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LIFE CYCLE COSTING IN OFFICE BUILDINGS: KEY PERFORMANCE INDICATORS FROM DGNB DENMARK

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Abstract: The purpose of this paper is to analyse and discuss lessons learned on life cycle costing (LCC) in office buildings certified according to the Danish version of the sustainable certification scheme DGNB. The methodology of this paper is based on an action research approach in which the authors have been actively engaged in developing and implementing the DGNB certification scheme. The findings of this study include sharing key performance indicators on life cycle costing from DGNB certified office buildings. The preliminary results indicate that the construction cost will cover half of the total life cycle costs in a 50 year period, while maintenance and operation costs may cover almost one-third of the total life cycle cost. The remaining one-fifth of the life cycle costs are divided between cleaning costs and supply costs for energy and water at a ratio of some 2:1, which implies that cleaning costs are more important than energy costs. While Danish clients and consultants generally have a strong focus on energy optimisation, this paper would like to suggest a need to redirect the attention of building professionals towards cleaning.

Keywords: Life cycle costing, key performance indicators, sustainability, cleaning cost, maintenance.

1. INTRODUCTION

The Brundtland report (1987) “Our Common Future” set a new agenda for a sustainable development with its focus on a balanced development of the three pillars: environment, social affairs and economics. During the 1980s and 1990s Denmark was taking a leading position on sustainability, but that came to a standstill in the 2000s due to new political priorities. In the late 2000s the construction industry started pushing for a certification scheme for buildings. Among other this led to a thorough investigation of four major certification schemes, namely BREEAM, LEED, DGNB and HQE and a test of each of these on two office buildings (Birgisdottir et al., 2010). Following this foundational work, a joint committee of policy makers, business representatives and researchers was established to formulate the general requirements for a certification scheme in Denmark and to suggest either the development of a new national scheme or the adoption and adaptation of an existing scheme. The choice fell on the German certification scheme DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen). Despite the scheme requiring more resources to do a certification of buildings, it was considered superior to the other schemes because: it is a second-generation scheme; it builds on the European standard for sustainable construction works EN15643; it focuses on performance rather than measures; it embraces a broad definition of sustainability rather than the hitherto prevalent narrow focus on energy and environment; and it weights economics on an equal footing with environment and social quality.

With overwhelming support from the industry, a new organisation Green Building Council Denmark (DK-GBC) was established to manage the DGNB scheme and promote sustainable construction more generally. Today DK-GBC has some 275 members covering the most prominent businesses, academia and public agencies across all the main stakeholders in construction. The first English translation of the international guideline of DGNB for office buildings was published in 2012 and tested in seven pilot projects. Over the next two years the guideline was revised through several iterations, adapted to Danish building customs, and translated into Danish. Since 2014 the initial focus on office buildings has been expanded to include other building types like hospitals, residential buildings, educational and day care institutions, and urban areas. Further, the system is designed in a flexible manner making it possible to certify other less frequent types of buildings if needed and for major refurbishments. In late 2016 a new version of the guideline for office buildings was published to accommodate for recent changes in the building regulations. In addition, a new guideline on buildings in operation is now under preparation along with updated versions of the other existing guidelines for other types of buildings.

From 2014, the Danish version of the DGNB certification scheme has gradually moved into a more steady state of operation. This gradual development holds promising prospects as new certified projects are pouring in these years. These are not limited to office buildings but also include other building types. Hence, data are now becoming available for the first DGNB certified office buildings in Denmark, which offers a unique opportunity to look into the performance of office buildings in a consistent manner due to the standardised assessment procedure of DGNB.

As pointed out by Cole and Sterner (2000) the limited direct use of life cycle costing in green building design is mainly related to constraints in data accuracy and in current design practices. Hence, the purpose of this paper is to analyse and discuss lessons learned from key performance indicators on life cycle costing (LCC) in office buildings certified according to the Danish version of the sustainable certification scheme DGNB. This will accommodate for a stronger and evidence-based grounding of sustainable design in the future.

2. STATE-OF-THE-ART

This section will provide a brief overview of international standards and guidelines, describe shortly the link between sustainability and life cycle costing, provide an overview of the historical development and present trends in Denmark on life cycle costing, and introduce the use of life cycle costing in the Danish version of the certification scheme DGNB.

