Commissioning Process for Realization of Energy Efficient Building

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Abstract

The author had participated IEA/ECBCS Annex projects since 1987, starting from Annex 16 for BEMS, ending at Annex 40 for Commissioning. I used to recognize how this line of continual set-up of subjects to optimize HVAC design and maintenance through system simulation, BEMS measurements, fault detection and diagnosis and building optimization technologies, which led the way to building commissioning, had been well designed just as by god's hand. The author, being involved in volunteer works of promoting commissioning process in Japan from both the academic as well as practical points of view, is convinced that life-cycle commissioning idea may be the only way to recover professional technologies as well as ethics with the HVAC engineering for energy conservation and CO_2 reduction, the percentage of which is too often told only in the political sense without any firm technical belief and readiness for a future life.

The author review building commissioning concept along with some comments on BEMS and BOFD relating to commissioning, and then looks into the bottleneck for optimum procedure during building production and maintenance, together with an actual commissioning example.

1. INTRODUCTION

Since 1987 at Annex 16 of IEA/ECBCS, which was the first ECBCS/Annex that Japan had ever participated, the author had worked for several Annexes before he withdrew from involvement in any new Annexes after Annex 40. The BEMS (Building and Energy Management System), or the BACS (Building Automation and Control Systems) in the ISO definition, was the subject of Annex 16 research to prepare users' guidance for BEMS introduction. Annex 17 was used to be held together with Annex 16 at the same meeting site for which Japan could participate as an observer, when the author was made known that the dynamic HVAC simulation was one of the forefront technologies among HVAC engineering topics.

Shortly before that instant I had got touched with HVACSIM$^+$, the US/NBS born superior dynamic simulation program in the public domain through the late Dr. Tamami Kusuda and was to begin study with my students how to use it. BEMS and dynamic simulation became two principal keywords for me, which followed consequent participation to Annex25 'Building Optimization, Fault Detection and Diagnosis', with Dr. R.Kohonen as the operating agent, then Annex40 'Commissioning of Building HVAC Systems for Improved Energy Performance', with Dr. J.C.Visier as the operating agent. In parallel with these activities ISO/ TC205/WG3 'Building Control Design' for the 'Building Environmental Design' started. Standardization efforts of BACS hardware, functions, protocols have been done and BACS application and project implementation/integration parts which involves commissioning are now on the way for standards. As the BEMS, or BACS, is important not only for building maintenance but also for design of controls, measurement, optimization and BOFD analyses, the commissioning is also not only for initial commissioning process but for operation and maintenance in the meaning of continuous commissioning. Presentation shall then begin with the commissioning concept and then the latest project of my involvement.

2. COMMISSIONING

2.1 Commissioning Concept

It is doubtless that the commissioning, to be abbreviated as Cx hereafter, is a key concept to realize energy-efficienct building systems. What do you imagine from the term of Cx? Some may think of commission of terror activities, such as 9/11 commission report, others may identify it as testing, measuring, adjusting and balancing before handover, such as traditionally having been defined in U.K., and other few people will claim that, according to ASHRAE Guideline 0-2005, Cx means the initial Cx process for new buildings, that is, a quality-focused process for enhancing the delivery of a project, the process focuses upon verifying and documenting that the facility and all of its systems and assembles are planned, designed, installed, tested, operated, and maintained to meet the OPR (owner's project requirements). In Japan, SHASE Cx guideline for building services systems issued in 2005 adopted more global definition for Cx, the concept of which was introduced into Annex 40 final report with the following explanation.

Cx is performed under the supervision of a qualified CA for the purpose of ensuring that building systems are designed, installed and functionally tested, and are capable of being operated and maintained to meet OPR from viewpoints of environment, energy and facility usage. These viewpoints mean to maintain the indoor environment in healthy and comfortable conditions, to minimize the amount of energy consumed and discharged, to conserve the urban /global environment, to keep maintainability of the building systems and to give a long life to the building systems.

Thus, building Cx is closely connected to the energy conservation and global environment issue to minimize CO_2 emission during building construction and maintenance over lifelong.

2.2 Life –cycle Commissioning Process

Cx process is defined for production stage that includes program, design, construction, TAB and performance testing of the system before handover. However, performance of HVAC is closely related to seasonal conditions, so that it demands whole season Cx in addition, whereas in many cases an optimal state can not always be achieved at the end of the post-acceptance step due to changing occupancy, unskillful O&M (operating and maintenance engineers), try-and-error tuning of control parameters, etc.

