REQUIREMENTS FOR COMMISSIONING HVAC SYSTEMS USING BEMS AND COMMISSIONING THE BEMS ITSELF BASED ON QUESTIONNAIRE SURVEYS

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Summary: In this paper the present status and requirements for commissioning of HVAC Systems using Building Energy Management Systems (BEMS) and commissioning the BEMS itself are investigated and summarized. The information presented is based on the results of the questionnaire and interview survey of experts which was carried out in four countries; Japan, the USA, France and Canada. This paper intends to clarify the requirements and future scope of the above issues by analyzing similarities and differences between the countries.

Keywords: commissioning, BEMS, HVAC, questionnaire survey

INTRODUCTION

This paper intends to investigate requirements for commissioning HVAC systems using BEMS and commissioning the BEMS itself based on questionnaire and interview survey of experts in four countries; Japan, the USA, France and Canada. In the present study BEMS is defined as a computerized system with a central work station performing not only energy management but also other functions such as automatic control of HVAC systems and their rational operation, etc. A BEMS would be a powerful system to assist commissioning work, but to make it possible, the BEMS itself must be well commissioned in advance of utilization. The key objective of this paper is to clarify the requirements for commissioning with BEMS in order to identify the types of improvements required for the commissioning process and the tools that should be developed.

SURVEY TO EXPERTS IN JAPAN AND THE USA

As a part of IEA Annex 40, questionnaire was prepared by the Japanese workgroup with the help of Annex 40 international members and translated into English for use in the US. This questionnaire was used to survey Japan and the US experts with experience of commissioning HVAC systems using BEMS and commissioning of the BEMS itself in 2002 and 2003 [1), 2)].

The number of Japanese respondents was 142 and that of the US was 10. Because there are too few US responses to get statistically meaningful results, the Japanese results are presented primarily and the US results are discussed when significant differences between two countries exist.

- **Document Preparation for Commissioning**

To perform commissioning documents such as design specifications, factory inspection reports of equipment, etc., are necessary. For each of the projects in which respondents were involved, the availability of each document was scored using four arbitrary levels as follows; existing prior to commissioning = 3, obtained during commissioning = 2, hard to obtain during commissioning = 1, and not provided = 0.

Using the average of all the scores, the availability of documents was evaluated by six arbitrary levels or ‘ranks’ as follows: rank 1: very good given for the average score between 3.0 and 2.75, rank 2: fairly good (2.75

~ 2.5), rank 3: good (2.5 ~ 2.25), rank 4: rather insufficient (2.25 ~ 2.0), rank 5: insufficient (2.0 ~ 1.5) and rank 6: poor (< 1.5). The results are shown in Table-1.

Table-1 Score for document preparation

document name	score by rank
hardware specifications of BEMS	1
special design requirements for BEMS	2
manufacturer's test reports of local BEMS equipments	5
design specifications of network and interface	3
documents explaining the interface between BEMS and general HVAC control system	4
manufacturer's test reports of central workstations	6
software specifications, lists of management points	2
requirements in commissioning BEMS	5
specifications and requirements for energy performance	1
lists of target values	5
parameters and alarm set-points in control	5
specifications for data acquisition	5
locations of sensors and actuators, diagrams of pipe and duct network	4
HVAC equipment specifications	3
drawings of control panels	2
electrical drawings of BEMS	4

We can see that that there is a lack of many types of essential documents, such as "requirements in commissioning BEMS", "lists of target values, parameters and alarm set-points in control", "specifications and requirements for energy performance", etc., and this makes adequate utilization of BEMS for commissioning difficult.

The results of the US surveys are similar except that the overall score 0.2 points lower, and the availability of "specifications and requirements for energy performance", "manufacturer's test reports" and "electrical drawings of BEMS" is worse than Japan. The reason is attributed to the fact that commissioning of BEMS is generally conducted by BEMS manufacturers in Japan, while in the US it is conducted by commissioning authorities for whom it is often difficult to obtain the documents. In addition the consistency of drawings is low in the US, that is, inconsistency ratio is 20% in Japan and 55% in the US.