2.1 International standards and guidelines

Life cycle costing is about expanding the narrow focus on construction costs to include also the operating costs over time. Applying the principles of life cycle costing provides the ability to see the full picture including benefits and/or losses occurring during different stages of the lifetime of a building. Hence, life cycle costing can improve the decision-making process, ensure long-term thinking and fair comparison of design solutions with different cost profiles over time, and potentially create more attractive facilities.

Life cycle costing (and whole life costing) belongs to the broader field of strategic investment and financing (see e.g. Hedegaard and Hedegaard, 2008). While the term life cycle costing is generally recognised in construction, the term total cost of ownership is more widespread in other business sectors (see e.g. Ellram, 1993) and in the recent European directive on public procurement (Directive 2014/24/EU).

A range of different approaches and tools to manage life cycle costing or whole life costing already exist both nationally and internationally. Two international standards define life cycle costing: the international standard ISO15686 series on service life planning (ISO, 2008) followed by the European standard EN15643 series on sustainability of construction works (CEN, 2012). Part 5 of the standard ISO 15686 defines whole life costing as an:

"economic assessment considering all agreed projected significant and relevant cost flows over a period of analysis expressed in monetary value. The projected costs are those needed to achieve defined levels of performance, including reliability, safety and availability." (ISO, 2008: 9)

Several guidelines have also been published over the years including:

- a Norwegian de facto standard for calculating life cycle costs in construction (Bjørberg et al., 1993);
- a comprehensive overview of different LCC models and engineering design issues within various business areas of application (Dhillon, 2010);
- a textbook for engineering students on economic analysis, estimation and management in product development of complex systems (Farr, 2011); and
- a practical guide to selecting materials from a whole life costing perspective (Caplehorn, 2012).

A ratio of 1:5:200 between construction costs, maintenance and operational costs, and business costs has frequently been quoted (Evans et al., 2004). As pointed out by Hughes et al. (2004) it is difficult if not outright impossible to reproduce this ratio. In general, historical analyses of building operations and maintenance costs are rare, but Bejrum et al. (1996) is a notable exception. A recent review of 45 peer-reviewed papers by Goh and Sun (2016) suggests that there is a renewed interest for LCC calculations, but much work still needs to be done towards extending LCC to include considerations for sustainability.

2.2 LCC and sustainability

As pointed out by Haapio (2008) examples that link life cycle costing, service life planning and environmental assessments are not very widespread. When it comes to the economic effects of sustainable construction through the use of LCC calculations, the government of California at Sustainable Building Task Force in 2003 conducted a study of the economy of green buildings (Kats et al., 2003). Data has been collected from 25 LEED certified office buildings and eight LEED certified schools located in the United States. Construction costs are compared with the costs of the same buildings, if they had been listed as conventional buildings. It is concluded that:

"In the most comprehensive analysis of the financial costs and benefits of green building conducted to date, this report finds that a minimal upfront investment of about 2 per cent of construction costs typically yields life cycle savings of over 10 times the initial investment. For example, an initial upfront investment of up to $100,000 to incorporate green building features into a $5 million project would result in a savings of at least $1 million over the life of the building, assumed conservatively to be 20 years." (Kats et al., 2003: 7)

A later study of 30 schools in USA examined the additional costs of building "green" and the effects on life cycle costs compared to traditional building (Kats, 2006). The increased costs of construction are less than 2 per cent and provide economic benefits that are 20 times greater. However, most gains will benefit society through better education, while only a small part of these gains in terms of e.g. reduced costs for consumption of energy, water and health insurance ends at the school. Nonetheless, these gains are four times higher than the additional costs.

In England, studies of "green office building" has demonstrated that the benefits of greater productivity and lower labour costs for the company amounts to six times the energy savings over a 20 years period (Edwards, 2006). Hence, there is considerable more to gain on productivity and health than on reduced energy costs.

