the building.

(10) The energy performance of buildings should be calculated on the basis of a methodology, which may be differentiated at regional level, that includes, in addition to thermal insulation other factors that play an increasingly important role such as heating and air-conditioning installations, application of renewable energy sources and design of the building. A common approach to this process, carried out by qualified and/or accredited experts, whose independence is to be guaranteed on the basis of objective criteria, will contribute to a level playing field as regards efforts made in Member States to energy saving in the buildings sector and will introduce transparency for prospective owners or users with regard to the energy performance in the Community property market.

(11) The Commission intends further to develop standards such as EN 832 and prEN 13790, also including consideration of air-conditioning systems and lighting.

⁽¹⁾ OJ C 213 E, 31.7.2001, p. 266 and OJ C 203 E, 27.8.2002, p. 69.

⁽²⁾ OJ C 36, 8.2.2002, p. 20.

⁽³⁾ OJ C 107, 3.5.2002, p. 76.

⁽⁴⁾ Opinion of the European Parliament of 6 February 2002 (not yet published in the Official Journal), Council Common Position of 7 June 2002 (OJ C 197, 20.8.2002, p. 6) and decision of the European Parliament of 10 October 2002 (not yet published in the Official Journal).

⁽⁵⁾ OJ L 237, 22.9.1993, p. 28.

⁽⁶⁾ OJ L 40, 11.2.1989, p. 12. Directive as amended by Directive 93/68/EEC (OJ L 220, 30.8.1993, p.1).

- (12) Buildings will have an impact on long-term energy consumption and new buildings should therefore meet minimum energy performance requirements tailored to the local climate. Best practice should in this respect be geared to the optimum use of factors relevant to enhancing energy performance. As the application of alternative energy supply systems is generally not explored to its full potential, the technical, environmental and economic feasibility of alternative energy supply systems should be considered; this can be carried out once, by the Member State, through a study which produces a list of energy conservation measures, for average local market conditions, meeting cost-effectiveness criteria. Before construction starts, specific studies may be requested if the measure, or measures, are deemed feasible.
- (13) Major renovations of existing buildings above a certain size should be regarded as an opportunity to take cost-effective measures to enhance energy performance. Major renovations are cases such as those where the total cost of the renovation related to the building shell and/or energy installations such as heating, hot water supply, air-conditioning, ventilation and lighting is higher than 25 % of the value of the building, excluding the value of the land upon which the building is situated, or those where more than 25 % of the building shell undergoes renovation.
- (14) However, the improvement of the overall energy performance of an existing building does not necessarily mean a total renovation of the building but could be confined to those parts that are most relevant for the energy performance of the building and are cost-effective.
- (15) Renovation requirements for existing buildings should not be incompatible with the intended function, quality or character of the building. It should be possible to recover additional costs involved in such renovation within a reasonable period of time in relation to the expected technical lifetime of the investment by accrued energy savings.
- (16) The certification process may be supported by programmes to facilitate equal access to improved energy performance; based upon agreements between organisations of stakeholders and a body appointed by the Member States; carried out by energy service companies which agree to commit themselves to undertake the identified investments. The schemes adopted should be supervised and followed up by Member States, which should also facilitate the use of incentive systems. To the extent possible, the certificate should describe the actual energy-performance situation of the building and may be revised accordingly. Public authority buildings and buildings frequently visited by the public should set an example by taking environmental and energy considerations into account and therefore should be subject to energy certification on a regular basis. The dissemination to the public of this information on energy performance should be enhanced by clearly displaying these energy certificates. Moreover, the displaying of officially recommended indoor temperatures, together with the actual measured temperature, should discourage the misuse of heating, air-conditioning and ventilation systems. This should contribute to avoiding unnecessary use of energy and to safeguarding comfortable indoor climatic conditions (thermal comfort) in relation to the outside temperature.
- (17) Member States may also employ other means/measures, not provided for in this Directive, to encourage enhanced energy performance. Member States should encourage good energy management, taking into account the intensity of use of buildings.
- (18) Recent years have seen a rise in the number of air-conditioning systems in southern European countries. This creates considerable problems at peak load times, increasing the cost of electricity and disrupting the energy balance in those countries. Priority should be given to strategies which enhance the thermal performance of buildings during the summer period. To this end there should be further development of passive cooling techniques, primarily those that improve indoor climatic conditions and the microclimate around buildings.
- (19) Regular maintenance of boilers and of air-conditioning systems by qualified personnel contributes to maintaining their correct adjustment in accordance with the product specification and in that way will ensure optimal performance from an environmental, safety and energy point of view. An independent assessment of the total heating installation is appropriate whenever replacement could be considered on the basis of cost-effectiveness.
- (20) The billing, to occupants of buildings, of the costs of heating, air-conditioning and hot water, calculated in proportion to actual consumption, could contribute towards energy saving in the residential sector. Occupants should be enabled to regulate their own consumption of heat and hot water, in so far as such measures are cost effective.
- (21) In accordance with the principles of subsidiarity and proportionality as set out in Article 5 of the Treaty, general principles providing for a system of energy performance requirements and its objectives should be established at Community level, but the detailed implementation should be left to Member States, thus allowing each Member State to choose the regime which corresponds best to its particular situation. This Directive confines itself to the minimum required in order to achieve those objectives and does not go beyond what is necessary for that purpose.

- (22) Provision should be made for the possibility of rapidly adapting the methodology of calculation and of Member States regularly reviewing minimum requirements in the field of energy performance of buildings with regard to technical progress, *inter alia*, as concerns the insulation properties (or quality) of the construction material, and to future developments in standardisation.
- (23) The measures necessary for the implementation of this Directive should be adopted in accordance with Council Decision 1999/468/EC of 28 June 1999 laying down the procedures for the exercise of implementing powers conferred on the Commission ⁽¹⁾,

3. 'energy performance certificate of a building': a certificate recognised by the Member State or a legal person designated by it, which includes the energy performance of a building calculated according to a methodology based on the general framework set out in the Annex;
4. 'CHP (combined heat and power): the simultaneous conversion of primary fuels into mechanical or electrical and thermal energy, meeting certain quality criteria of energy efficiency;
5. 'air-conditioning system': a combination of all components required to provide a form of air treatment in which temperature is controlled or can be lowered, possibly in combination with the control of ventilation, humidity and air cleanliness;
6. 'boiler': the combined boiler body and burner-unit designed to transmit to water the heat released from combustion;
7. 'effective rated output (expressed in kW)': the maximum calorific output specified and guaranteed by the manufacturer as being deliverable during continuous operation while complying with the useful efficiency indicated by the manufacturer;
8. 'heat pump': a device or installation that extracts heat at low temperature from air, water or earth and supplies the heat to the building.