- **Time Spent for Sub-Works in Commissioning**

Commissioning work can be divided into many sub-tasks. To understand how much time was spent for each sub-task would be useful in order to get knowledge to improve commissioning work. The results shown in a time ratio are; 53% for "test and adjustment", 18% for "collecting information and having meeting", 13% for "documentation", 9% for "waiting and time-wasting", 7% for "education and training of maintenance personnel". It can be said that tools to assist documentation work would be beneficial, and that providing the necessary documents and streamlining the commissioning process is needed to avoid wasting time.

The ratios for the US are similar to that of Japan, however, examining the content of the "testing and adjustment" work precisely by subdividing it we can find differences as shown in Table-2. That is, in the US more time is spent for "functional test" than Japan. This might be due to the fact that commissioning is relatively established in the US with functional testing as a major part of the process, but in Japan ordinary checks of work such as point-to-point check, and checking of installation and wiring are often taken to be a larger part of commissioning at present.

- **Utilization of Local DDC Systems and Operator Work Stations**

An investigation was made into how data taken from local DDC components and operator work stations (OWS) were used for commissioning. The level of local DDC data utilization to carry out comprehensive test is very high (93%). The breakdown of it is 59% for “real-time data”, 25% for “engineering parameters stored in DDC components”, and 15% for “trend data”. The figures for the US are similar. The utilization for the commissioning of HVAC components such as chillers is less (75%). But it is far less in the US (55%). The purposes for data usage are “control capability test” (47%), “Performance test” (29%), and “Alarming capability” (23%). We can see that the usage for performance test is unexpectedly low for both Japan and the US.

The data taken from OWS is also effectively used for comprehensive test (83%). The purposes of the data usage are “HVAC operation for commissioning” (46%), “commissioning of OWS itself” (34%) and “gathering data for commissioning” (21%). The OWS data usage in commissioning of heat source equipments is not high (74%), which is less in the US (55%).

In the case of local DDC, the percentages of load condition during commissioning are 40% for “actual load”, 32% for “no load”, and 27% for “artificial load”. However in the US no commissioning is conducted under no load condition, which is very different from Japan. The trend is almost the same in the case of OWS.

- **Total Evaluation**

We asked the respondents to evaluate the level of commissioning completed. The results are shown in Table-3. It can be seen that many respondents are not satisfied. The low values for "checking of installation and wiring" and "TAB" in the US supposedly mean that these works are not conducted with the responsibility of commissioning authorities.

The completion percentage in “training” of the US is much higher than that of Japan. This might be due to the different business practice for post-acceptance. That is, in Japan a few engineers provided by the HVAC system constructor generally stay to support maintenance staff in operational adjustment and tuning after construction, which is not common in the US. In spite of the low evaluation rates in each subtask quite many respondents (65%) think that commissioning of BEMS itself was completed well or agreeable. The reason might be due to the additional work done during the post-acceptance phase as explained. The major problems identified in projects having a disagreeable level of commissioning completion are “scheduling” (52%), “organization” (23%), “procedural” (15%), and “cost” (10%).

Many Japanese respondents (69%) think that simulation tools are useful for commissioning, while only 25% do in the US. The expected tools needed to be developed are “statistical analysis evaluation” (30%), “automatic commissioning report production” (23%), “static simulation” (19%), “dynamic simulation” (17%), and “training” (10%). In the US the expectation for “dynamic simulation” tool is low (5%), while the expectation for “training” tool is high (21%).

With respect to how commissioning should be conducted, such as how test and evaluate room air

Table-2 Time spent for subdivided work of testing and adjustment

	Japan	USA
Checking of installation and wiring	25%	15%
Calibration of sensors etc.	10%	10%
Point-to-point check	27%	9%
Inputting parameters	14%	8%
Functional test	25%	59%

Table-3 Estimated completion rate of commissioning

	Japan	USA
Checking of installation and wiring	20%	6%
Point-to-point check	20%	20%
TAB	16%	6%
Functional test	18%	9%
Documentation	15%	10%
Training	11%	50%

temperature distribution, 36% of respondents think that the documents describing how to do it are available and 44% (67% in USA) think they are unavailable. These results indicate that the targets in commissioning, i.e., the design intent regarding BEMS, are not clear enough to perform proper commissioning.