In this way, each building shall be continually commissioned during operation stage in order to achieve optimal operating conditions, no matter whether it was previously commissioned at the construction stage by the initial Cx process or not. A life-cycle Cx, or a continuous Cx, is thus defined including Cx at operation stage, where O&Ms shall take an important role by being included in a Cx cycles as on-going Cx process.

The initial Cx process as well as various kind of Cx process that shall ultimate in life-cicle Cx are classified as graphically shown in Figure 1.

One may ask why the initial Cx is necessary, if anyway Cx at operation stage is necessary to obtain maximum performance of the system. The answering points are;

1) If a system was not designed in energy efficient and/or environment friendly way, the innate system performance can never be graded up only by operation and control efforts.

2) In many cases the design contents are not sufficiently developed before bidding so that any re-design and other modification during construction phase may give a chance to devaluate quality rather than grade up.

3) Building owners usually request contractors to complete works within a period as short as possible, which naturally results in poor TAB process with none of building owner's recognition how grave consequences will result later in high operation cost and poor environment.

4) Usually non-commissioned system has poor control design, especially without clear view for year-round environmental quality and very often with high energy cost.

2.2.1 Initial Commissioning Process

Initial Cx process basically applies to new construction but a large scaled retrofit project due owner's decision after retro-commissioning or continuous commissioning will follow the similar procedures. In order for the process to be really successful, it shall begin with program phase to define expected year 'round energy and environment performance, CO_2 emission and sustainability under the constraints of cost and construction schedule in OPR. Without doubt cost factor is fundamental and defines the level

