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COMMISSIONING TOOLS: A WAY TO MANAGE GROWING COMPLEXITY OF ENERGY SYSTEMS IN BUILDINGS

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Summary

Demands of building users regarding the environment are growing. We all request a comfortable and healthy indoor environment but we don't accept any more excessive use of natural resources and pollution of outdoor environment.

The heating ventilation and air conditioning industry seeks solution to fulfil these higher requirements. Many new products and systems are developed. We are clearly leaving the time of low efficiency stand alone products to enter the period of high efficiency integrated systems.
Moving from products to systems enable to develop more efficient and flexible solutions but leads to a higher level of complexity. The management of this complexity request new approaches, new skills, new tools. Commissioning is one of these new approaches.

The paper presents the results of annex 40, a research group set up within the Energy Conservation in Building and Community Systems program of the International Energy Agency to develop commissioning tools. The papers address 1) tools to manage the commissioning process 2) manual commissioning tools 3) use of building energy management system to assist in building commissioning 4) use of models to improve commissioning. Finally one presents a vision of future work necessary to enable an enhanced operation of existing and new buildings.

1 Introduction

The demands of building users regarding the environment are growing. We all request a comfortable and healthy indoor environment but we do not accept any more excessive use of natural resources and pollution of outdoor environment. The energy consumption and the energy costs should indeed be kept on a low level.

The heating, ventilation and air conditioning (HVAC) industry seeks solutions to fulfil these higher requirements. Many new products and systems are developed such as high efficiency generation systems using renewable energy sources, low energy cooling systems, natural ventilation systems and integrated control system. We are clearly leaving the time of low efficiency stand alone products and entering the period of high efficiency integrated systems.

Moving from simple products to large systems enables one to develop more efficient and flexible solutions, but leads to a higher level of complexity. Complexity for the building owner increases, who has to define more in details the Owner's Project Requirements (OPR). Complexity for the designer increases who has to design and define a full system on the basis of a growing number of attractive components. Complexity for the installer increases who has to install large systems which are all different, often innovative and have complex control and complex interactions. Complexity for the users increases who have access to more and more choices for the operation of the building.

The management of this complexity requires new approaches, new skills and new tools. Most of these were not available 20 years ago and are not yet taught at school.

Commissioning is one of the new approaches to manage the complexity of today's building and HVAC systems.

Commissioning is a quality assurance process for achieving a good system efficiency. It consists in clarifying building systems' performance required by the building owner, auditing actions of the players involved in the project in order to realize the performance and verifying that the systems enable proper operation and maintenance through the Functional Performance Testing.

The Commissioning is performed for the purpose of ensuring that building systems are designed, installed and functionally tested, and capable of being operated and maintained to meet with owner's project requirements from the viewpoints of environment, energy and facility usage. The commissioning begins in

the pre-design phase and it can be applied through the whole life of building including all phases, which are the pre-design, design, elaboration, construction and operation and occupancy phases

2 Annex 40 an international research project

The Energy Conservation in Buildings and Community System programme of the International Energy Agency supports has supported for years project to facilitate and accelerate the introduction of energy conservation, and environmentally sustainable technologies into healthy buildings and community systems.

The Annex 40 project : "Commissioning of Building HVAC Systems for Improved Energy Performance" lasted form 2001 to 2004 and aimed at developing, validating and documenting tools for commissioning of buildings and building services. [Visier 2002]

10 countries (France, Japan, Canada, Belgium, Switzerland, Sweden, USA, Germany, Norway, Finland) took part as full members, observers participated from 4 other countries (The Netherlands, Korea, China, Hungary).