Additional costs of building green can be reduced by choosing the right strategy at the planning and design stage (Syphers, 2003). In previous practice, the extra cost of new construction varied between 0-2.5 per cent for LEED Silver certification and up to 5-8.5 per cent for LEED Platinum certification. A study in Seattle – one of the leading municipalities on green buildings – documented a downward trend towards lower additional costs over time. In 2000 the additional costs of an LEED Silver certification varied between 4 per cent for large buildings and up to 6 per cent for small projects. In 2003 these costs for all projects was reduced to near zero per cent. It is therefore concluded that it is possible to build at normal costs and obtain a certificate by choosing the right strategy. An appropriate strategy includes careful programming of ambition, additional costs of design, interdisciplinary collaboration, early involvement of contractor and technical contractors, use of energy calculations and attention to daylight and good insulation.

2.3 LCC in Denmark – history and new trends

Life cycle costing has a long history in Denmark. The very first publication on life cycle costing or economic optimisation of insulation was issued by the national building research institute as its very first publication in 1949 (Becher, 1949). Over the years a number of publications on aspects of life cycle costing has been issued by the national building research institute among others on insulation of pipes (Becher and Engelsen, 1957), an SBi Direction on economic assessment of energy-saving measures (Johnsen and Andersen, 1982), an evaluation of ten demonstration projects on life cycle costing (Haugbølle and Henriksen, 2002), tables of service life times (Aagaard et. al., 2013) and the national calculation tool LCCbyg (Haugbølle et al., 2016).

To support the uptake and dissemination of life cycle costing in Denmark, a wide range of initiatives etc. have been taken for the past 20 years or more by many other actors in Danish construction. These include among others:

- the release of manuals and guidelines for designers and managers,
- development of ICT-based calculation tools,
- publication of reference books about service life times and depreciation tables for cooperative-housing and insurance,
- national standards for overall financial calculations, operating principles, and calculation of economic indicators,

- establishment of databases with key figures for the construction and operation of public housing, building defects and benchmarking of facility management, especially for office buildings, and
- collecting and evaluating experiences and lessons learned from national as well as international outlooks to for example England and the other Nordic countries.

Applying the principles of life cycle costing has for several years been mandatory in both social housing projects and governmental building projects. However, the approaches in the two separate sectors were quite different. While the social housing sector has since 1998 developed and applied a consecutive set of sector-specific tools, the government building agency effectively neglected its obligations to apply and disseminate knowledge on life cycle costing. This negligence, however, recently came to a sudden end when the agency was criticized in strong terms by the Danish National Audit Office and the Danish Public Accounts Committee. Since then, the government building agency has taken action on life cycle costing. These actions have been further fuelled by the recruitment of a new CEO, who came from a municipal building agency with a high profile on sustainability and life cycle costing.

In addition, three other recent trends have stimulated a wider use of life cycle costing in the built environment:

1. New governmental regulation on quality assurance, public-private partnerships and life cycle costing in public construction issued in 2013, which requires all public clients (including municipalities and counties) to apply life cycle costing in projects above certain thresholds.
2. The establishment in 2012 of the certification scheme DGNB adopted by the Green Building Council Denmark for sustainable buildings and urban areas in which economics have a very prominent position.
3. The new European procurement directive from 2014 that supports the use of total cost of ownership (TCO or life cycle costing) as an award criterion in competitive tendering rather than just lowest price.

2.4 LCC in DGNB Denmark

The concept of sustainability applied by the DGNB certification scheme addresses six criteria groups, which is further divided into approximately 50 individual criteria. The six criteria groups cover:

- environmental quality,
- economic quality,
- sociocultural and functional quality,
- technical quality,
- process quality, and
- site quality.

Each criteria and criteria group is scored according to predefined weights summing up to a total of 100 per cent. The criteria group on economic quality accounts for 22.5 per cent of the total score.

In the Danish version of the DGNB certification scheme, life cycle costing (LCC) is one of three criteria within the criteria group of economic quality. The other two criteria are flexibility and adaptability, and robustness. The LCC criteria accounts for 40 per cent of the score of economic quality, hence this one criteria alone accounts for 9.6 per cent of the total score in the Danish version of DGNB.

In order to ease the work with LCC calculations in certified projects and ensure compliance with the calculative assumptions, an LCC tool was developed specifically for DGNB certification by the national building research institute in cooperation with Green Building Council Denmark. The tool was developed as a spreadsheet solution based on Microsoft Excel.

