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## **Building Commissioning: What can Denmark learn from the US experience?**

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### **Abstract**

*Building commissioning has been gaining momentum and awareness within the building industry as a comprehensive quality assurance process that can be used throughout the buildings life cycle to ensure that the needs and requirements the owner has for the building are met. Although building commissioning is gaining momentum it is still far away from being viewed as normal practice within the building industry. Of the countries that are the closest to succeeding in making building commissioning normal practice, USA is the clear leader. In countries where commissioning is taking its first steps or has not yet been used it would be wise to try to learn from the leading nations, how they have implemented commissioning to decrease the time it will take for commissioning to become normal practice. Since the USA is among the leading nations in implementing commissioning, there is a lot that can be learned from how that process has evolved and all the effort that has been put into research on building commissioning.*

*This article investigates how the commissioning process is undertaken at a leading commissioning providing consulting company in Denmark and presents a case study with a comparison between two shopping malls out of which one has not been through a commissioning process, while the other has. The benefits of commissioning are outlined and proposals for how the process can be improved in the Danish consulting company compared to the well established ASHRAE 0-2005 guideline. Finally the article discusses and concludes what the future steps for commissioning in a country like Denmark should be based on how commissioning has evolved in the US.*

**Keywords:** Building, Commissioning, Quality Assurance, Energy Reduction, Shopping Malls

## Introduction

Building commissioning can be described in a general way as a quality assurance process that ensures that a building and its technical systems meet the needs and requirements defined in the Owner's Project Requirements (OPR). The following points further describe what building commissioning involves (Grondzik, 2009, California Commissioning Collaborative, 2006, and Heinz & Casault, 2004):

- Enforces co-operation between participants of the building process.
- Encourages and documents communications between owner, designers, contractor and operation and maintenance (O&M) personnel.
- Documents all problems that contradict the OPR and their solutions in a structural way.
- A systematic quality assurance process which through test and verification ensures that the building meets the OPR.
- Ensures that O&M personnel are provided with needed training to be able to maintain the building at owner's intended performance level.
- A process that focuses on outcome first then what equipment is used to achieve the outcome.

The following points describes what building commissioning is not (Grondzik, 2009 and California Commissioning Collaborative, 2006):

- It is not a replacement for existing quality inspection process, but an addition to that process.
- It is not an additional phase to the existing building process phases - it runs parallel with the building process.
- It is not an isolated testing event of single equipment.
- It is not a testing, adjusting and balancing tool.

Commissioning, as it is defined today, is not a new term or concept. It can be said to have developed with increasing project complexity. Commissioning has been used for decades in ship building industries. One of the reasons it may have been easier to sell the idea that commissioning should be an essential part of the ship building process, is due to the high risk of life lost if systems or equipment fail. Therefore it is extremely important that no flaw is overlooked and the cost of commissioning is therefore quite small compared to the cost if a flaw is discovered in a production after it has been produced and complete productions have to be recalled. So if a ship passes a commissioning process it has been ensured that the equipment, systems and personal have successfully completed a thorough quality assurance process and the ship is ready to be used (California Commissioning Collaborative, 2006).

The building commissioning takes the same approach on new buildings as done on ships. It begins in the pre-design phase and goes through design, construction and occupancy and operation phase, and ensures through intensive quality assurance processes that requirements and needs defined by the owner are met. As the practice is today all participants of the building project can benefit from the commissioning process, but the main direct advantages of commissioning are still mainly beneficial for the owner of the building, the O&M personnel, and the occupants of the building.

The main advantages that building commissioning can bring for the owner of the building are (Heinz & Casault, 2004, California Commissioning Collaborative, 2006, and Mills, 2009):

- Owner's needs and requirements for the building are identified and documented in the OPR along with measurable acceptance criteria for each need and requirement.
- Encourages increased communication between all involved parties.
- Reduces the number of requests for information, change orders and conflicts which increases the likelihood that the construction is finished on time and within budget.
- Verifies that the building meets all the requirements defined in the OPR.
- Has been proven to be a cost effective quality assurance process.
- Reduces energy and operating costs by ensuring high performance level and efficiency of all commissioned building systems.
- Uses whole life cycle cost calculation as a decision tool throughout the building commissioning process.