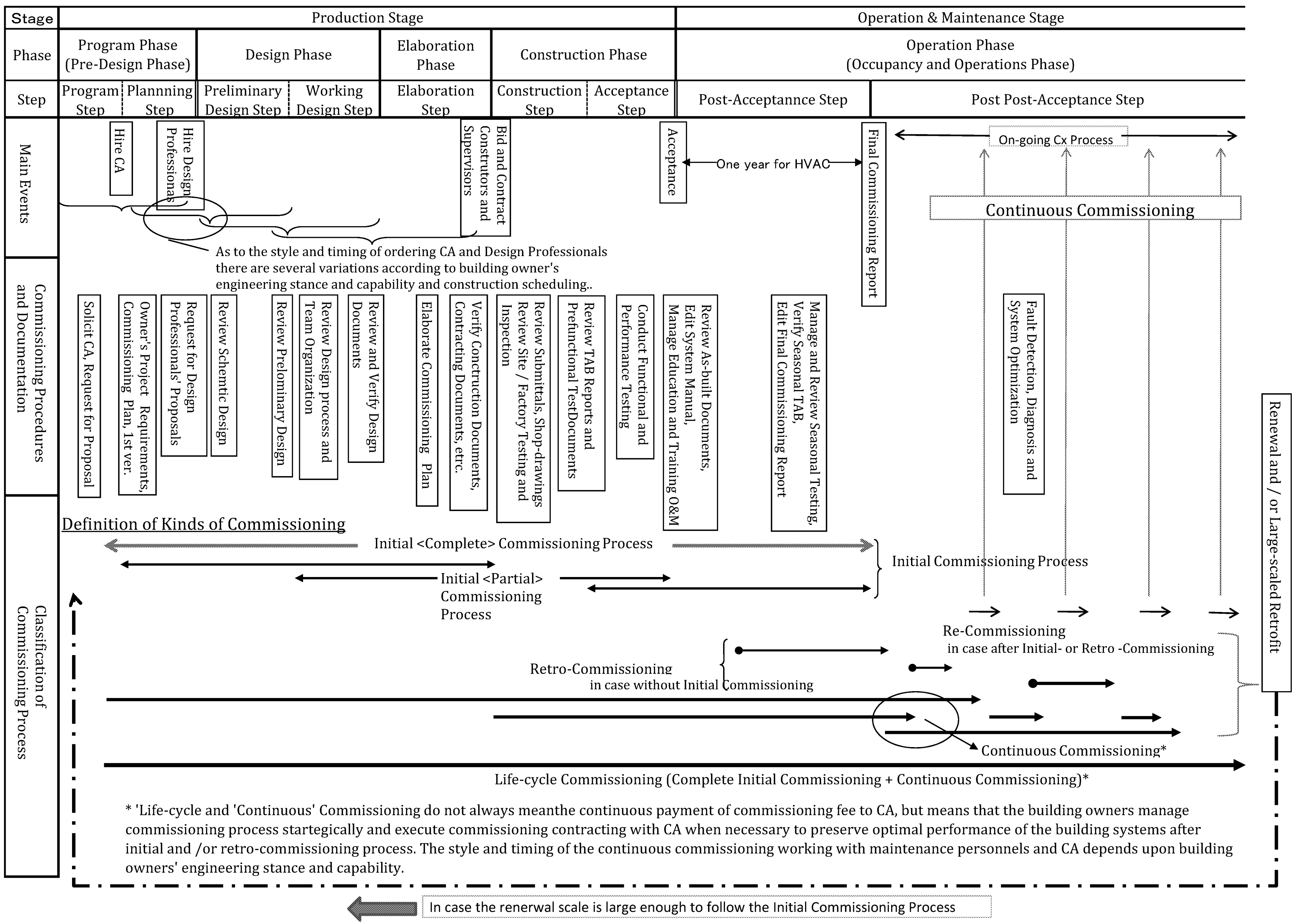

Figure 1. Structure of Life-cycle Commissioning Process

of quality, so that the cost per performance of applying initial Cx process depends upon how the owner can hire qualified and experienced CA (Cx authority, a manager of the Cx project concerned), who could manage the process to define OPR and Cx plan, review and check not only designer's concept but also actual skill and correctness of their drawings and engineering procedure with the help of assisting CEs (Cx engineers). Here, CA and CE shall be qualified by a certain authorized body and independent from the project concerned. CE works under the CA in his professional field and most experienced phases / steps of the project.

If well commissioned and fully documented construction documents with Cx specifications are transferred to contractors and construction supervisor, the construction phase Cx may be rather easier, if the construction supervisor who is hired separately by the building owner carries out his duty properly. In other case, as when Cx process begins at the stage of construction, CA must work on documentation for program phase and design phase as post-fact, because Cx needs OPR as a principle to execute the process, when, in order not to raise any additional cost, he will be forced to follow the designer's concept and just point out design faults but not any basic concept. Then CA's jobs during construction phase will be limited just to check and review of TAB and insufficient functional performance testing at acceptance step, which looks like the conventional concept of Cx in U.K.

2.2.2 Commissioning during Operation Phase

When initial Cx was exactly applied, continued Cx until one year after acceptance is included in the initial Cx's scope of work. And yet, because a system definitely degrades in years, becomes faulty or in-optimal state and then malfunctions, Cx process shall be continuously executed by some responsible personnel. Figure 1 shows at the far right what role the combination of 'on-going' Cx and 're-Cx' has in the life-cycle Cx process. It should be noted that the figure does not show the present status of quality assurance process of HVAC construction and maintenance, but the system to be taken in the near, not long, future in order to accomplish save-our-globe programs proposed elsewhere. Keeping it in mind, the O&M will take more and more important role in the building maintenance. Even if they are low- paid and inefficient now, their status shall be graded up and their efforts for energy saving and CO_2 reduction shall be appreciated so that students feel interested and skilled professional engineers participate in this field of business. With this premise in mind, the figure expects O&M team to be engaged in on-going Cx with the help of intermittent re-Cx by hired CA and/or CEs. This combination of Cx activities forms ideal continuous Cx during operation to complete an ideal life-cycle Cx with life-cycle BOFDD (building optimization, fault detection and diagnosis).

More comments shall be needed to illustrate the Figure-1 such as events and documentation details and retro-Cx, refer the Annex40 reports (Visier, et. al., 2005) for that purpose.

3. BOFDD AND COMMISSIONING

The term BOFDD has come to be recognized among HVAC experts owing to the IEA Annex activities (Hyvarinen et al., 1996). BOFDD is defined as follows and the life-cycle BOFDD is shown in Figure-2. The figure can also define a life-cycle Cx from the performance realization point of view, especially stressed on operation stage. (Nakahara, 2003).