3. METHODOLOGY

3.1 Action research approach

The methodology of this paper is based on an action research approach in which the authors have been actively engaged in developing and implementing the DGNB certification scheme in Denmark. The first author has been responsible for developing the spreadsheet tool for life cycle costing, executing educational activities and performing external third-party audits (conformity checks). The second author has been employed in Green Building Council Denmark since 2014 with the main responsibility of developing the DGNB guidelines and tools, planning and executing educational activities, managing the entire audit procedure, and undertaking promotional activities.

Action research as a concept was introduced by social psychologist Kurt Lewin (1946). He described action research as a spiral with each turn consisting of three stages: planning, action, and reflection on the results of the actions. In more current versions, this spiral has been extended to include other steps like problem formulation, research/study process, analysis and interpretation of results, and communication of results. Action research or participatory action research is an experimental type of research of interventions, development, and change in and of a practical situation. In action research, researchers work collaboratively with practitioners in the development of research questions, methodology, participatory processes and analysis to systematically implement and evaluate a change in practice. Participatory action research is not tied to any particular method, but can be seen as an empowering context where several methods may be included or even created as part of the research project (Launsø and Rieper, 2005).

3.2 Data material and analysis of data

The data material for this paper has been produced as part of the ongoing efforts of the DGNB certification scheme. This means that all data are gathered in a systematic manner from the same source.

The number of certified projects included in the study is rather small and therefore no advanced statistical tests have been applied in the analysis of the data. The number is small due to a deliberate highly selective approach in which only certified projects with the same overall characteristics were included. More projects could have been included but they were left out to ensure that they did not obfuscate the results due to differences in building types, time, version of certification manual etc. Further, pilot projects with somewhat different calculative assumptions were left out even if the projects could have been recalculated using revised assumptions.

In total, 10 building projects were included. All projects are office buildings constructed in 2015-16. They all follow the directions set out in the DGNB guideline NBK2014 for new office buildings, version 2014. The size of the projects spans from 1,500 m^2 to 16,000 m^2 with an average of some 7,000 m^2. All projects pass the threshold for being certified at the highest possible level (Gold, now labelled Platinum) with regard to the criteria for economic quality, but the projects do not necessarily achieve the same overall score. The study only includes data from final certifications of projects, while preliminary certifications are left out.

3.3 LCC assumptions by DGNB Denmark

The life cycle costs are calculated using the method of net present value (NPV). It should be noted though that only costs and not revenues are included. Doing LCC calculations require a number of assumptions that are decisive for the results. Hence, DK-GBC established a technical committee for each building type to discuss and inform the selection of appropriate general calculation assumptions with regard to the calculation period, discounting rate and price developments for different cost groups. Further, costs and price development rates are calculated as nominal costs. The general calculation assumptions are:

- Calculation period: 50 years.
- Year of calculation: year of obtaining DGNB certificate.
- Nominal discount rate (flat): 5.5 per cent.
- General price development: 2 per cent pro anno.
- Potable water and sewage price development: 3 per cent pro anno.
- Energy price development: 4 per cent pro anno.

The LCC calculations of DGNB include four main cost groups:

- Construction costs.
- Costs of maintenance and replacements.
- Supply costs.
- Cleaning costs.

Construction costs are calculated per m^2 gross floor area. Only 50 per cent of the area of basements is included to reflect the lower unit price of these areas. As construction and maintenance costs vary with the location of the project, these costs are normalised with a correction factor for location in the interval of 0.85-1.05 in line with what is customary in Denmark. The construction cost groups is based on the most widespread and well-known classification system named SfB, which has been in operation in Denmark since its development in Sweden in the 1950s (Byggecentrum, 1988). Only the first six main SfB groups are included, while costs for site, consultancy fees, furniture and equipment, VAT etc. are excluded:

- (1.) Substructure.
- (2.) Structure, primary elements.
- (3.) Completions.
- (4.) Applied finishes.
- (5.) Sanitation and HVAC services.

- (6.) Electrical services.