HAVE ADOPTED THIS DIRECTIVE:

Article 1

Objective

The objective of this Directive is to promote the improvement of the energy performance of buildings within the Community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness.

This Directive lays down requirements as regards:

- (a) the general framework for a methodology of calculation of the integrated energy performance of buildings;
- (b) the application of minimum requirements on the energy performance of new buildings;
- (c) the application of minimum requirements on the energy performance of large existing buildings that are subject to major renovation;
- (d) energy certification of buildings; and
- (e) regular inspection of boilers and of air-conditioning systems in buildings and in addition an assessment of the heating installation in which the boilers are more than 15 years old.

Article 2

Definitions

For the purpose of this Directive, the following definitions shall apply:

- 1. 'building': a roofed construction having walls, for which energy is used to condition the indoor climate; a building may refer to the building as a whole or parts thereof that have been designed or altered to be used separately;
- 2. 'energy performance of a building': the amount of energy actually consumed or estimated to meet the different needs associated with a standardised use of the building, which may include, *inter alia*, heating, hot water heating, cooling, ventilation and lighting. This amount shall be reflected in one or more numeric indicators which have been calculated, taking into account insulation, technical and installation characteristics, design and positioning in relation to climatic aspects, solar exposure and influence of neighbouring structures, own-energy generation and other factors, including indoor climate, that influence the energy demand;

⁽¹⁾ OJ L 184, 17.7.1999, p. 23.

Article 3

Adoption of a methodology

Member States shall apply a methodology, at national or regional level, of calculation of the energy performance of buildings on the basis of the general framework set out in the Annex. Parts 1 and 2 of this framework shall be adapted to technical progress in accordance with the procedure referred to in Article 14(2), taking into account standards or norms applied in Member State legislation.

This methodology shall be set at national or regional level.

The energy performance of a building shall be expressed in a transparent manner and may include a CO₂ emission indicator.

Article 4

Setting of energy performance requirements

- 1. Member States shall take the necessary measures to ensure that minimum energy performance requirements for buildings are set, based on the methodology referred to in Article 3. When setting requirements, Member States may differentiate between new and existing buildings and different categories of buildings. These requirements shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation, as well as local conditions and the designated function and the age of the building. These requirements shall be reviewed at regular intervals which should not be longer than five years and, if necessary, updated in order to reflect technical progress in the building sector.

2. The energy performance requirements shall be applied in accordance with Articles 5 and 6.

3. Member States may decide not to set or apply the requirements referred to in paragraph 1 for the following categories of buildings:

- buildings and monuments officially protected as part of a designated environment or because of their special architectural or historic merit, where compliance with the requirements would unacceptably alter their character or appearance,
- buildings used as places of worship and for religious activities,
- temporary buildings with a planned time of use of two years or less, industrial sites, workshops and non-residential agricultural buildings with low energy demand and non-residential agricultural buildings which are in use by a sector covered by a national sectoral agreement on energy performance,
- residential buildings which are intended to be used less than four months of the year,
- stand-alone buildings with a total useful floor area of less than 50 m².

Article 5

New buildings

Member States shall take the necessary measures to ensure that new buildings meet the minimum energy performance requirements referred to in Article 4.

For new buildings with a total useful floor area over 1 000 m², Member States shall ensure that the technical, environmental and economic feasibility of alternative systems such as:

- decentralised energy supply systems based on renewable energy,
- CHP,
- district or block heating or cooling, if available,
- heat pumps, under certain conditions,

is considered and is taken into account before construction starts.

Article 6

Existing buildings

Member States shall take the necessary measures to ensure that when buildings with a total useful floor area over 1 000 m² undergo major renovation, their energy performance is upgraded in order to meet minimum requirements in so far as this is technically, functionally and economically feasible. Member States shall derive these minimum energy performance requirements on the basis of the energy performance requirements set for buildings in accordance with Article 4. The requirements may be set either for the renovated building as a whole or for the renovated systems or components when these

are part of a renovation to be carried out within a limited time period, with the abovementioned objective of improving the overall energy performance of the building.

Article 7

Energy performance certificate

1. Member States shall ensure that, when buildings are constructed, sold or rented out, an energy performance certificate is made available to the owner or by the owner to the prospective buyer or tenant, as the case might be. The validity of the certificate shall not exceed 10 years.

Certification for apartments or units designed for separate use in blocks may be based:

- on a common certification of the whole building for blocks with a common heating system, or
- on the assessment of another representative apartment in the same block.

Member States may exclude the categories referred to in Article 4(3) from the application of this paragraph.

2. The energy performance certificate for buildings shall include reference values such as current legal standards and benchmarks in order to make it possible for consumers to compare and assess the energy performance of the building. The certificate shall be accompanied by recommendations for the cost-effective improvement of the energy performance.

The objective of the certificates shall be limited to the provision of information and any effects of these certificates in terms of legal proceedings or otherwise shall be decided in accordance with national rules.

3. Member States shall take measures to ensure that for buildings with a total useful floor area over 1 000 m² occupied by public authorities and by institutions providing public services to a large number of persons and therefore frequently visited by these persons an energy certificate, not older than 10 years, is placed in a prominent place clearly visible to the public.

The range of recommended and current indoor temperatures and, when appropriate, other relevant climatic factors may also be clearly displayed.

Article 8

Inspection of boilers

With regard to reducing energy consumption and limiting carbon dioxide emissions, Member States shall either:

- (a) lay down the necessary measures to establish a regular inspection of boilers fired by non-renewable liquid or solid fuel of an effective rated output of 20 kW to 100 kW. Such inspection may also be applied to boilers using other fuels.

Boilers of an effective rated output of more than 100 kW shall be inspected at least every two years. For gas boilers, this period may be extended to four years.