This article investigates how the commissioning process is undertaken at a leading commissioning providing consulting company in Denmark and presents a case study with a comparison between two shopping malls out of which one has not been through a commissioning process, while the other has. The article starts by explaining the methodology used and presenting the company and the case. Then follows a literature review with a brief outline of the evolution of commissioning in the US and recent research from the US that provide evidence on the benefits of building commissioning particularly in relation to energy consumption. After that the results of the empirical study on the current practice in the Danish consulting company and of the case study of the two shopping malls are presented. Based on this proposals are put forward for how the process can be improved in the Danish consulting company compared to best practice according to respected US guidelines. Finally the article discuss what the future steps for commissioning in a country like Denmark should be based on how commissioning has evolved in the US and conclusions are made.

## **Methodology**

This research has been undertaken as part of a study in 2010 by the first author and supervised by the second author resulting in a master thesis (Ágústsson, 2010). The study has included literature reviews to identify relevant guidelines, case studies, surveys and other research to gain deeper knowledge about commissioning and collect information on the results commissioning has had on buildings in the US.

The empirical study was carried out in collaboration with a major Danish consulting engineering company, which is recognised as a leading national provider of building commissioning service. The consulting company was established as a one man firm by the founder – a Danish civil engineer - in 1957, but it expanded quickly and has for decades been on the three largest Danish consulting companies with activities around the world. In 2006 the company became part of another consulting group, which is one of the largest in Europe with an annual turnover of EUR 846,2 million (2008) and over 11.000 employees distributed on 150 offices around Europe and 20 offices in other parts of the world. In Denmark the company has approx. 1.300 employees. The company's building commissioning services have developed in Denmark from consulting on building O&M over the last 10 years and it is part of a department

for Facility Management consultancy. None of the company's offices in other countries are as experienced in building commissioning as the main office in Denmark.

The collaboration involved that the first author had a workplace in the company for three months and participated in project meetings and an on-site inspection as part of the company's building commissioning activities for customers as well as undertaking interviews and frequent informal talk with the company's commissioning experts. The projects included design of a new data centre, but the main project was a new shopping mall, which was starting up during this period, and the on-site inspection took place as part of the start up process. The purpose of this participatory research was to gain deeper understanding of how commissioning methodology is used in practice and analyse differences between the methodology according to US guidelines and the current practice in the Danish consulting company.

It was also arranged with the consulting company and one of its regular customers responsible for management of shopping malls, that a special case study was undertaken with a comparison of two similar shopping malls, where the main difference is that commissioning was used in one but not the other. The consulting company had done the building commissioning on one of the projects and there were data from a guarantee inspection five years after handover of the other project. The case study included comparison of the results (energy consumption and O&M costs) to analyse if and how the use of the commissioning process had an effect on the building process, performance of the building systems, and the building itself. The research mostly included document studies, and the results have been presented and discussed with commissioning experts from the company.

## **Literature Review**

Among the countries, where commissioning is being used within the building industry, it is closest to becoming normal practice in the US and therefore is it interesting to start by a brief look into how the evolution has been and what were the key decisions in implementing commissioning.

As stated earlier, commissioning is not a new concept and neither is building commissioning. Many of the components that make building commissioning, what it is today, have been around and used for some time all over the world. From the late 1960's and up to late 1970's environmental consciousness movements began their lobbyism to try to change the public's attitudes regarding energy consumption. The idea got more momentum with the energy crisis in the 1970's. The answer to this change of public's attitude towards energy consumption was answered with actions to reduce energy consumption by increasing the efficiency of lighting and heating/air conditioning (National Energy Management Institute, 2001).

From 1977 to 1993 was the first period where commissioning was used in relation to buildings more or less similar to the practice today. The first users and providers of building commissioning were mostly from the public sector. An early exception was The Walt Disney Company, who included commissioning in the design, construction and start up of Expo Center

in 1981. During these years the first commissioning committees were formed to make guidelines that would then later on be published.

In 1994 the US government issued an executive order stating that all federal buildings should take up and use commissioning. The next four years were used to conduct building commissioning demonstration projects and workshops to enlighten those involved with responsibility for management of buildings and those interested in how commissioning works and what benefits can be achieved. Due to professionals and the industry seeing the advantages of commissioning and the concept gaining momentum, commissioning articles began to be published regularly.