The calculation of costs of maintenance and replacement is done according to the following principles:

- The reference service life time of building components follows the official table of service life times provided by the national building research institute.
- A component is replaced when its projected life time expires.
- Replacement cost is assumed to be a constant percentage and calculated as 125 per cent of the initial cost to include the costs of both reacquiring a new component and replacing and disposing of the worn out component.
- Maintenance cost is set as a constant percentage for each building component, but varying from one building component to another.

The supply costs are calculated as follows:

- Amounts of water and sewage are calculated using the DGNB ENV2.2 water and sewage calculator.
- The amount of energy for heating as well as electricity consumption for building services is extracted from the Be15 calculations that are mandatory to do in order to demonstrate compliance with the building regulations.
- Photovoltaic production of electricity is not included.

The cleaning costs are calculated based on standard cost of cleaning per m^2 and with a standard frequency. They are calculated for three subgroups:

- Grounds (although not applicable for offices).
- Building, exterior.
- Building, interior – spaces/type of rooms.

4. RESULTS

The LCC calculations of recently DNGB certified office buildings in Denmark has provided a number of observations and lessons learned with regard to the main cost drivers. Based on the assumptions specified in the previous section, Figure 1 illustrates the relative distribution of net present value divided into the four main cost groups for office buildings.

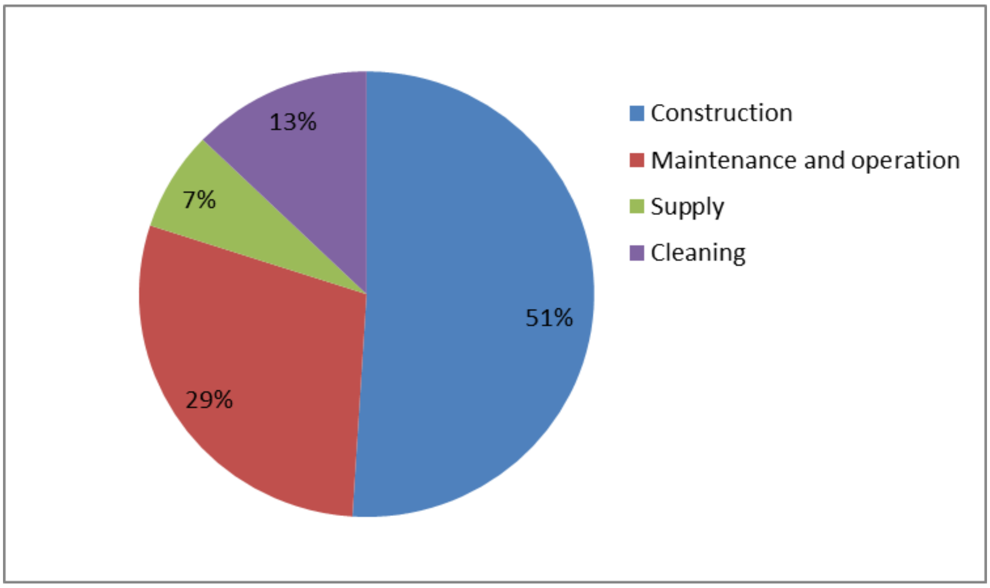

Figure 1: Distribution of main cost groups (per cent)

In a 50-year perspective the life cycle costs of each of the four main cost groups seem to be distributed with half of the NPV on construction costs, close to 1/3 of the NPV on maintenance and operational costs, and the remaining 1/5 of the NPV on supply and cleaning costs. The relative distribution of supply costs versus cleaning costs seems to be 1:2, meaning that cleaning costs are approximately twice as high as supply costs in total (water, sewage and energy including electricity consumption). Hence, construction costs seem to be of the same magnitude as maintenance and operational costs taken together. Business costs will surely outnumber both, but these costs are not included in the DGNB scheme.

The inventory of gross floor area, cleaning area etc. is essential as this is the denominator used in the calculations. In particular, special attention needs to be paid to the difference in costs associated with different types of space. On one hand e.g. parking areas and basements have comparably low construction costs and operational costs. On the other hand, other types of areas e.g. surgical theatres and laboratories with high intensity of installations have much higher costs than average with regard to both construction costs and operational costs. Hence, it seems prudent to differentiate between different types of spaces in the LCC calculations as the relative distribution between low, medium and high cost spaces will impact the resulting NPV.