For heating installations with boilers of an effective rated output of more than 20 kW which are older than 15 years, Member States shall lay down the necessary measures to establish a one-off inspection of the whole heating installation. On the basis of this inspection, which shall include an assessment of the boiler efficiency and the boiler sizing compared to the heating requirements of the building, the experts shall provide advice to the users on the replacement of the boilers, other modifications to the heating system and on alternative solutions; or

- (b) take steps to ensure the provision of advice to the users on the replacement of boilers, other modifications to the heating system and on alternative solutions which may include inspections to assess the efficiency and appropriate size of the boiler. The overall impact of this approach should be broadly equivalent to that arising from the provisions set out in (a). Member States that choose this option shall submit a report on the equivalence of their approach to the Commission every two years.

Article 9

Inspection of air-conditioning systems

With regard to reducing energy consumption and limiting carbon dioxide emissions, Member States shall lay down the necessary measures to establish a regular inspection of air-conditioning systems of an effective rated output of more than 12 kW.

This inspection shall include an assessment of the air-conditioning efficiency and the sizing compared to the cooling requirements of the building. Appropriate advice shall be provided to the users on possible improvement or replacement of the air-conditioning system and on alternative solutions.

Article 10

Independent experts

Member States shall ensure that the certification of buildings, the drafting of the accompanying recommendations and the inspection of boilers and air-conditioning systems are carried out in an independent manner by qualified and/or accredited experts, whether operating as sole traders or employed by public or private enterprise bodies.

Article 11

Review

The Commission, assisted by the Committee established by Article 14, shall evaluate this Directive in the light of experience gained during its application, and, if necessary, make proposals with respect to, *inter alia*:

- (a) possible complementary measures referring to the renovations in buildings with a total useful floor area less than 1 000 m²;

- (b) general incentives for further energy efficiency measures in buildings.

Article 12

Information

Member States may take the necessary measures to inform the users of buildings as to the different methods and practices that serve to enhance energy performance. Upon Member States' request, the Commission shall assist Member States in staging the information campaigns concerned, which may be dealt with in Community programmes.

Article 13

Adaptation of the framework

Points 1 and 2 of the Annex shall be reviewed at regular intervals, which shall not be shorter than two years.

Any amendments necessary in order to adapt points 1 and 2 of the Annex to technical progress shall be adopted in accordance with the procedure referred to in Article 14(2).

Article 14

Committee

1. The Commission shall be assisted by a Committee.
2. Where reference is made to this paragraph, Articles 5 and 7 of Decision 1999/468/EC shall apply, having regard to the provisions of Article 8 thereof.

The period laid down in Article 5(6) of Decision 1999/468/EC shall be set at three months.

3. The Committee shall adopt its Rules of Procedure.

Article 15

Transposition

1. Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive at the latest on 4 January 2006. They shall forthwith inform the Commission thereof.

When Member States adopt these measures, they shall contain a reference to this Directive or shall be accompanied by such reference on the occasion of their official publication. Member States shall determine how such reference is to be made.

2. Member States may, because of lack of qualified and/or accredited experts, have an additional period of three years to apply fully the provisions of Articles 7, 8 and 9. When making use of this option, Member States shall notify the Commission, providing the appropriate justification together with a time schedule with respect to the further implementation of this Directive.

Article 16

Entry into force

This Directive shall enter into force on the day of its publication in the *Official Journal of the European Communities*.

Article 17

Addressees

This Directive is addressed to the Member States.

Done at Brussels, 16 December 2002.

For the European Parliament

The President

P. COX

For the Council

The President

M. FISCHER BOEL

Appendix B. Current methods of energy performance assessment in Sweden

This appendix section lists the methods employed in Sweden (SE) when assessing the energy performance of buildings, as compared to methods employed in other countries. It shows the factors considered, input parameters, and output results. In Sweden, the application of energy performance calculations came into force in 1990, and the use of various building modeling simulation programs in simulating building energy performance is common when assessing the energy use of a building.




All figures reflected here are from the official European Collaboration in relation to Energy Performance Regulation for Buildings and Model Code Development: Towards a European Building Code (ENPER-TEBUC SAVE) report, commissioned by the European Commission.²¹⁴

Table B-1. Energy flows covered by energy performance calculations

	nl	be	fr	de	it	gr	lt	se	ch	uk	at	cz	dk	fi	ie	no	pt	ru
Transmission																		
Ventilation																		
Internal and solar gains																		
Heating system																		
Lighting																		
RE thermal																		
RE electric																		

Table B-2. The application of CEN standards when dealing with transmission losses

	at	ch	se	be	fr	no	de	uk	nl	it	ie	dk	fi	lt	pt	ru	sp
EN ISO 13789 Transmission heat loss coefficient																	
EN ISO 13370 Heat transfer via the ground																	
prEN ISO 10077-2 Thermal performance of windows, doors and shutters																	
EN ISO 6946 Thermal resistance and transmittance																	
EN ISO 10211-1:1995 Thermal bridges - Detailed method																	
EN ISO 14683 Thermal bridges - Simplified methods																	

-  Standard is mandatory regulation
-  Standard may be used as an alternative
-  Standard not applicable

²¹⁴ European Commission. (2003). *Energy Performance of Buildings. Calculation Procedures used in European Countries*. ENPER-TEBUC SAVE.

Table B-3. The input to building energy performance calculations

	at	be. fl	cz	dk	fi	fr	de	gr	ie	it	lt	n o	pt	ru	se	ch	n l	uk		
																		1	2	
Transmission	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ventilation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Internal gains	X	X	X	X	X	X 1	X	X	X	X 1,2	X	X	X	X	X	X	X	X	X	X
Solar gains	X	X	X	X	X	X 1	X	X	X	X 1,2	X	X	X	X	X	X	X	X	X	X
Lighting		X 2		X	X 1		X				X	X		(X)	X	X	X	X	X	X
Fan & pumps		X				X	X 1	X	X	X	X				X	X	X	X	X	X
Heating system (building)		X				X 2	X 1	X	X	X			X 2	X	X	X	X	X	X	X
Heating system (district)							X 1							(X)	X		X	X	X	X
DHW		X 1				X	X 1	X	X				X 2	(X)	X	X	X	X	X	X
Cooling system		X					X 1	X					X 2		X	X	X	X	X	X
RE thermal		X				X 1	X 1	X	X						X	X	X	X	X	X
RE electric		X						X							X	X	X	X	X	X