USER NEEDS SURVEY BY INTERVIEW IN FRANCE

In France 30 experts were interviewed to collect BEMS commissioning practices and user needs [3)]. The types of the experts are building owners, design engineers, BEMS manufacturers, etc. The results of the inquiry are sorted into the six aspects according to the main subjects reported by the different participants. The main aspects and requirements obtained are summarized as follows.

- **Organizational Problems and Requirements**

Due to the complexity of the organization in the field of building construction, the coordinator's function to check tasks is not well defined. Even on a well-organized construction site, the BEMS coordinator must search for information and the documents are not distributed to all the contractors involved. The time and the cost of testing are the important constraints.

Requirements: 1) to plan and coordinate checking tasks with the different contractors, 2) to make an official acceptance of the BEMS installation a few months after the end of the construction, And 3) to recognize at the design phase that the tuning and the optimization of the BEMS are usually achieved during the operating phase.

- **Awareness and Motivation**

The owner’s goals are to finish the construction in the prescribed time and cost. These objectives can be in contradiction with the validation tests that are usually expensive and long to achieve. The owner would not have to use the BEMS so he is less motivated by the requirements of the operating phase of the building.

Requirements: 1) to involve the future maintenance team or operator, the person with the greatest motivation to correctly carry out the phases of requirements, early on in the project of implementing a BEMS, 2) to develop the benchmarking, e.g. energy consumption, maintenance costs, of different types of buildings,and 3) to find financial or legislative incentives to motivate building owners to ask for a high quality of BEMS installation.

- **Skill and Expertise**

The skill and expertise of some designers or installers do not meet the level of qualification for designing and implementing BEMS. Some complex functions of the BEMS require experts to find and solve the incoherence of the design and the implementation. The level of skill of BEMS installers is rarely stated in the book of specifications.

Requirements: 1) to adapt contractors payments according to their expertise and the quality of their approaches, 2) to define standard checking and tuning procedures, 3) to define a quality-label that helps to assess the expertise of BEMS designers or installers, and 4) to develop training courses for designing, implementing, checking and tuning BEMS.

- **Legal Aspect**

The contractual situation concerning BEMS installation and checking and the levels of responsibility is not well defined. The designer acts as an adviser and is not responsible of BEMS problems. The installers are often

in the front line when problems happen.

Requirements: 1) responsibilities of the designers, the installers and the BEMS suppliers should be defined according to the type of project, and 2) an external expert should be able to arbitrate in case of conflict.

- **Technical Aspects**

The methods to check the BEMS inputs/outputs and functions are not specified. The sensor calibration is usually made with help of consistency tests but the methods of calibration accepted by all do not exist. There is a demand for tools and data to estimate the performances. The difference of vocabulary between industry and customers leads to a significant gap in the definition of needs and a difficulty in communication between actors.

Requirements: 1) to define BEMS inputs/outputs checking and calibration methods accepted by all and economically feasible, 2) to simplify the implementation phase of BEMS with configuration tools open to all users, 3) to implement easy to handle products for automatic self-checking, self-tuning and self-configurable tools, 4) to provide an implementation mode in the BEMS, 5) to define indicators of performance with reference values that can be applied to the BEMS, and 6) to define a standard vocabulary to describe systems and functions of the BEMS.

- **Documentation**

The book of specifications does not correctly present the future user's requirements. It is often too general, fragmented, or on the contrary too rich in detail and doesn't take account of all phases of a project. It often does not include all documents needed and does not mention about the costing of checking, tuning and configuration. The documents presented at the end of the project are usually not complete and of low quality.

Requirements: 1) to define the book of specifications according to the needs of users, the budget of the project and the needs for checking, 2) to provide functional analysis book in which needs are clearly explained, 3) to carry out the validation of the functional analysis book by a third party, 4) to provide clear, standard and well documented checking and tuning sheets, and 5) to define clearly in the book of specification what should be the content of the documentation presented at the end of the BEMS project.