Since 1999 one of the biggest evolvment for commissioning is the inclusion of commissioning in LEED which makes it mandatory if a building wants to go for a LEED certification. Along with this have been continuous evolvments where more guidelines, commissioning associations, energy standards and white papers have been made and published (Portland Energy Conservation, Inc., 2010).

### ***Guidelines from the US***

A number of different guidelines on building commissioning have been published in the US. The development of guidelines includes a thorough review of the multitude of publications on commissioning and the building commissioning process, and from that information is incorporated in industry guidance and best practice suggestions. Well established guidelines include:

- ASHRAE Guideline 0-2005, The Commissioning Process. (ASHRAE, 2005).
- The Building Commissioning Guide (U.S. General Services Administration, 2005).
- California Commissioning Guide (California Commissioning Collaborative, 2006).
- Continuous Commissioning Guide Book (U.S. Department of Energy, 2002)

The ASHRAE Guideline 0-2005 is one of the most used guidelines in relation to building commissioning. It is written as a general guideline with no specific specialization in mind which adds to the versatility of the guide. Many other guidelines in the US have been based upon the ASHRAE Guideline 0-2005 such as the California Commissioning Guide. The ASHRAE guideline has also been used in published books such as the book Principles of Building Commissioning (Grondzik, 2009).

### ***Results of usage of commissioning in the US***

There have been a large number of studies and case studies of building commission in the US particularly with focus on the potential energy savings for instance PECE (1997), BESL (2007), Mills (2009), and a collection of case studies done by California Commissioning Collaborative (2010).

The most extensive study with respect to sample size was done by Mills (2009) for the California Energy Commission and Public Interest Energy Research (PIER), which investigated how much energy savings have been achieved with building commissioning, how cost effective building commissioning is and how important one-time non-energy benefits are to deciding if a building commissioning process is cost effective. The results from the initial research were published in

2004 and over the next 5 years the research continued with larger sample size and the accumulated results were published in 2009.

The study done by Mills (2009) contained 399 commissioning projects, 322 on existing buildings and 77 on new constructions, with total square meter size of 9.2 million square meter (m<sup>2</sup>) and the total cost for all the commissioning projects was \$4.3 million.

The key results of this study are presented in table 1 and as can be seen from these median values is that commissioning has had quite a positive impact on energy savings in buildings with relatively low cost which gives a reasonable payback time which backs up the idea that commissioning should be viewed as an investment instead of added cost. This study also confirmed what had been used as a rule of thumb for estimating commissioning cost for new constructions (0.5-1%) (U.S. Department of Energy, 2010).

*Insert table 1 here*

On top of these key results the study found, that the tendency is towards increased energy savings over time. However it should be noted that it is not always the experience that increased energy savings occur, but often the reason can be traced back to cut backs in O&M staff training or other maintenance oriented issues (Mills, 2009).

### ***Commissioning internationally***

The International Energy Agency carried out a major project on commissioning of buildings and HVAC systems for improved energy performance in a commission called Annex 40 work. The final report includes 27 case studies from 12 countries around the world (Visier, 2004).

Guidelines on building commissioning have been published in other countries than the US. Among the few in English language is a set of seven commissioning codes published by the Chartered Institute of Service Engineers in the UK covering different types of technical systems as well as commissioning management (CIBSE, 2003). A guidebook on lifecycle commissioning of buildings' energy efficiency and indoor climate have been published in Finland and in Finnish language (Pietiläinen, 2007).

### **Empirical results**

Before going into the results of the investigation of the current practice of building commissioning at the Danish consulting company the authors want to list the reasons why the ASHRAE Guideline 0-2005 was chosen to be the guide for the comparison. Early in the co-operation between the first author and the Danish consultant company they stated that they had used ASHRAE Guideline 0-2005 as a reference to form their initial practice. The first author researched the ASHRAE guideline and after going through it and seeing that still today that the ASHRAE guideline is used as it is and also used as a base for newer guidelines such as the California Commissioning Guideline it was found interesting to see how their process has developed compared to the ASHRAE guideline.

The investigation of the current practice of building commissioning at the Danish consulting company showed that their process is not as detailed as described in the ASHRAE Guideline 0-2005. That does not necessarily mean that it is not as good but it is missing a few steps throughout the process. The reason for this is not solely because of the way the company has developed their commissioning process but also due to how the market has responded to commissioning and what the customers expects of commissioning regardless of what consultants have to offer.