The Annex was organized in 5 tasks according to the structure illustrated in Figure 1:

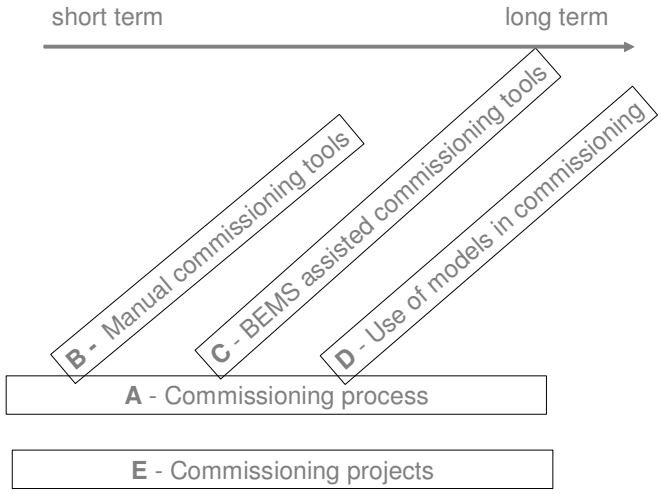

Figure 1 : Organisation of Annex 40

Two groups of deliverables will be publicly available in 2005 after a revision process managed by the executive committee of the AIE ECBCS.

The annex report, a synthesis of the annex work will enable the interested readers to get in about 150 pages an overview of the annex work.

The annex web site www.commissioning-hvac.org and CD will present in addition the detailed results of the annex: tools description, software presentation, commissioning site presentation…

One presents here a summary of the results achieved..

3 Tools to manage the commissioning process

3.1 Defining a commissioning plan

The key challenge to commission a building is to well manage the process. A central document for that purpose is the commissioning plan which defines the actions to be performed. The commissioning plan will be the key tool for the different players to understand what is meant by commissioning on a specific project, what amount of effort and money it will require and how it will be managed.

Three types of tools were developed or used within the annex to support the definition and application of the commissioning plan: standard model commissioning plans, checklist and matrix for quality control (see table 1)

Examples of standard model commissioning plans, check list and matrix for quality control are available on the final annex CD and web site. They are supported by description of their application to different projects.

3.2 Understanding the words used

Exchanges within the annex prove the absolute necessity to clarify the words used within the annex. A detailed multilingual glossary was developed and is available on the annex web site [Akashi 2004]. An interesting feature of the glossary is the possibility to establish directly hyperlinks from any document to the definitions inside the glossary.

Tool	description	Level of detail
Standard model commissioning plan (SMCP)	A typical description of commissioning actions all along a project To be used as a guideline to define the commissioning plan for a given project	Medium
Checklist	Minimum level of definition of a commissioning plan. Is specific to a given type of HVAC system	Low
Matrix for Quality Control (MQC)	An extended tool for the management of the quality of the whole construction project. Includes commissioning plan as well as other elements in a very structured way	High

Table 1: 3 tools to support the definition of commissioning plans

3.3 Selecting commissioning organisation

Three main different organizations for commissioning can be supposed and differentiated as follows.

In the first approach the commissioning tasks are performed by a commissioning authority which depends only on the building owner and which is fully independent of the other players in the construction process. This first approach insures that a new eye is looking at all aspects especially taking into account operation and maintenance issues. It gives a maximum security to the owner. The main disadvantages are the extra costs for this new activity and the risk of lower involvement of the other players in the quality aspects. Commissioning advocates consider that these costs lead to high savings and that the cost benefit ratio is very good.

This approach would only guarantee a commissioning as a series of processes to define and realize owner's project requirements from the program step to the post-acceptance step and hopefully through the lifecycle of a building, if a well certified commissioning authority is directly hired by the building owner.

In the second approach commissioning tasks are performed by the usual players: architects, engineers, installers… This lead to a commissioning process much more embedded in the day to day practice of these players. The challenge here is to well differentiate the commissioning tasks from the usual design, installation, testing and balancing tasks. It is also important to make the building owner confident that these tasks are really performed.

This confidence could be obtained if a third party certifies that the commissioning tasks are actually implemented. Different certification procedures can be used. For single family houses the certification can be a certification of the house itself. For larger project it is not manageable to certify the building a certification of the players seems to be an efficient way to get confidence.

The third approach is an intermediate one and consists in having most of the actions performed by the usual players and to have a commissioning authority in charge of verifying that they are effectively performed.