Table B-4. The output to building energy performance calculations

Parameters included in the results:

	at	be.fl	cz	dk	fi	fr	de	gr	ie	it	lt	n o	pt	ru	se	ch	n l	uk	
HEATING																			
Space heating	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Active solar heating		X	X			X	X								X	X	X	X	
Ventilation	X	X	X	X	X	X	X		X	X	X			X	X	X	X	X	
Cooling		X						X							X		X		
Lighting		X						X		X				X	X		X		
DHW		X DW			X	X	X	X	X					X	X	X	X	X	
ELECTRICITY																			
Fans		X				X			X	X	X			X		X	X	X	
Pumps		X				X			X	X	X					X	X	X	
Lighting		X				X		X			X			X		X	X		
Appliances											X			X		X			
Heat gener.		X				X			X	X							X		

Result of calculated energy per year included in the results:

	Primary energy (consumption at power plant)	CO ₂	Final energy (delivered energy at building site)	Net energy (net energy use in the building)	Distinguish heat and electricity
Austria				kWh/ m ² year	
Flanders-Belgium	MJ/m ³ year: DW MJ/m ² year: O&S				
The Czech Republic				kWh/m ² year	
Denmark				MJ/ m ² year	
Finland			kWh/year		
France	kWh/year				
Germany	kWh/ m ² year				
Greece		YES	kWh/m ² year	kWh/m ² year	YES
Ireland				kWh/m ² year	
Italy	kJ/m ³ day C				
Lithuania			kWh/m ² year		YES
Norway				kWh/m ² year*	
Portugal			kWh/m ² year		
Russia	kJ/m ² C day or kJ/m ³ C day		kJ/m ² C day or kJ/m ³ C day		YES
Sweden				Qac < Qref	
Switzerland			MJ/m ² year	MJ/m ² year	
The Netherlands	MJ/m ² year				
United Kingdom		YES*			

In Sweden, the energy performance of the building is calculated as a whole, with considerations for separate zones. In calculating the maximum value of energy consumption, a reference-building model is employed, with the parameters in Table B-5 considered. In other countries, a formula-based approach may be employ instead.

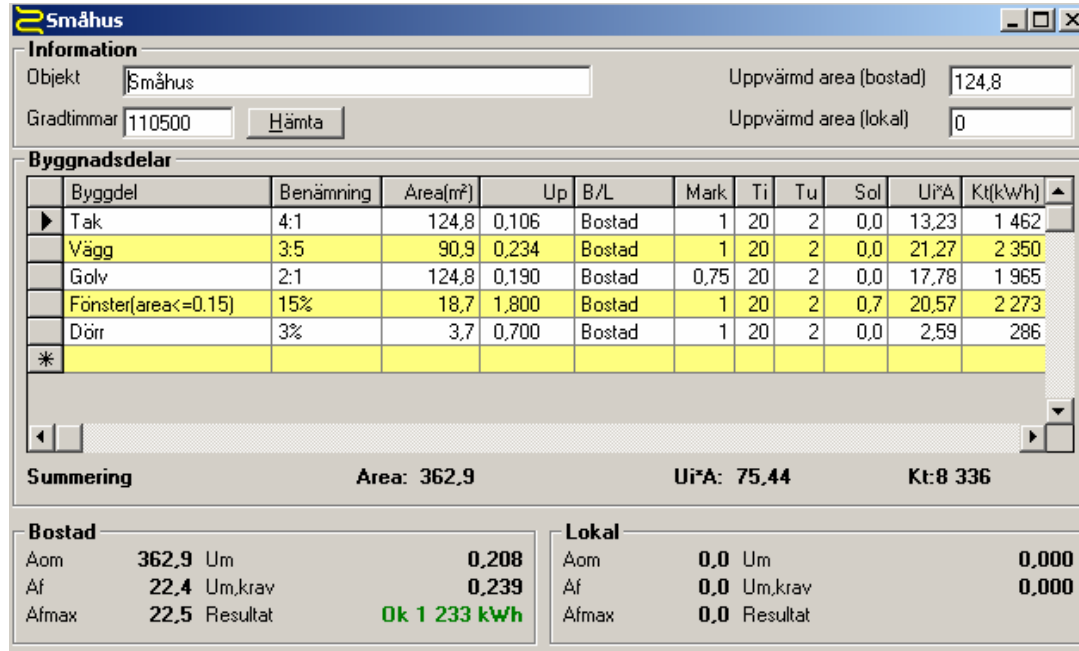
Table B-5. Parameters considered in the referenced building model

	Fi	fr	gr	pt	se
Size of building	X	X	(X)	X	X
Shape of building	X	X	X	X	X
Weather data	X	X	(X)	X	X
Internal temperature	X	X	(X)	X	X
Occupancy	X	X	(X)		(X)
Internal gains	X	X	(X)	X	(X)
Fuel		X	(X)		(X)
Window size	X	X	(X)	(X)	X
Window orientation	X	(X)	(X)	X	X
Shading	X	X	(X)	X	(X)
Lighting	X	X	(X)		(X)
Quantity of DHW	X	X	(X)		(X)
Ventilation rate	X		(X)	(X)	(X)

Parenthesis indicate a default input value

The use of any recognized simulation program is employed in Sweden with results used for building design, while other countries base calculations on EN832, EN ISO 13790 or national codes. Results of simulation programs employed in Sweden for energy performance calculations can be seen in Figure B-1.

Figure B-1. Simulated reference building energy performance results



Appendix C. Building assessment information and data

Qualitative aspects: Building description survey

Where standardization for measurements should be corrected to Standard International (SI) units, where applicable. Locations could be corrected to references to the geographical position, in terms of latitudes and longitudes, if information is found lacking. The information in this appendix section is obtained according to the US Department of Energy, National Renewable Energy Laboratory.²¹⁵

Table C-1. Building description survey

Term	Units	Value
Dates of data collection (start and end)		
Principle Building Activity		
Location (city, state, zip code, country)		
Year Constructed (major renovation years)		
Total area	(ft ²)	
Conditioned/Semi-conditioned area	(ft ²)	
Number of floors (total/conditioned)		
Climate Zone		
Number of workers (main shift)		
Number of computers and other electrical equipment (identify) and the average electrical load for that equipment		
Weekly operating hours		
Ownership occupancy		
Space in building vacant for at least three consecutive months	(ft ²)	
Energy sources		
Energy end uses		
Space-heating energy sources		
Primary space-heating energy source		
Cooling Energy Sources		
Water-heating energy sources		
Cooking energy sources		
Percent of floor space heated	(%)	
Percent of floor space cooled	(%)	
Percent of floor space lit when occupied	(%)	
Percent of floor space lit when unoccupied	(%)	

Where the “ft²” should be replaced with the unit of “m²”.