Figure 2 shows the absolute net present values for each of the four main cost groups as well as the total sum in DKK/m^2. Figure 2 also shows the dispersion, in terms of the range of a set of data, as the difference between the largest and the smallest values for each of the four main cost groups as well as the total (marked with a black vertical line).

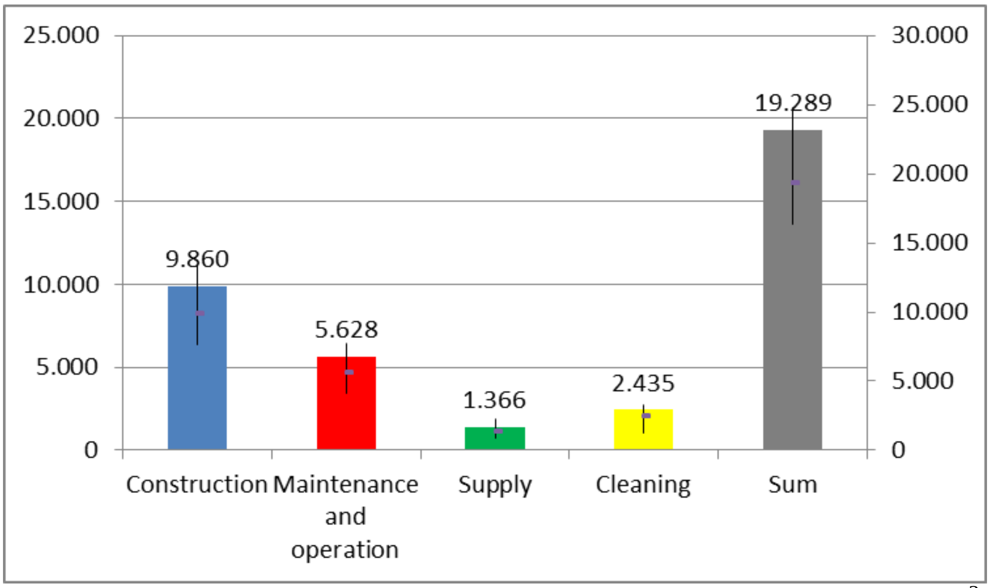

Figure 2: Distribution of main cost groups and the range of values (DKK/m^2)

Figure 3 shows the distribution of construction costs on the six main groups of the SfB classification, while Figure 4 shows the distribution of the maintenance and operation costs of the same six groups. Taken together, Figure 3 and Figure 4 indicate some notable observations. First, while the first three SfB groups (substructure, structure and completions) account for more than half of the construction costs, they only account for 1/3 of the maintenance and operation costs. Second, the maintenance and operation costs of applied finishes are twice the construction costs. Third, the last two SfB groups on technical installations (sanitation and HVAC services and electrical services) accounts for approximately 1/3 of the construction costs but make up half of the maintenance and operation costs.