REVIEW OF COMMISSIONING PROCESS OF CANADA

An extensive survey was carried out to investigate present status and needs in commissioning of HVAC systems in Canada [4)]. In the present report some important results related to commissioning using BEMS and BEMS itself are taken out from the report. The study consists of two approaches. Phase I was done through a literature survey and a targeted survey combining a questionnaire and interview. The interviewees included 8 commissioning practitioners, 4 representatives of controls companies or contractors, 3 public sector building owners who specify commissioning, 2 private sector building owners and 2 energy service companies; in total 19 experts. Phase II concentrated on the commissioning of building control systems. Interviews were carried out to four controls companies (two Canadian controls companies and two Canadian subsidiaries of international controls companies) and one controls expert representing a building owner.

- **Results of Phase I Survey**

At present the predominant application of commissioning is limited mainly to the acceptance phase of the building. Controls company respondents reported practicing this type of commissioning on every project and found less significant barriers to the adoption of commissioning. Lack of tools, time constraints, and lack of expertise were perceived to be the least significant barriers to the adoption of commissioning.

Client perceptions of value versus cost for the commissioning process are key barriers to the adoption of comprehensive commissioning. Automated tools aimed at functional testing, during the acceptance phase, would target a large existing commissioning market and automated tools targeted to comprehensive commissioning would potentially help to increase penetration of practices that to date have limited market acceptance.

- **Results of Phase II Survey**

Since commissioning of controls is crucial to ensure that the building's thermal comfort systems successfully meet the design objectives, five controls experts were interviewed to profile roles, procedures and trends in the commissioning of control systems and the HVAC equipment controlled by them.

➢ **Key Roles**

The primary responsibility for commissioning of control systems on most projects are the controls contractors. Less frequently, there are projects which have a separate commissioning authority. Even in these cases, the controls contractor usually does most of the testing and exercising of the system. The controls contractors are typically key players in the commissioning of major components of HVAC equipment, such as chillers, air-handling units and chilled water systems. The reason for this is that control systems are used in large buildings to commission HVAC equipment and systems. Typically, the controls contractors provide technicians to be present to operate the control system to facilitate this work, and on some projects take primary responsibility for these tasks.

➢ **HVAC and BEMS Commissioning in New Construction**

Commissioning procedures for BEMS are well-established and in wide use and there is a trend towards greater use of automation in the commissioning process. Controls contractors indicated they usually develop a commissioning plan for their equipment. Tasks such as wiring checks and point-by-point testing of actuators and sensors are conducted during the construction phase. The central operating console of the BEMS is often one of the last pieces of equipment to arrive on-site, mainly because of concerns about the safety of the computer. Most controls commissioning tasks are therefore performed before the central operating console is present on site, often with a laptop computer. All BEMS manufacturers incorporate some diagnostic capabilities in their equipment. Survey respondents indicated that fault diagnostic capabilities are options on their systems. International contacts indicated that systems capable of diagnosing the causes of abnormal behavior in HVAC components, as envisioned in IEA Annex 34, are still under development and not yet on the market.

➢ **HVAC and BEMS Commissioning in Existing Buildings**

Continuous commissioning is not common overall, but is practiced by controls contractors in the context of service contracts, in order to demonstrate compliance with energy performance criteria or comfort requirements specified in the contract. To meet these needs, controls firms increasingly make use of the data monitoring, trending, and reporting capabilities of BEMS, as well as the capability to access BEMS-monitored data remotely.

➢ **Implications for Commissioning Tool Development**

Controls manufacturers and their contractors will be important stakeholders and, potentially, key collaborators in the development of advanced commissioning tools. Most controls respondents expressed interest in collaborating on the development of commissioning tools that will work with their systems. Because of the timing of the arrival of the central operating system relative to BEMS commissioning, automated tools for initial commissioning must be capable of running stand-alone on a laptop computer. For retro-commissioning or on-going commissioning, these tools may run on the central BEMS computer. Some BEMS manufacturers have developed fault diagnostic capabilities as options for their control systems. The sophistication of these options varies and some of the systems are not yet commercial products, but BEMS interviewees indicated that their companies are intent on further development.