Source: NREL (2002)

²¹⁵ US Department of Energy, National Renewable Energy Laboratory. (2002). *Protocol for Monitoring and Reporting Commercial Building Energy Performance*. High Performance Buildings Measurement and Documentation Projects. Draft, May 2002. http://www.eere.energy.gov/buildings/highperformance/performance_metrics/pdfs/bldgenegyperf_protocol.pdf [2003, May 29].

Quantitative aspects: Measured aspects

This appendix sub-section features the measured aspects for the quantification of energy performance and efficiency in buildings. Where energy consumption figures are recorded as input for the according performance assessment.

In normalizing these figures, it should be noted that energy figures should be expressed in terms of kWh as opposed to kBtu, and the distinction between heat energy and electricity consumption made, as far as possible. Where references measured in “feet”, should be replaced with the SI unit of “meters”. This information is obtained according to the US Department of Energy, National Renewable Energy Laboratory

Basic Level I Reporting:

Table C-2. Annual energy totals and energy use intensities for Level I reporting

	Total Energy MBtu	EUI Kbtu/ft ² /yr	Total Cost \$	Norm. Cost \$/ft ² /yr
Annual Total Energy				
Annual Totals by Source				
Electricity				
Natural Gas				
Fuel Oil				
District Heat				
District Chilled Water				
Propane				
Renewable (Specify)				
Other (Specify)				

Where the following metric conversions should be used:

1. “MBtu” into “MWh”
2. “kBtu/ft²/yr” into “MWh/m²/yr”
3. “\$/ft²/yr” into “\$/m²/yr” or the equivalent monetary unit

Table C-3. Monthly daily average energy use (Btu or kWh) and demand (Btu/hr or kWh/hr) for Level 1 reporting.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Monthly Total Energy													
Monthly Totals by Source													
Electricity (demand)													
Electricity (energy)													
Natural Gas													
Fuel Oil													
District Heat													
District Chilled Water													
Propane													
Renewable (Specify)													
Other (Specify)													

Level II Reporting:

Level II reporting of input data involves the previous Level I information, and involves the input graphs of monthly average dry bulb temperature and relative humidity. Where possible, information regarding the global horizontal solar radiation may be included.

The graphs shown below in Figures C-1 and C-2 are examples of energy use data that should be compiled prior to the assessment in audits of existing buildings. The categories, although not reflected here, should include the 6 identified aspects listed in Section 5.2, discounting the “building envelope” factor. In Figure C-1, the “equipment” category should be further segregated into sections for HVAC, lifts, service hot water and other electrical loads.

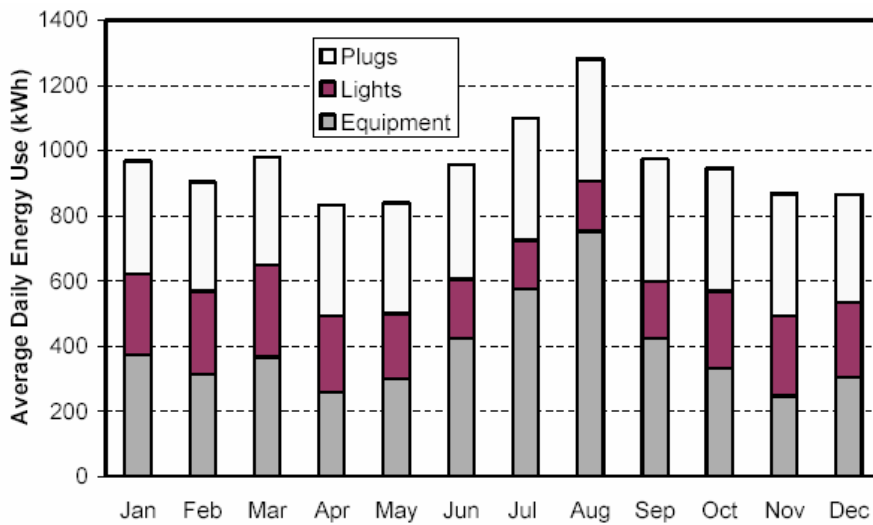


Figure C-1. Average daily energy use by month, in kWh

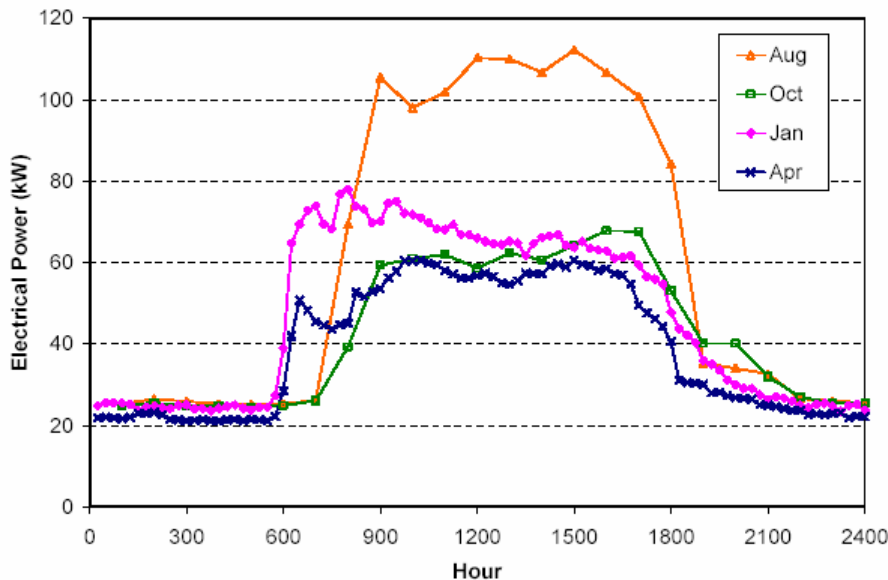


Figure C-2. Average daily energy use profiles for peak summer and winter months and the swing months
 Source: NREL (2002)

Quantitative analysis: Assessment of energy performance in the identified aspects

With the Level I and II reporting obtained from both qualitative and quantitative aspects in a building, as shown in the previous appendix sub-sections, the input data can be applied in the corresponding heat and electricity performance calculations for existing office buildings.