Building commissioning was first used by the consulting company in the year 2000 and since then they have been developing their process. The company has not been involved in many whole building commissioning projects but over the last 10 years they have gained a lot of experience in commissioning projects with main focus on HVAC systems.

Apart from the size of the project the steps that the company follows throughout the commissioning process are always the same just with different emphases from project to project. The steps that describe their commissioning process are:

- Interview the customer of what his expectations, needs and requirements are for the building systems that is going to be commissioned.
- Verify that the OPR (usually called building programme in Denmark) clearly states what the acceptance criteria for performance level and efficiency are for the building system.
- Scrutinise the construction documents regarding the specific building systems that will be commissioned and document all the consultants observations on issues that might not fulfil the OPR in a “commissioning report” (Issue log).
- The design team receives a copy of the commissioning report and is asked to review the issues and comment on what actions will be taken.
- The commissioning authority goes over the comments and responds were needed.
- Develop testing paradigms together with the contractors
- On site inspection when building systems are close to finished being installed.
- When the building system has been installed it is tested and the data gathered to verify if it fulfils the OPR.
- Analyze the test data to determine if the system fulfils the OPR.
- Update the commissioning report to show present status of issues that were identified.
- Send the customer a copy of the commissioning report and the test results for the building system.

### ***Comparison of two shopping malls***

The two shopping malls that were compared are placed in two provincial towns in Denmark. Shopping mall 1 opened in 2003 and did not go through a commissioning process, while shopping mall 2 opened in 2008 and did go through a commission process. Table 2 shows key information for both shopping malls:

*Insert table 2 here*

The fact that the same building code from 1995 was used for both shopping malls makes these two shopping malls comparable without having to take into consideration changes to energy standards that were included in the new building codes from 2008. The client (the company



responsible for management of the shopping malls) and the main contractor was also the same in both shopping malls and shopping mall 1 was used as a building reference for shopping mall 2. Therefore, a lot of uncertainties such as work procedures, building structure and contractors' experience could be eliminated.

In shopping mall 1 building commissioning was as mentioned not used and there have since the opening in 2003 been numerous problems with the building performance which have still not all been solved. This has affected the comfort and energy consumption of the building.

The consulting company served as commissioning authority throughout the building process for shopping mall 2 and the commissioning team consisted of experts who initially developed the OPR together with the client representatives. This was in the beginning the facilities director, later in the process it became the client's project managers and during the final stages it was the local O&M manager. The main focus of the commissioning process was to lower operational costs by decreasing energy consumption of the building and creating the basis for structured O&M.

The data available to analyze were monthly values for consumption of electricity, energy used for heating and hot water production and water consumption. Of these three measurements the commissioning process mainly addressed the electricity consumption and energy used for heating by increasing efficiency. Therefore the main focus of the analyses will be to identify if the commissioning process was successful in reducing electricity consumption, and energy used for heating and the water consumption will be used to determine whether the energy is used for heating or hot water production.

The period that will be analyzed is the time that both shopping malls have been in operation which is from May 2008 to April 2010. The research was done in May 2010.

### ***Electricity Consumption***

Electricity is the main energy source for most of the systems that are used in shopping malls and of those the following systems have high consumption: Light, cooling, hydraulic, and ventilation.

It is important that these systems are designed properly, installed correctly and tuned to achieve high efficiency as the main source for heat in stores in shopping malls is the lights in each store. All this extra heat requires added cooling and if these two systems are not carefully designed and tuned, it can increase the electricity consumption drastically. These two systems were among the issues that the commissioning team focused on in shopping mall 2.

Table 3 shows the electricity consumption per  $m^2$  and the difference between the consumption of the shopping malls for each year.

*Insert table 3 here*

As can be seen in table 3, shopping mall 2 used 40% less electricity per  $m^2$  for 2008 and 2009 and for the months that have passed of 2010 the difference is 54%. This significant difference between the shopping malls is probably not solely due to the fact that commissioning was used in

the building process of shopping mall 2. However, the difference is to some extent the success measure of the commissioning process to have identified and recommended specific care for:

- Cooling systems
- Automatic controls
- Hydraulic balancing
- Careful planning of lighting zones and lighting control in public areas
- Meetings with design engineer about whole life costing issues for ventilation and cooling
- O&M personnel were included in the commissioning process during the construction phase and because of that did know the system well before the opening.