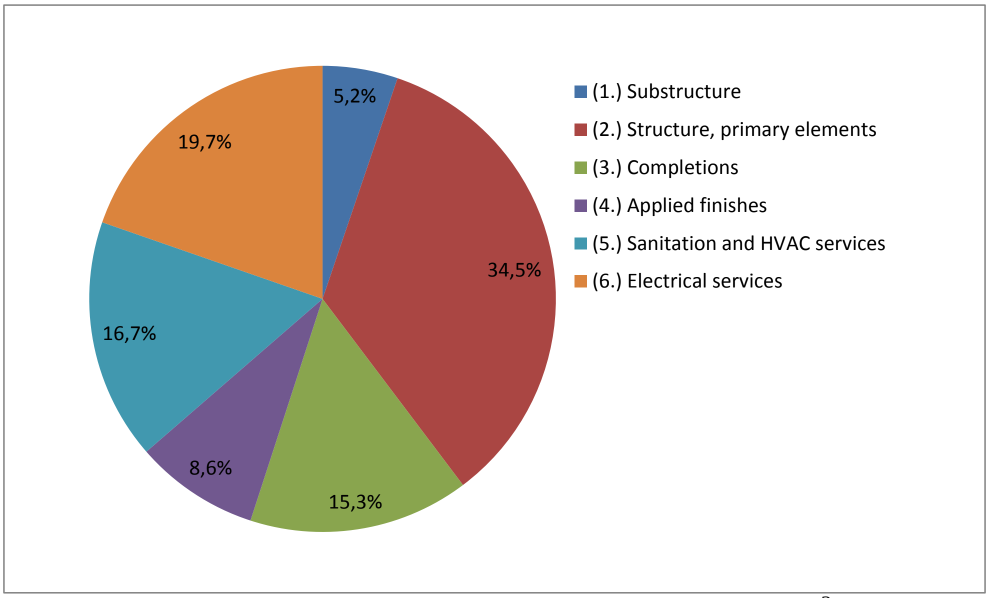

Figure 3: Distribution of construction costs (DKK/m^2)

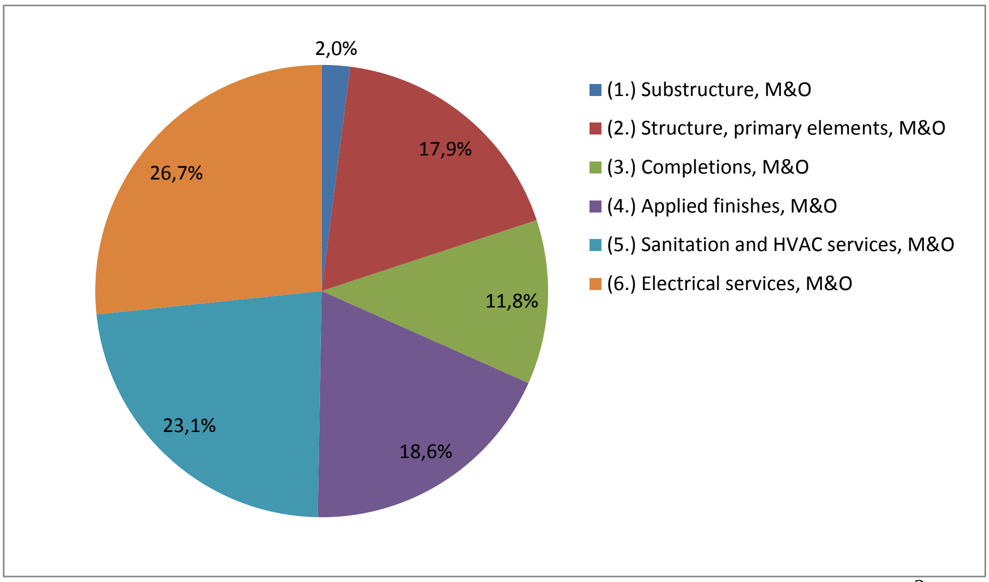

Figure 4: Distribution of maintenance and operation costs (DKK/m^2)

The analysis of the key performance indicators in Figure 3 and Figure 4 has demonstrated that certain construction cost drivers compared to maintenance and operation costs are more important. In particular, special attention should be paid to technical installations with their relatively short lifetime expectancy and high maintenance and operation costs. Similarly, applied finishes are driving maintenance and operation costs disproportionally compared to the construction costs. This phenomenon is even more pronounced when the cost of cleaning is added.

5. CONCLUSIONS

The preliminary results presented here indicate that construction costs cover half of the life cycle costs in a 50 year period, while maintenance and operation costs may cover close to one-third of the life cycle cost. The remaining one-fifth of the life cycle costs are divided at a ratio of some 2:1 between cleaning costs and supply costs for energy, water and electricity, which implies that cleaning costs are more important than energy costs. While Danish clients and consultants generally have a strong focus on energy optimisation, this paper would like to suggest a need to refocus the attention of building professionals towards cleaning.

While the certification scheme DGNB Denmark is now gathering many valuable insights and is sharing them with the DNGB consultants as well as the construction industry in general, there are still a range of areas that needs attention in the future. To mention one, evidence-based experiences on the building envelope – one of the most important parts of any building – are still in short supply with regard to comprehensive optimisations taking into account sun shading systems, cleaning of windows, heating and cooling, indoor climate issues etc.

As the numbers of certified projects are increasing rapidly the authors are looking forward in the near future to be able to report on new developments and to solidify key performance indicators, not only with regard to office buildings but also when it comes to other types of buildings.

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