Building optimization is the process of minimizing an overall objective function that includes all cost of building operation (e.g., energy, maintenance, personnel) with the constraint of environmental condition. The building optimization can be performed with respect to both design and control variables. When the substantial object of building optimization is reflected, the measures will even include manual operation using BEMS, the retrofit of building services engineering systems and thermal and optical performance of the building structure from the viewpoint of building management

As shown in the figure, the BOFDD system is hierarchically composed in the operation stage of the figure. The higher stage of BOFDD is meaningful only after the fault recovery at the lower stage. Each stage consists of three steps, the fault detection, fault diagnosis and fault recovery from right to left. Tools for BOFDD to be used in each stage are mostly common with those used at the design stage, which are the simulations, mathematical models, database and

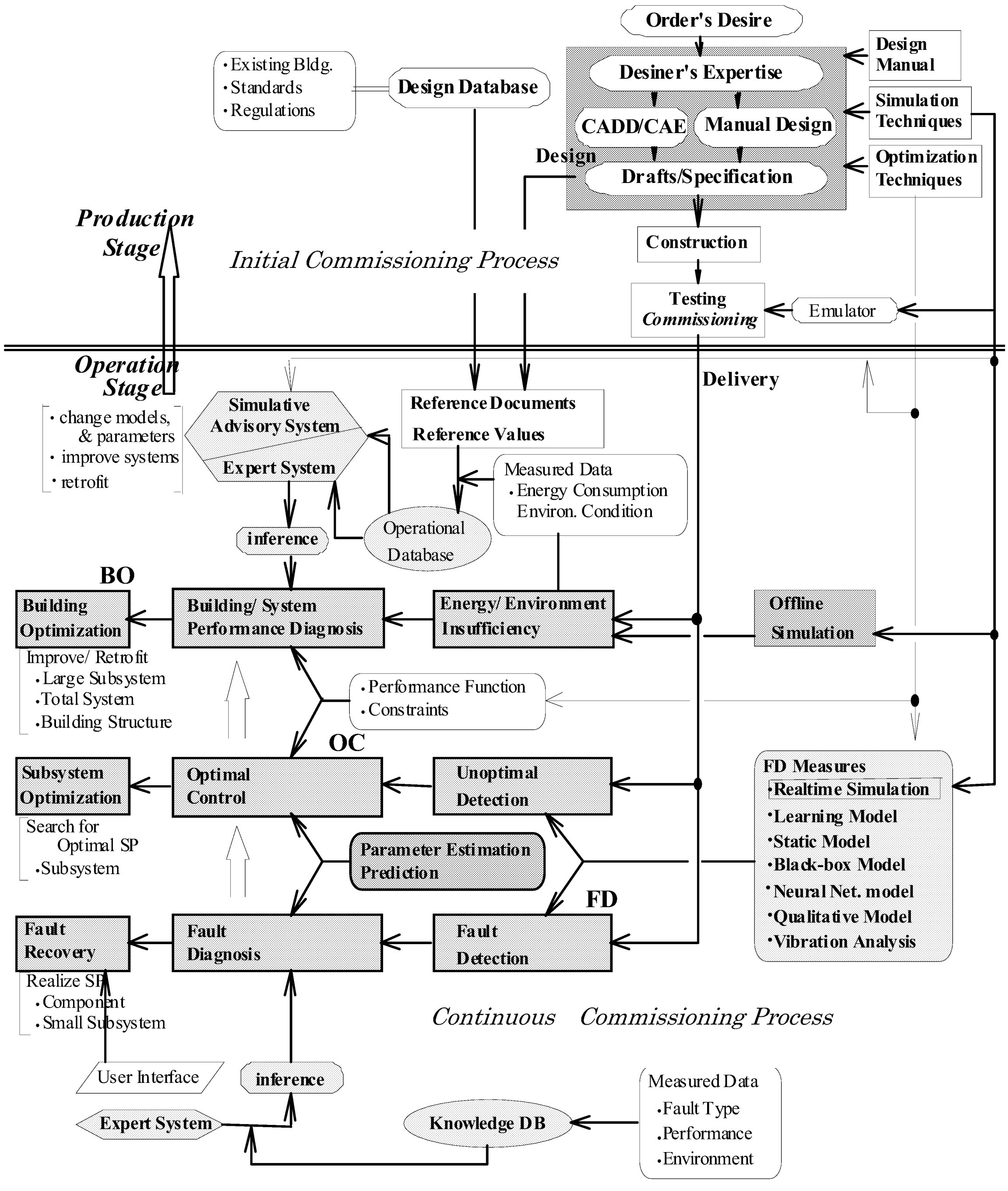

Figure 2 Total structure of life-cycle BOFDD

expert systems. There are two approaches for BOFDD, one is the top-down and the other, the bottom-up. The former refers to OPR, actual operating data on BEMS and data base provided by other buildings and regulations using expert system. Figure 3 shows actual approaches to BOFDD and Continuous Cx process and tools. The dark shaded frames in Figure 3 are actual BOFDD process with developed tools shown in other frames as the modeling process of expert system. Shaded zone at the left half of the figure correspond to the Cx process in operation phase as shown in Figure 1, that is, the on-going detection for the on-going Cx and the detailed diagnosis at either re-Cx process or retro-Cx process when the building system meets the Cx process for the first time.