There are also reasons that may have increased the electricity consumption in shopping mall 1 and therefore increased the difference between the shopping malls. Some of the reasons are:

- Problems with O&M providers.
- High turnover of O&M personnel.
- Limited focus on data analysing to identify upcoming problems and possible improvements.
- No specific O&M related focus on technical installations, HVAC, Cooling, Building Management Systems etc. during the building process have resulted in installations below average measured with an O&M scale.

#### ***Energy used for heating and hot water production***

Table 4 shows the energy used for heating and hot water production per m<sup>2</sup> and the difference between the consumption of the shopping malls for each year.

*Insert table 4 here*

Table 5 shows the yearly water consumption for both shopping malls per m<sup>2</sup> for the time period May 2008 to April 2010.

*Insert table 5 here*

The data available does not give a clear picture how the difference is because during the period from July to September in 2009 the meters in shopping mall 2 were probably not working as intended since the difference in consumption between July to September in 2008 and the same months in 2009 drops by 9950% to 481%. The person responsible for O&M for shopping mall 2 could not give any explanation for this difference.

The commissioning process in shopping mall 2 did not have any focus on decreasing water consumption for the shopping mall, so they are only presented here to show that water consumption is quite consistent between years in both shopping malls and the energy difference can therefore be assumed to be due to heating. Consumption for shopping mall 2 from May to December for 2008 and 2009 did only increase by 0.4% and the first 4 months of 2010 compared to 2009 has decreased by 8% and the story is similar for shopping mall 1, where consumption only increased by 6% from 2008 to 2009 and just 3% for 2010 compared to same months of 2009. Therefore it can be assumed that the difference between the two shopping malls in energy used for heating and hot water production is mainly due to difference in energy used for heating.

It should be clear now that that shopping mall 2 uses less energy per  $m^2$  compared to shopping mall 1, but is shopping mall 1 a bad example that would make most shopping malls look good in comparison? To answer this question the yearly consumption per  $m^2$  values for 2009 are compared to a normal curve for energy consumption for shopping malls in Denmark in 2005 (ELO-sekretariatet, 2010). The electricity consumption and energy used for heating for shopping mall 1 is between the 25% and 50% and the water consumption is below 10%. This shows that the energy consumption for electricity and heating is below mean values compared to the normal distribution curve for shopping malls in Denmark in 2005 and the water consumption is below the 10%. Even though the normal distribution curve is from 2005 this indicates that shopping mall 1 is far from being the worst example.

### ***Operational and maintenance costs***

Even though there might be factors that could have an effect on the total energy consumption of these shopping malls, good or bad, it should though be clear, that shopping mall 2 uses less energy per  $m^2$ . But is shopping mall 2 also less expensive in O&M of the building systems than shopping mall 1? To get a rough idea how these two shopping malls compare, the data on operational cost for building systems for both buildings will be analyzed since commissioning mainly affected the building systems in shopping mall 2.

The data that was available limited the possibilities to identify non-energy benefits in shopping mall 2 due to commissioning, but with the data available the O&M costs, excluding energy costs, for both shopping malls were analyzed to find out if there is a difference between them. The data that was available in both cases was from the first year in operation and up to April 2010. But the O&M cost data for shopping mall 2 in 2008 is missing several values, therefore it does only give meaning to compare 2009 and January to April of 2010.

The work that is included in the O&M building system cost data is all service and repair on building systems such as ventilation, cooling and Building Management Systems. Table 6 shows the values per  $m^2$  for both buildings for the period described earlier.

*Insert table 6 here*

As table 6 shows, the difference between the operational costs of the buildings is not great. Shopping mall 2 has 11% lower O&M costs per  $m^2$  in 2009, but for the period of 2010 included shopping mall 2 used 12% more than shopping mall 1. Due to the short period of a time available for comparison the data are not extensive enough to show trends in O&M costs and therefore is it hard to justify that one building has lower O&M costs than the other. However from the data available it seems that O&M costs per  $m^2$  for these two buildings might be quite similar. Since it can be expected that there are some spikes in O&M costs due to several reasons such as:

- Regular service of building system that is not annual.
- Work related to equipment changes e.g. changing filters.
- Service and repair due to unforeseeable situations.