In a long term view the two first approaches could lead to very different perspectives. With the first approach commissioning will become a work in itself with commissioning specialists. So the success of people working in the commissioning field would rest on having their work recognized by the market. In the second approach commissioning could become a part of each party's work as a way to improve quality. Commissioning work will in this second approach disappear as such and will only become common practice.

Intense discussions are going on in different countries on the advantages and drawbacks of the different approaches. It is probably not possible to define which approach could be the best one. Depending of the national experiences, project size, owner wishes one approach or the other could be used.

4 Manual commissioning tools

Functional performance test are the core of commissioning. They are devoted to the detection of possible malfunctions and to their diagnosis. The malfunction may be due to : Selection or sizing mistake, Manufacturing fault or initial deterioration, Installation fault, Wrong tuning, Control failure, Abnormal conditions of use.

A standard format was defined to describe the Functional Testing Procedures and different procedures were developed and applied. The annex report describes a general approach to develop FPT procedures, a set of documented procedures and also includes a description of main sources of existing FPT.

5 The use of building energy management system to assist in building commissioning

Building energy management systems (BEMS) are seen by some players as a future key tool to enable an efficient commissioning. Nevertheless this dream can be achieved only if the BEMS system itself is properly commissioned.

The annex has realised an enquiry on the state of the art of BEMS commissioning in Japan, Canada, USA and France. The results presented in the report highlight the difficulties to be overcome [Yoshida 2004].

The annex has then clarified the different approaches for using BEMS to commission HVAC and energy systems [Vaezi 2004]

5.1 Methods for automatic commissioning

Two approaches to commissioning using the control system that have been considered as a function of BEMS in Annex 40 are passive testing and active testing. Passive tests involve using the control system to monitor and record sensor and actuator signals from energy systems operating under normal conditions. These tests are non-invasive in that they do not introduce any artificial disturbances into the systems. The most important aspects of passive testing are to properly select points to monitor and to apply appropriate data analysis methods. Active testing involves making artificial changes to the systems under control in order to interrogate behavior. Active tests can reveal more information about a controlled system in a shorter time period than passive tests, but can be more expensive to implement and disturb the controlled conditions.

Four main techniques were studied to implement automatic commissioning tools: model based, rule based, performance index based, logic tracer.

1. A model-based method involves comparing the measured performance of a component or a system with the predictions of the model describing it
2. A rule-based method transforms physical and logical prior (expert) knowledge of a system into a set of rules, e.g., IF/THEN. The rules should duplicate the same reasoning that an expert would use. Performance indices are calculated values or control values that quantify the performance of a control loop, component, or system
3. The performance index-based method involves comparing indices of similar controllers or components under specific conditions (outside air temperature, humidity, etc) or under a specific period (instantaneous, one hour, one week). Limits can be set to define a range of values corresponding to acceptable behavior and values that lie outside the range can indicate that a problem exists
4. The control logic tracer approach allows control algorithms to be visualized and understood by designers and operation managers. This understanding enables to diagnose faults by tracking down the causes when operation or control in a HVAC system fails

The annex has also addressed possible approaches for the implementation of the automation of commissioning. It includes a description of the different possible architectures and a discussion about communication issues, data bases, and user interfaces.

In addition to the description of these different techniques and the approach to follow to implement them in a real BEMS, the final report describes 8 automated tools tested during the annex

Technologies for carrying out automated commissioning are still in their infancy and very few tools are available for practitioners to use. However, the annex work has demonstrated that tools can be built using existing infrastructure at relatively low cost. In many cases, tools are software programs which can be implemented on most microprocessor-based platforms.

One obstacle to getting tools deployed on a wide scale is the difficultly in setting up communication with control products from different vendors. However, open protocols such as BACnet and LON are making this easier. Also, there is a cost in identifying the correct sensors and command signals on a control system, whereas this cost needs to be balanced against the benefits of the automated methods.

6 Use of models in Commissioning

Models are more and more widely used for the design of HVAC components and for the design of whole buildings and energy systems. The annex has developed approaches for the application of models for commissioning purposes.