4. DESIGN PHASE COMMISSIONING

An example project of initial, but partial, Cx process for construction phase and after by the author, the CA, for a laboratory building is found elsewhere (Nakahara, 2003) (Ito, 2004). Here introduced is an example of design Cx.

Why and how the design Cx shall be carried out is one of the heavy discussion points. It looks in the U.S. that not a few percentages of building owners know its necessity from the viewpoint of quality assurance of environment and energy, cost effectiveness, but in Japan, as well as in many other countries, they do not, or will not, recognize faults during design process. It is funny how they could believe, without strictly defining the OPR, that building systems can be well completed and accepted with satisfactory quality they should like to have. Without doubt, not a few of them must have noticed it but also know that any additional OPR-like notice necessarily escalates the cost of construction as well as design. Many other building owners may seem inconsistently still believe in A&Es' good-will without giving them reasonable amount of money and time. To break through these barriers is most necessary not only for the sake of construction relating parties but also for general public who will suffer energy and environment, indoor as well as outdoor and global depletion, degradation and high social cost that they must bear.

The author's experience as CA for a certain hospital facility shows exactly that mentioned above, which is also explained in the following. The facility includes hospital with six hundreds beds and 80,000 m^2 of total floor area, nursing college and other facilities in addition that summed up as approximately 120,000m^2.

4.1 Director's Enquiry

The client, the director of the hospital wanted have sustainable hospital from the viewpoint of indoor air quality, contribution against global warming and for energy conservation, which also realize energy cost reduction benefiting

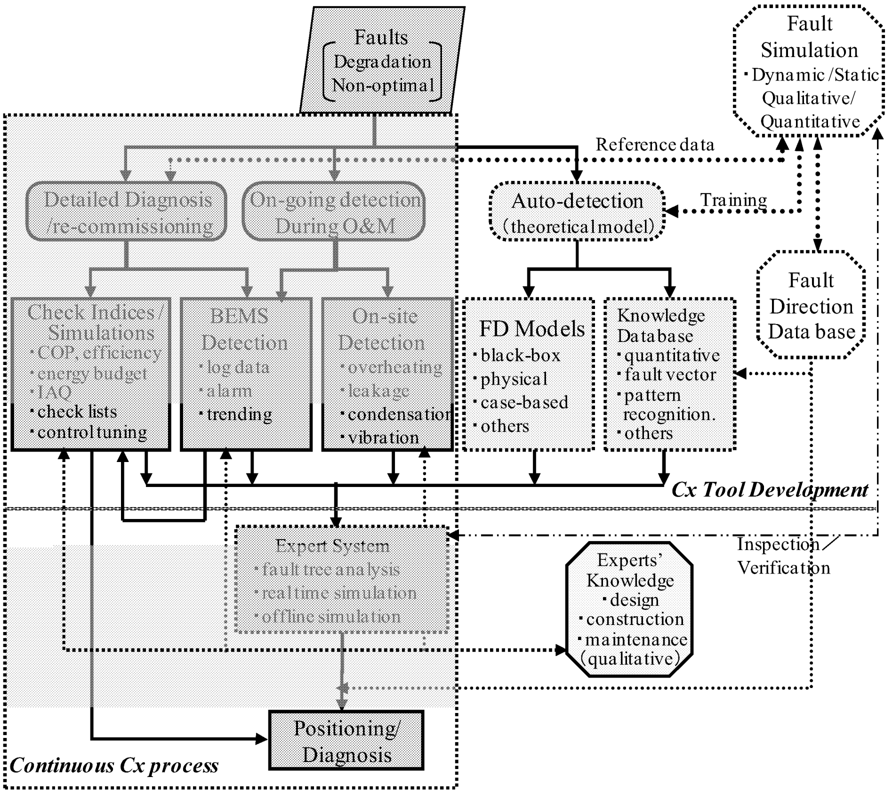

Figure 3 BOFDD and Continuous Cx

hospital management. Barriers to break through seemed to come from the property of the project order and character of the project organization. The director, therefore, recognized advantage of Cx process and hired CA to be paid on annual basis. The CA,the author, was particularly asked to decide optimal central energy plant system, in addition to ordinary Cx process, to advise the design professional who had already submitted basic design concept of it.