For shopping mall 2 it can be seen as a positive result that O&M costs are similar, because it indicates that it is not more expensive to run and maintain a building systems that have a high performance level.

***Would commissioning have had positive effect on shopping mall 1?***

In 2008 it was five years since shopping mall 1 had been taken into operation and therefore it was time for the 5 year guarantee inspection. The same consulting company doing the commissioning on shopping mall 2 was hired to do the five year inspection of shopping mall 1. The results from the five year inspections showed a number of problems and a closer analysis revealed that a lot of these problems were either design flaws or poor methods of work by the contractors. This also shows that the quality assurance process used during the building process was far from being successful and the owner of the building did not have his needs and requirements fulfilled.

The five year inspection categorized the problems into three different categories:

- Construction: 118 issues
- HVAC: 62 issues
- Electricity: 32 issues

Of course it is not expected that the results from a five year inspection are zero issues but when the issues that were reported are reviewed, it shows that some of these issues could have been prevented, if commissioning had been used along with the normal quality assurance process as the following examples shows.

Construction issues:

- Screws between brackets and washer/rail in windows were galvanised instead of being stainless. This causes heavy corrosion between the screw, bracket and washer/rail.
- Joints of pipes from toilets were not according to standard which caused bad odour inside the building.

HVAC issues:

- 23 out of 62 issues concerned lack of documentation and one of the key benefits of commissioning is to ensure proper documentation.
- Drawings of HVAC systems were not completed, neither drawings from design phase nor drawings that have been updated to show the system as-built.

Electricity issues:

- Ground wires were found unconnected in the fuse box and the main fuse box was not delivered according to specification
- In general electrical and other outlets were not labelled

It is not guaranteed that a commissioning process would have identified all these issues but if the process is well developed and the members of the commissioning team are experienced, it is more likely that at least the biggest issues would have been identified. Problems such as lack of documentation, joint of pipes from bathrooms, and electrical and other outlets locations during the building process, are example of issues, which could have resulted in first cost savings, if commissioning had been used and discovered the problems up front. This would lower the payback time of the commissioning process and the cost of applying the necessary solution to fix an issue is always cheaper during construction than to apply the changes in operation phase. So

based on the issues identified in the five year inspection report it is clear, that shopping mall 1 would have gained a lot to have included a commissioning process throughout the building process.

### **Proposals for Improvements**

No process is perfect so there is always room for improvements, but as the process gets better the value of the improvement may become less visible. As mentioned earlier the commissioning process, that the Danish consulting company has developed is missing few steps compared to a typical commissioning process such as is recommended in ASHRAE Guideline 0-2005. To find possible improvements the commissioning process in the company was compared to ASHRAE Guideline 0-2005 and the improvements that are regarded to give the most value are mentioned below.

#### ***Clearer order and setup***

This includes:

- Use the internal network storing system more.
- Add the possibility for participants in the project to view and/or upload newer version of documents or drawings through a web site that would also update the internal network storing folder.

This improvement would not only improve the commissioning process but all projects where there are multiple participants since the newest version of all documents whether it is a drawing or a time schedule is always available at this specific website that is accessible by all relevant participants.

#### ***Improve documentation***

This includes:

- Consequent use of a commissioning plan that is updated throughout the building process according to section 5.2.4 in ASHRAE Guideline 0-2005.
- Publish commissioning reports after each phase and a final report after construction that summarises key commissioning activities and issues from the issue log according to 5.2.7 and 7.2.15 in ASHRAE Guideline 0-2005.
- More strict and standardised use of documents, commissioning plan, OPR, Basis of Design, Issue log, milestone reporting, plan for continuous commissioning etc. all with the focus that bureaucracy is minimised!
- Seek certification of the commissioning processes.

In the early stages of a project a document called commissioning plan should be prepared and it should be kept it up to date throughout the project. This will serve as a good overview tool for the commissioning authority and the commissioning team to see who is responsible for each activity. The company responded that such a plan is used in some projects but agreed that it should be used in all projects.