SUMMARY OF FOUR COUNTRIES RESULTS [1)]

The followings are the summary of the questionnaire and interview survey results carried out in four countries.

- **JAPAN**

One of the most common issues identified by respondents in Japan was that, in spite of the tools already available, too much data was required for configuration before they could be used. This was viewed as one of the main barriers preventing practitioners from starting to use commissioning tools. Also, commissioning and testing features that were already built into the control system were seen as being too complicated and not easy to use. Insufficient documentation and training was also highlighted as a problem in getting practitioners to use new technology more widely. Respondents in Japan also emphasized the importance of making it easier to handle trend data, set-up databases, and perform analyses. A lack of standardization with regard to point names, data access, and visualization was identified as an important problem.

- **USA**

For the projects selected, respondents indicated that the most difficult documents to obtain to assist them in the commissioning process were the factory inspection documents from the control system manufacturer. When asked to estimate work percentages for commissioning steps, about 55% fell into categories of “Collecting information” and “Testing and adjusting work”. There was, on average, more time spent on “Waiting or time wasting” then there was spent on “Education and training of maintenance personnel”. All respondents said they used data for comprehensive functional testing at the local controller level. Most said they recorded the “Real time data taken from components” and/or from “Engineering parameters stored in components”. Asked whether a simulation tool would be effective for testing the control system, only one respondent indicated an interest. Two survey questions asked about training for operating personnel. In both instances, the answers indicated that less time and effort is given to training as part of the commissioning process than other steps.

- **FRANCE**

There was demand for the control system to be better utilized in the commissioning process. Several issues were identified that could be improved to make commissioning more effective: organization (complexity of the organization), awareness and motivation (budget and time constraints), skill and expertise (division of the tasks and the systematic use of sub-contractors), legal aspect (contractual situation concerning installation checking is not well defined), technical aspects and documentation (methods to check the control system are not specified). Taking into account the constraints of the different participants in the commissioning process is an important issue.

It is important to define standard design documents (functional analysis), procedures for checking, calibrating and tuning, methods and tools to assess functional performance, automatic or semi-automatic embedded functions to help in commissioning (self-checking, self-tuning, self-configuring), and benchmarking procedures or tools.

- **CANADA**

Commissioning tools currently in use in Canada are limited to document templates intended for the construction and acceptance phases of projects. Automatic tools were almost non-existent or were in early stages of research. The responses to the questionnaire indicated that a demand does exist for (automated) tools to assist

commissioning but that there are barriers to their adoption. The responses indicated certain features that a commissioning tool should have in order to be beneficial. In particular, commissioning tools should be able to demonstrably reduce costs and reduce the need for technical expertise on site. Tools should also automate parts of the testing process that are most labor intensive and repetitive. Furthermore, benefits of tools need to be easily quantifiable to encourage adoption.

CONCLUSIONS

In this paper, the present status and requirements in commissioning of HVAC Systems using BEMS and BEMS itself are investigated based on the results of questionnaire and interview survey to experts carried out in four countries: Japan, the USA, France and Canada. The level of commissioning and its penetration into real projects is quite different among the four countries, however, many common aspects can be found as reported. We can see: the availability of essential documents required for commissioning is very low and cooperation between the parties involved in commissioning is not well organized, and responsibilities are not sufficiently clear in most countries. The application of automated tools for commissioning using BEMS is still in an early stage but the need is high and the challenge for the development is continued in many countries. The benefit of the tools should be demonstrated in real projects in order to enhance the progress.

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REFERENCES

1) IEA/ECBCS Annex 40 “Commissioning of Building HVAC Systems for Improved Energy Performance”, Final Report, 2004 (to be published)
2) **Harunori Yoshida**; Using the Building Control system in Commissioning – Needs and Examples from Japan, Seminar 58 Automated Commissioning Tools, ASHRAE winter meeting 2004.
3) **H. Vaezi-Nejad, M. Jandon, J.C. Visier, EDF: B. Viaud, B. Clémençon**; Enquiry on BEMS Commissioning Practices and User Needs in France, Annex 40 working paper, 2001
4) Marbek Resource Consultants Ltd., Review of commissioning processes and tools, July 2001