This was an extraordinary rare situation for the hospital director to keep such philosophy in addition to his profession as acting medical doctor, considering that his successor two years later did not admit to apply Cx process further after construction phase.

4.2 Design Cx Process

4.2.1 Process Outline

Figure 4 shows the principal Cx procedures during the design phase of the hospital. In conclusion, the design professional lacked in time to elaborate on energy system optimization that CA proposed as the result of detailed simulation study. Also he founds difficulty in finalizing full documentation before elaboration phase including bidding process. As mentioned above, the process ceased just at the time when construction phase meeting began, whereas remaining valuable experiences and materials for the future Cx business.

4.2.2 Energy System Optimization Procedure

Reviewing the schematic design by the design professional, the CA noticed the following facts and decided to fulfill the request of the hospital director to select optimal energy system. This was the very chance for the author to identify how grave problems exist in the HVAC design stage as the general state of the art.

1) Load estimation for preliminary design was not based on whatever obtained data from the present project as reasonable as possible, but on outdated statistical data.
2) Annual load calculation for each room, if any, was not based on annual calculation, much less based on taking proper internal heat generation into account for full season.
3) Load calculation was not dynamic.
4) As the consequence proposed energy plant looked oversized that will force the plant ineffective and uneconomical operation.
5) Window glass was not selected to have sufficient low U value with low-e glass for a energy-efficient and comfortable hospital.
6) Detailed efficiency characteristics of heat pumps and other machines, combination of which definitely contributes optimality of the plant, was not considered, which came from the lack of annual load estimation.
7) The number of system options for comparison was not enough.
8) Proper simulation programs were not used, because that kind of programs as DOE2 or Energy-Plus popular in the U.S. has not been prepared for general public in Japan.
9) CA could provide two kinds of simulation tools having sufficient precision.

It should be noted that this phenomena of engineers' suffering for many not-enoughs is quite popular in modern society; for example; not enough time, not enough fee, not enough knowledge, not enough staffs, not enough skills, not enough interests, and so on. It is very risky status not only for air-conditioning engineering but also for the crises on the energy depletion, global warming and building sustainability.

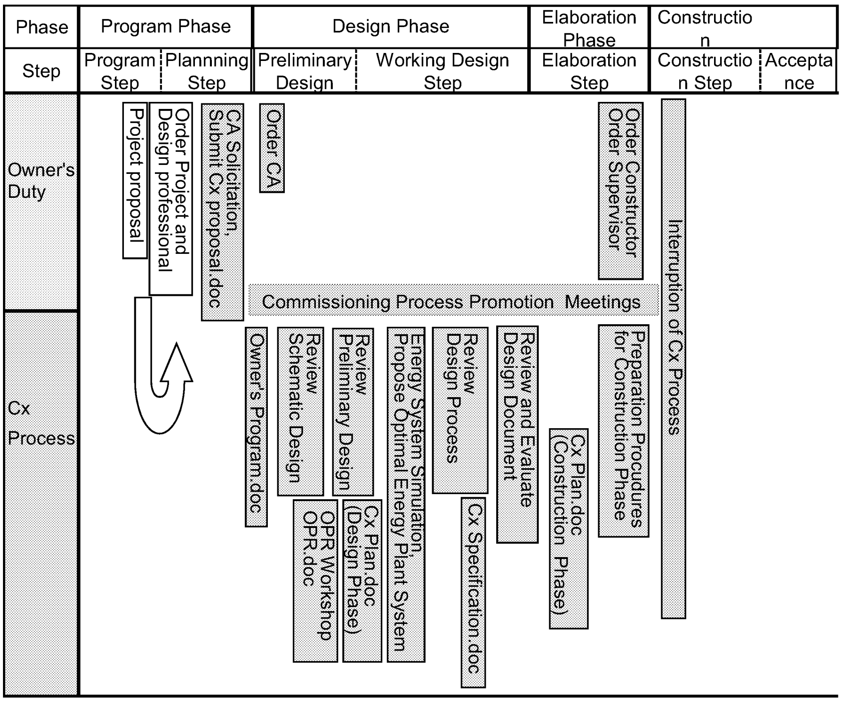

Figure 4 Design Cx Process for a Hospital

(1) System Menu Dialogue and Selection

Figure 5 shows menu sheet to construct energy plant system options of a simulation tool called TES_ECO, or T-tool. It includes co-generation and thermal storage system options in addition to various kinds of electric and heat driven heat pumps either combined with thermal storage or not.