6.1 Use of models at the component level

At the component levels two main uses of models were studied.

In the first use the model is embedded in the functional performance test. It enables to represent the "normal" behaviour of the system. The functional performance test then compares the actual and the normal behaviour. The model is used each time the functional performance test procedure is applied.

The steps necessary to get a good performance are the followings:

- Configure the models with manufacturer data and system design information
- Perform an active test under a specific set of conditions to check initial performance
- Analyse test result and fix possible problems
- If needed perform again an active test
- Recalibrate the model using the results of active test
- Monitor performance during on going operation.

In the second use the model is only used for the design of the functional performance test. A test usually includes a number of parameters (operating conditions, thresholds…) which shall be optimised. Models are used to simulate the behaviour of the system under different conditions. The test is then applied on the simulated data and their parameters are optimised.

The annex enabled to describe different architectures which can be applied to implement Functional Performance Test using models in real buildings. The architectures differ by the ways used to transfer information between models and measurements.

Finally, in order to facilitate the use of models in commissioning the annex has collected a model library and a toolbox of software routines which were developed to help implementing model based functional testing tools at the component level.

6.2 Use of models at the whole building level

A clear understanding of the different possible use of models at the whole building level for commissioning was achieved by the annex. Six categories were defined [Claridge 2004]

1) Models may be used early in the design process – to assist in "commissioning" the design. Typically, models configured for rapid use, such as TRNSYS Light, Enerwin, etc. are used for this purpose. They may or may not be used for energy simulation. This modelling is not used during the commissioning after construction.

2) Use in the standard commissioning of new buildings. A design simulation of the building may be used to predict heating cooling performance and the predictions may be compared with measured use –significant deviations then serve as clues to identify problems in the building. The design simulation should change the occupancy schedules if necessary to reflect the actual occupancy of the building. Simulation may also be used at this stage to refine and optimize control strategies. Relatively complex simulations are used for this purpose.

3) Design simulation for on-going commissioning. The same simulation developed in the design process may then be run at specified intervals, e.g. weekly, monthly, etc. and the model predictions are compared with the measured energy consumption. Deviations may serve to trigger an alarm when building performance degrades. Diagnostics for the probable causes of such deviations need to be developed. These simulations will probably be run off-line, but may be run on-line if the control system can accommodate the simulation.

4) Use of calibrated simulation for retro-commissioning. A rapidly calibrated simulation may be used as a diagnostic aid and to predict the savings that will be achieved from implementing proposed commissioning measures.

5) Calibrated simulation for on-going commissioning. The calibrated simulation developed in the retro-Cx process may then be run at specified intervals, e.g. weekly, monthly, etc. and the model predictions are compared with the measured energy consumption. Deviations may serve to trigger an alarm when building performance degrades. Diagnostics for the probable causes of such deviations need to be developed. These simulations may be run off-line or on-line if the control system can accommodate the simulation.

6) Use of simulation to evaluate new control code. Either the design simulation or a calibrated simulation may be used to test the energy impact of proposed changes in control code before implementation. This will generally be done off-line.

A series of papers illustrating each simulation application is available on the annex web site.

7 Commissioning projects

A collection of 27 demonstration sites has been used to assess the commissioning tools developed within the Annex. Each participating country has been involved in at least one commissioning project.

The objectives were :

- To test and to improve the procedure developed
- To demonstrate the advantage of commissioning

This mandatory involvement of all partners in real projects also enabled an in-depth interaction with potential users of the tools developed within the Annex.

Detailed descriptions of the different demonstration sites are available on the annex web site.

8 Future work needed

The tools developed within the annex.

The annex work has clearly shown the interest of commissioning as well at its today's limits.

A new annex is under preparation with three main objectives.

- Extending previously developed methods and tools to address advanced systems in low energy buildings
- Developing methodologies and tools to enable optimization of operation of buildings in use.
- Quantifying and improving the Costs and Benefit of Commissioning, including the persistence of benefits and the role of automated tools in reducing costs and improving persistence

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