Thermal heat performance

Technical aspects on how to calculate each component of thermal performance shown in Figure C-3, is listed with detail in EN832 and EN ISO 13790.

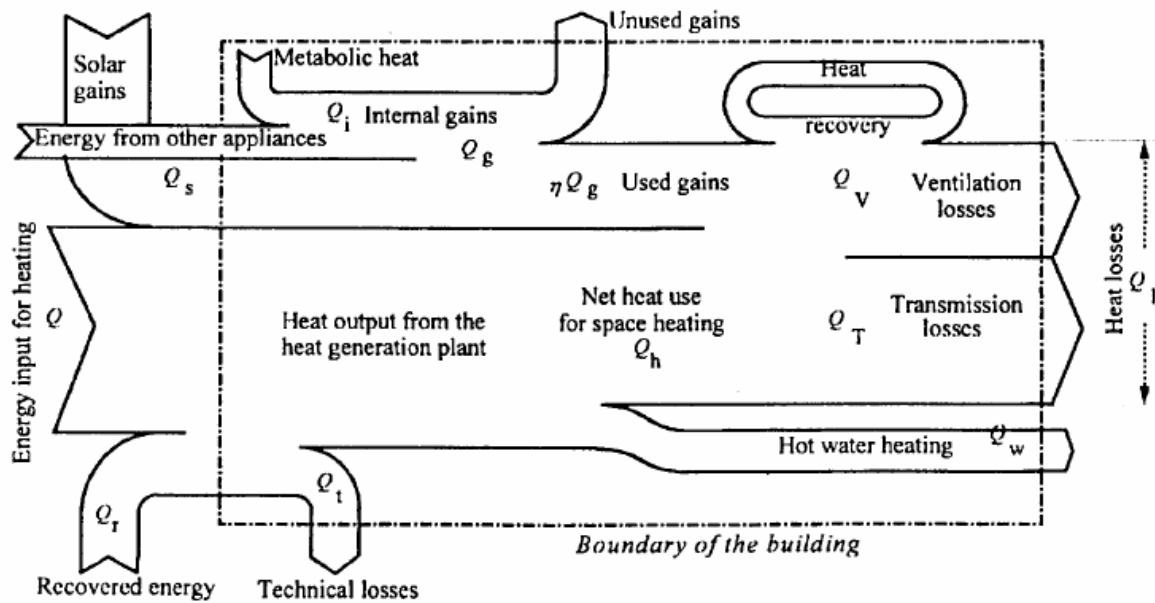


Figure C-3. Annual heat energy balance of a building according to EN832

Source: CEN (1998)

In accordance to the Directive, it is concluded that the application of these CEN methodologies would satisfy the requirements for energy performance, in relation to the building envelope as well as the heating load for HVAC and service hot water systems.

In Sweden, the practice of space heating in commercial buildings is largely supplied through the local district-heating network and this is considered to be highly efficient.

Performance of electricity consumption

HVAC system cooling loads

Another existing method of computing and estimating the cooling load is described by F. W. H Yik, et al, and shown in Figure C-4. This method, similar to the current practice in Sweden, involves the 2-step procedure of:

- i. Predicting required loads for indoor comfort based on thermal performance simulation software, and,

- ii. Calculating the electricity consumption of the HVAC system with other computer simulation programs.

The application of this method, for HVAC system cooling loads, could be adopted for the calculation of energy performance, and ranked to assess efficiency if required.

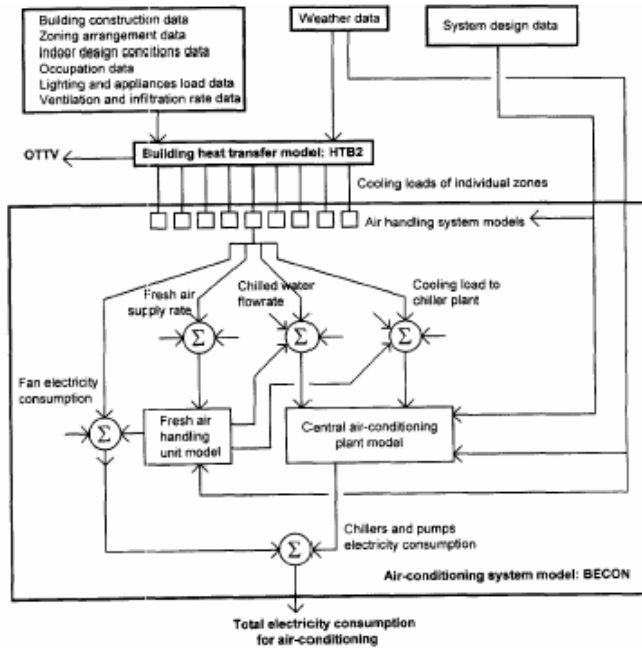


Figure C-4. Air-conditioning electricity consumption estimation method used in HK-BEAM assessment
 Source: F. W. H. Yik, et al. (1998)

Current alternatives to the electricity-intensive system of cooling involve the use of district cooling, where the market for its distribution has grown considerably since 1992. The concept for district cooling is similar to district heating networks, where a central cooling plant, is located near a cold water source, for example, the sea. As opposed to energy-intensive cooling loads, district cooling systems consume 0.17kWh of energy for the delivery of 1kWh of cooling energy.²¹⁶

²¹⁶ Gräslund, J., Johansson, L. (1999). *Miljöpåverkan avseende primärenergiebehov och CO₂-utsläpp för kontorsfastigheten*. p. 10.

Appendix D. A case study on the Hagaporten

In the verification-testing phase of this thesis, with the approach as seen in Figure 6-1, the 6 identified aspects are tested in order to determine how each aspect contributes to energy consumption, influencing the energy performance of a commercial building. The hypothesis in this study is, then, to test the extent and significance of energy performance enhancement, and efficiency, with respect to the identified 6 design parameters, under *ceterius parabus* conditions, given that the same quality of indoor environment conditions should be always be provided.

Justifying the approach, this analysis verifies the validity of the methodology presented in Section 5, based on the 6 identified aspects, fostering the discussion on the importance and significance of these aspects in relation to energy performance and efficiency.