The principles of selecting options are:

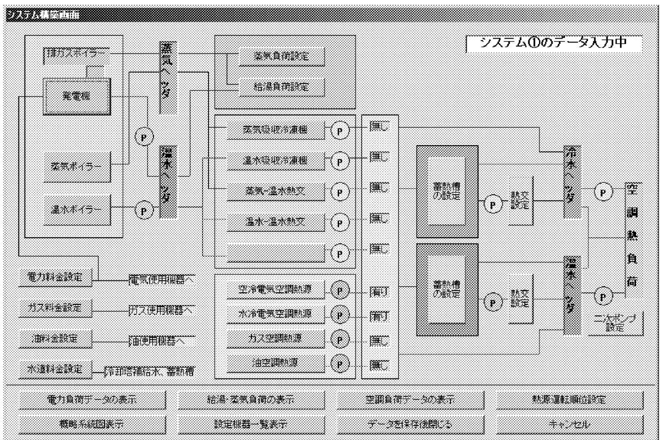

Figure 5 System Menu Sheet of T-tool

1) For security, co-generation system and combined energy source systems using gas and electricity with proper ratio are to be adopted.
2) Optimal size of generators and their efficiency are to be selected.
3) Decide priority of exhausted heat use either for heating or for hot water supply.
4) Use heat pumps of the highest COP. (here, heat pump, or HP, includes chiller-only machine and absorption machine, too)
5) Evaluate merit of heat recovery (HR) HP and/or air source HP for heating energy.
6) Decide optimal capacity ratio of gas and electricity driven heat pumps.
7) Choose optimal operation mode for thermal storage.

Table1 System Menu Example

	System feature	Combination
A0	Non-Storage Centrifugal	INV-driven Centrifugal Ref.(695RT×4) +Boiler(5t/h×2)
A2	Thermal Stotage Centrifugal＋HRHP	Centrifugal (920RT×2)+HRHP(527/664kW) +Boiler(5t/h×2)
B2	Thermal Storage w/CGS600kW Centrifugal ＋HRHP	CGS(600kW)×2+ExAR(210RT) +Centrifugal(650RT×2)+HRHP(527/664kW) +Boiler(4t/h×3)
C2	Thermal Storage w/CGS300kW Centrifugal＋HRHP	CGS(300kW)×2+ExAR(100RT) +Centrifugal (700RT×2)+HRHP(527/664kW) +Boiler(4t/h×3)
E1	Thermal Storage E/G=2/1 Complex w/CGS600	CGS(600kW)×2+ExAR(210RT) +Centrifugal (920RT)+HRHP(527/664kW) +AR(300RT)+Boiler(4t/h×3)
E2	Thermal Storage E/G=1/1 Complex w/CGS600	CGS(600kW)×2台+ExAR(210RT) +HRHP(527/664kW) +AR(630RT)+Boiler(5t/h×3)
F	Non-Storage w/CGS600 AR E/G=0/100	CGS(600kW)×2+ExAR(210RT) +AR(630RT×4)+Boiler(5t/h×5)

Note: HRHP: Heat Recovery Heat Pump, water sourse
CGS: Co-generation system w/Exhaust gas
ExAR: Exhausted heat driven Absorption machine

(2) Example of Simulation Results

In addition to the option shown in Table 1 many other variations were evaluated to obtain an optimal system. Example calculation results are shown in Figure 5~7. Figure 5 shows Annual cooling, heating, hot water, steam and base electricity demands. Figure 6 and Figure7 show annual primary energy consumption and CO_2 gas exhaustion. Figure 8 is the result of cost analysis. The line graph is the result of another tool that shows almost the same answer, which means both programs were mutually verified.

Thus, several candidate options were selected and the report was submitted to the client. To discuss about the system into more detail is not the purpose of the present report, except for adding one thing that the small difference among