The company calls their issue log a commissioning report, but it is suggested that they change the name to issue log and start publishing actual commissioning reports after each phase and a final version at the end of the commissioning process. Publishing such reports after each phase gives a good overview of how the last phase progressed and whether it was in line with what was expected so that issues if necessary can be taken care of in next phase instead of realising at the end of the commissioning process, that some activity or other issue was not getting the expected results or needed attention.

***Increase the scope of the commissioning process***

This includes:

- More emphasises on ensuring O&M staff are capable of maintaining the performance level according to 7.2.3 in ASHRAE Guideline 0-2005.
- Persuade the customers to include more focus points, for example the building envelope.

High performance level and efficiency are not guaranteed and even though it is achieved at the beginning of operation, it needs to be sustained. To sustain the performance level, competent O&M staff is needed which is capable of maintaining the building system so the energy savings are sustained throughout the lifetime of the building. From the data from shopping mall 2 it can be seen that the systems are not very consistent from year to year and by putting more emphasises on ensuring O&M staffs capability to maintain the performance level, the benefits of the commissioning process are more likely to be long lasting.

To further develop their commissioning process without increasing its scope could be to examine what has worked in countries that are more experienced with commissioning in similar projects, in size and complexity and try to learn from their experience and improve their commissioning process to achieve even better results.

***Data gathering after commissioning***

This includes:

- Start gathering data on energy consumption and O&M costs of building systems that have been commissioned.

To start such data gathering data on building, that have been commissioned, serves mainly two purposes:

- To increase the knowledge that can be learned from previous projects.
- To be used as a benchmark of the success the company's commissioning process has achieved in its previous projects.

The data gathered on energy consumption and O&M costs can increase what can be learned of previous projects by seeing how solutions to problems develop over time. From that the solutions that did not last can be eliminated instead of being repeated with good intention, and solutions that resulted in long lasting benefits can be used with the evidence that they are likely to last. The results from such data gathering can then also be used by the company to see how their commissioning process is developing based on results and this evidence can then be used to show possible new customers what has been the results from previous commissioning projects.

But regardless of how or what route the company chooses to take to further develop their commissioning process, it would be wise to establish data gathering on their commissioning projects to be able to review how their recommended changes behave over time and in what direction the process is developing based on results from previous projects.

## **Discussion**

US is among the nations that are the closest to getting commissioning seen as normal practice due to the evolvement of commissioning from 1994 to 1998 where it was set in laws that all federal buildings should take up a commissioning program and future buildings should use commissioning from the beginning. Due to this legislation there has been a lot of effort put into making guidelines to further develop the commissioning process and there has been invested heavily in data gathering on commissioning projects and analysing of this data to publish what results can be expected of commissioning. It is clear that the results that have been achieved with use of commissioning in the building industry in the US are very positive and if the development keeps moving in that direction it will be a huge success for the commissioning process and next to guaranteed that commissioning will become part of the “normal” building process in US. The increasing momentum that LEED and other Green Building initiatives is gaining will push the development further in that direction

The research that have been conducted in the US with the purpose to measure the impact commissioning has had on buildings in close context to the financial aspects can be used as a reference for other countries to see what can be achieved with today’s knowledge and experience. There have not been any similar studies performed in Denmark or other European countries but with time that will hopefully change. Since such studies are quite important both as an “advertising” tool to have facts behind the possible results that are advertised and to see without doubt what effects commissioning has had on buildings and how the development is. Such studies can serve a similar purpose as regular benchmarking of buildings to identify in time if the development has gone of path.

The commissioning process in Denmark has over the years been allowed to develop without supervision from authorities or professional bodys. This might be fine, but it seems important to start doing research into what results the commissioning process is achieving. This is especially important due to the fact that there is no certification process for companies or employees offering commissioning service and therefore there is no guarantee that the results are overall positive. It is important that the organization that carry out such research is capable of being objective and has no financial connections to any of the stakeholders, since that would decrease the credibility of the results from the research. With these requirements it would be most suitable that a university or an independent institute would undertake such a research and work in co-operation with companies that are or have provided commissioning service in building projects.

To develop a guideline even though it is not from scratch takes a lot of time and is quite expensive. By developing international guidelines that could then later on become an ISO standard and each country could add additional rules if they feel needed could prevent slow development of commissioning in nations that are taking their first steps in usage of

commissioning. Also it would ensure that the development of the practice would be in the right direction from the beginning. When such an international guideline has been established it could be followed with a certification process similar to the ASHRAE certification process that would verify that commissioning providers are operating according to the guideline.