In this appendix section, some of the general features these 6 aspects are tested with a computer energy modeling program, and the above stated hypothesis is tested with respect to a particular building. The verification procedure samples the extent of energy-intensiveness of each aspect in order to verify the validity of the framework methodology presented in Section 5. Each feature is tested against a generalized “typical” case, assumed to be reflected by the Skanska Headquarters at the Hagaporten in Stockholm. This “typical building” case is, therefore, assumed to reflect the general conditions of energy performance in an existing office building within Sweden. It is important to note that this assumption is not without the consideration of temperature-corrections, which would be necessary in order to generalize the application of the results according to the local climate of each particular region in Sweden.

An Introduction to the Hagaporten

The building, Hagaporten²¹⁷, in Stockholm has been chosen as the generalized building with which the methodology is pegged against and verified. The building serves as the Stockholm headquarters of Skanska AB, and the total building area is 71 000 m². Several aspects of its energy performance were tested with the aid of the computer program, ABB Ventac.²¹⁸ It should be stated that the role of ABB Ventac and IDA ICE are similar energy modeling programs that perform the same function, but there may be differences in the specific accuracies of each program, based on the specified codes and equations behind each marketed program.

The Approach & Verification Procedure

This generalized approach of verification has been applied by different authors, such as Yik, Burnett, Jones, Lee (1998) in the assessment and confirmation of the criteria with the use of a hypothetical building model “representative of the typical configuration for a commercial office building in Hong Kong”.²¹⁹ Likewise, Bevington (1984) uses a similar approach, with the use of a fictitious building and the comparison of results generated for “actions that

²¹⁷ “Hagaporten” - Råsundavägen 2, 169 83 Solna, Sweden.

²¹⁸ Gräslund, J., Johansson, L. (1999). *Miljöpåverkan avseende primärenergiebehov och CO₂-utsläpp för kontorsfastigheten*.

²¹⁹ Yik, F. W. H., Burnett, J., Jones, P., Lee, W. L. (1998). p. 211.

might follow good information-measuring energy performance”.²²⁰ Similarly, in this method of verification, the study systematically assesses identified characteristics of the commercial office building, including the passive and active components as according to Section 5.4, in order to determine the impact of energy use given the general performance of commercial buildings in Sweden.

It can be noted that besides data verification, building simulation tools can, otherwise, be used for purposes such as:²²¹

1. The evaluation of design parametric options according to performance standards and compliance to existing building energy codes, as stated in the iterative method of testing, seen in Figure 6-2.
2. It can be used primarily for in optimization of holistic building design.
3. To include innovation into the building design process.
4. The economic and financial evaluation of cost-effectiveness and payback periods in relation to building retrofits, refurbishments and other energy conservation measures in existing buildings.
5. More importantly, it can be used for the development of energy performance standards by the relevant authorities, such as the Boverket.

1. Building Envelope

Using results from the building simulation modeling by Gräslund, J. (1999), conducted on the building, Hagaporten, several generalities can be drawn. In the study, different characteristics of the building envelope design were tested, with the significance of energy performance results reflected in Table D-1. This is similarly shown in Figure D-1, where different combinations of façade options and air handling units (AHU) were tested and the resulting cost based on life-cycle analysis, is reflected in terms of primary energy consumption in MWh per year.

Table D-1. Energy consumption and performance results of building envelope characteristics

Parameter	Specific change	Specific change in energy use per year
Heavier structure	+ 100/150mm	Approximately - 1kWh/m ²
Insulation increase	+200mm	Approximately - 3kWh/m ²
	+1000mm	Approximately - 5kWh/m ²
Increase in use of glass	40%-60% increased use	Approximately + 7kWh/m ²
	40%-100% increased use	Approximately + 22kWh/m ²
Use of low U-value glass	1.0-1.4W/m ² K	Approximately - 5kWh/m ²

²²⁰ Bevington, P. L. (1984). *Measuring energy performance*. p. 33.

²²¹ Sustainable Energy Coalition. (2000). *Energy Efficiency and Buildings*. Energy Efficiency and Renewable Energy Technologies for a Cleaner Tomorrow. <http://www.sustainableenergy.org/resources/technologies/buildings.htm> [2003, June 6].

Source: Gräslund, J. (2003)

2. Building Envelope with certain HVAC Systems

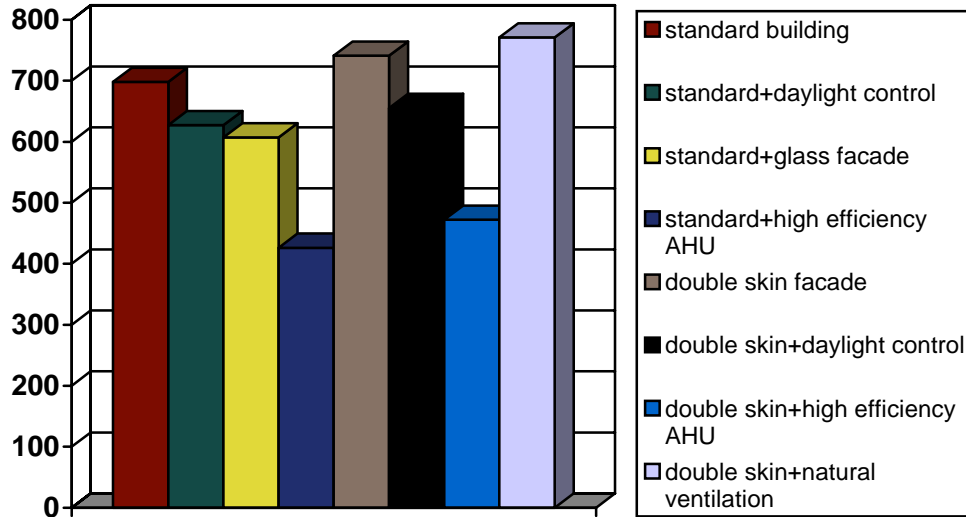


Figure D-1. Primary energy consumption based on different facades and HVAC systems for the Hagaporten in MWh per year

Source: Gräslund, J. (2003)

HVAC Systems

The Hagaporten planned to use sub-stations for district heating and cooling instead of owning a localized heating and cooling plant, which is the norm. This reflected much lower energy bills, as well as system costs. The figures presented here are based on a technical report by Gräslund, J. and Johansson, B. on the Hagaporten. The figures in Table D-2 reflect the amount of energy enhancement observed. Therefore, given the significant percentage of energy consumption from this particular component, it is expected that it will very likely contribute to the heaviest impact on building energy use.

Table D-2. Energy consumption and performance results of HVAC system characteristics

Parameter	Specific change	Specific change in energy use per year
Low speed AHU	1.6-2.5m/s	Approximately - 7kWh/m ²
High efficiency AHU	60%-85% efficiency	Approximately - 16kWh/m ²

Source: Gräslund, J. (2003)

The building models are tested with different types of heating and cooling systems and capacities, with the application of heat recovery for energy efficiency. The assumed equipment efficiency is modeled at 67% ($\eta=0.67$). The results found from the LCC/LCA-based modeling procedure are reflected in Figure D-2.

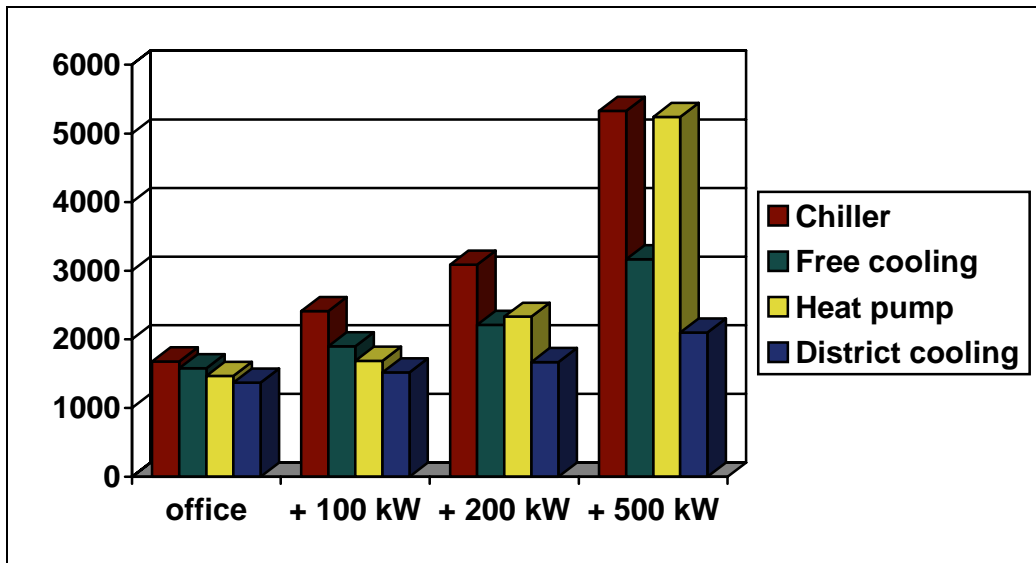


Figure D-2. Primary energy consumption in heating and cooling loads for the Hagaporten in MWh per year

Source: Gräslund, J. (2003)

Service water heating/cooling systems

Considerations for this aspect was included in the above respective modeling for HVAC systems. Service water heating and cooling was provided by the central sub-stations supplying space heat and air-conditioning to the building.

3. Lighting Systems

The lighting system in an office building is a primary service system that consumes energy in the form of electricity. It accounts for approximately 30% of the total electricity use in office buildings in Sweden, and when comparing the total lighting power installed in a room, known as “specific installed power lighting”.²²² Efficient lighting standards list energy efficient lighting systems to have a value below 10W/m², excluding desktop lamps.²²³ Supporting literature has shown that simple lighting replacements provide a potential reduction of 20% of the electricity consumed in lighting per year in Sweden.²²⁴

Furthermore, energy efficient lighting fixtures may reduce this value to 5W/m² of electricity consumption in office buildings. These fixtures have a life span of 20 years and are advanced lighting control systems, integrating daylight management and that automatically turn off after office hours.²²⁵

²²² Nilson, A., Hjalmarsson, C. (1994). Energy use in Swedish Office Buildings. 165 - 166.

²²³ Nilson, A., Hjalmarsson, C. (1994). Energy use in Swedish Office Buildings. 165 - 166.

²²⁴ Center for the Analysis and Dissemination of Demonstrated Energy Technologies. Energy Efficiency. OECD. IEA. (1997). *Energy efficient lighting and ventilation in an office building*. June 1997. <http://www.portalenergy.com/caddet/ee/R280.pdf> [2003, June 30].

²²⁵ International Association for Energy-Efficient Lighting. (2002). <http://www.iaeel.org/> [2003, June 30].

4. Electrical Appliances

Given that this component of energy consumption is highly dependant on tenant-preferences, this user-level aspect was not modeled in the study on the Hagaporten. Nevertheless, if it was conducted, it should be done with respect to the use of energy efficient technology, based on Energy Star requirements on office equipment, as adopted within the EU with Council Decision 2003/269/EC.

Although not assessed, the expected percentage-change in final energy (electricity) consumption is considerable. This is due to the substantial increase in energy use from office equipment reflected in trends from recent years. Electricity consumption, therefore, could be reduced significantly and more importantly; the replacements can be done with ease, as with limited disruptions to operations.

5. Lift Systems

This aspect has not been tested on the Hagaporten for energy efficiency. This can be justified because the total electricity consumption from the use of lifts in the Hagaporten is less than 10%, and improving the energy performance by 10-20% will collectively only contribute to 1-2% in overall final energy savings. Therefore, the marginal costs involved in assessing this aspect outweigh marginal benefits extractable.

Nevertheless, if this aspect were included, its analysis will be justified since the type of final energy consumption is electricity. Hence, the benefits of saving electricity will be larger than just 1-2% when converted into primary energy figures.

Results of the Hypothesis

The results from this case study clearly show that when the energy performance of a building is assessed in an integrated manner, that the extent of the advantages is increased significantly. This is especially so when incorporating the design of the building envelope in conjunction with HVAC systems. The exact extent of each assessed aspect can be seen in the according section, although it should be stated that not all the 6 identified aspects were tested.

Nevertheless, the results can be generalized to state that when the building envelope, HVAC and service water systems are integrally analyzed; there is a 25% potential reduction in the use of energy. When this is combined with the estimated 20% reduction in the use of electricity when energy efficient lighting is used, then the total net benefits are expected to weigh even more significantly.

It should be stated that this case study does not exactly follow the approach proposed in Section 5 and 6 of the thesis, but it does reflect the benefits and claimed advantages of an integrated framework methodology, when applied in Sweden.