## **Conclusion**

Denmark is one of many countries where it can be said, that even though commissioning has been used for some years, it is still in its early stage due to number of projects and their size. To compare the development of commissioning in Denmark and its usage to the evolvement in the US it can be said that Denmark is reaching the stage that US experienced in the years 1990-1993. With further and stricter energy requirements in building standards building developers and owners will see that to meet these requirements, building commissioning is among the answers.

The research results from the US and the comparison of the two shopping malls in Denmark indicates that use of building commissioning during the building process is likely to reach considerable reductions in energy consumption. However, companies offering building commissioning services still have problems to convince building owners that by using commissioning value can be added to the building and O&M costs reduced. A possible solution to this would be data gathering of commissioning projects and analyze the data to have facts regarding the results commissioning has achieved.

To answer the question what Denmark can learn from the US experience, is really to get the ball moving in the direction of commissioning being seen as normal practice. To achieve this the government in co-operation with the industry have to take a stand with putting building commissioning on the agenda and start by setting requirements that at least certain public buildings of specific size or type shall use commissioning. The most important step after such a stand has been made, is to follow it up with demonstration projects and workshops as was done in the US from 1994 to 1998 to educate and enlighten future commissioning providers and users. Then hopefully the private sector will realize what commissioning has to offer and the demand for commissioning will increase.

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Table 1: Key results from the study by Mills (2009)

	Existing buildings	New constructions
Median whole building energy savings	16%	13%
Median normalized commissioning cost:	\$0.3/square foot (ft <sup>2</sup> ) (\$3.23/m <sup>2</sup> )	\$1.16/ft <sup>2</sup> (\$12.48/m <sup>2</sup> ) 0,4% of construction cost
Median cost savings	\$0.29/ft <sup>2</sup> /year (\$3.12/m <sup>2</sup> /year)	\$0.18/ft <sup>2</sup> /year (1.93/m <sup>2</sup> /year)
Payback time	1.1 year	4.2 years

Table 2. Key information for the two shopping malls

Shopping mall no.	1	1
Opening year	2003	2008
Size	85.022m <sup>2</sup>	56.363 m <sup>2</sup>
Stores	85	80
Café/restaurants	5	2
Year of building code	1995	1995

Table 3. Electricity consumption for the two shopping malls

Electricity consumption	2008 (kWh/m <sup>2</sup> )*	2009 (kWh/m <sup>2</sup> )	2010 (kWh/m <sup>2</sup> )**
Shopping mall 1	45,91	39,07	9,11
Shopping mall 2	27,73	23,31	4,19
Relative difference	40%	40%	54%

\* = Only the time period from May to December of 2008.

\*\* = Only the time period from January to April of 2010.

Table 4. Energy used for heating and hot water production for the two shopping malls

Energy used for heating and hot water production	2008 (kWh/m <sup>2</sup> )*	2009 (kWh/m <sup>2</sup> )	2010 (kWh/m <sup>2</sup> )**
Shopping mall 1	10,393	30,195	20,201
Shopping mall 2	11,879	19,775	11,743
Relative difference	-14%	35%	42%

\* = Only the time period from May to December of 2008.

\*\* = Only the time period from January to April of 2010.

Table 5. Water consumption for the two shopping malls

Water consumption p. m <sup>2</sup>	2008 (m <sup>3</sup> /m <sup>2</sup> )*	2009 (m <sup>3</sup> /m <sup>2</sup> )	2010 (m <sup>3</sup> /m <sup>2</sup> )**
Shopping mall 1	0,165	0,257	0,085
Shopping mall 2	0,091	0,129	0,035
Relative difference	44%	50%	59%

\* = Only the time period from May to December of 2008.

\*\* = Only the time period from January to April of 2010.

Table 6: O&M costs for both shopping malls

O&M costs p. m <sup>2</sup>	2009 (DKK/m <sup>2</sup> )	2010 (DKK/m <sup>2</sup> )*
Shopping mall 1	5,62	1,81
Shopping mall 2	5,01	2,03
Relative difference	11%	-12%

\* = Only the time period from January to April of 2010.