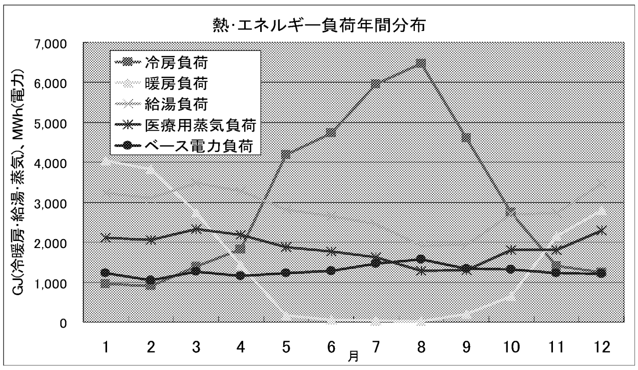

Figure 5 Annual Load

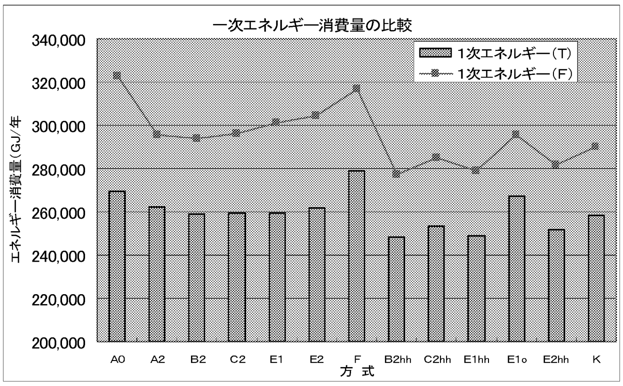

Figure 6 Primary Energy Consumption

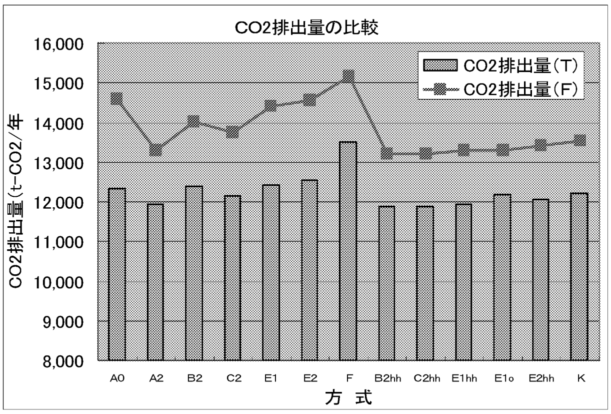

Figure 7 CO_2 Exhaustion

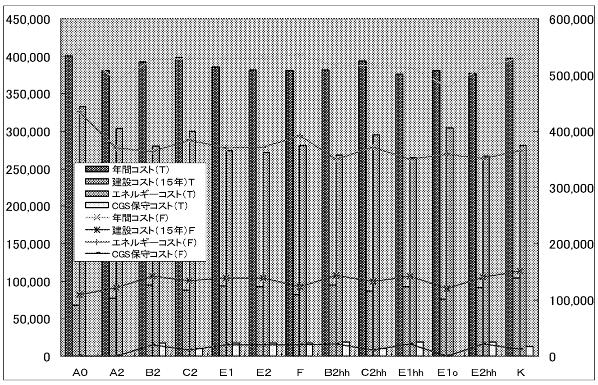

Figure8 Annual Cost Comparison

options means that all the candidate systems were already pre-filtrated beforehand.

5. DEFINING OPR TOWARD OPTIMAL INDOOR AIR QUALITY

5.1 OPR and Design Condition

OPR, owner's project requirements, is defined as follows by ASHRAE Guideline 0-2005.

<u>A written document that details the functional requirements of a project and the expectations of how it will be used and operated. These include project goals, measurable performance criteria, cost considerations, benchmarks, success criteria, and supporting information</u>.

It also describes that OPR forms the basis from which all design, construction, acceptance, and operational decisions are made (5.2.2.1). Among items of OPR to be defined, it includes the following selected items (5.2.2.4) that are deeply concerned with design conditions.

(a).Project schedule and budget
(f).User requirements
(g).Occupancy requirements and schedules
(i).Warranty requirements
(j).Benchmarking requirements
(l).System maintainability expectations
(o).Energy efficient goals
(p).Environmental and Sustainability goals
(t).Health, hygiene and indoor environment requirements

Project schedule and budget (a) dominate the quality level of requirements of the project. Requirements must be in accordance with them. Energy efficiency goals (o) and environmental and sustainable goals (p) also request designer a determined mind, and sometimes when the goal level such as LEED award was requested, it will justify to request additional design fee, which also reflect the client to elaborate on establishing program philosophy. Such items as user requirements (f), occupancy requirements and schedules, health, hygiene and indoor air environment requirement and others are parts of indispensable HVAC design conditions to be identified by the design professional for HVAC planning and calculations together with outside meteorological design conditions. Therefore, these items can be shifted to design phase commissioning as check and review items or can be replaced with declaration that they shall be checked at the schematic and preliminary design steps. The author rather recognizes the necessity of more professional view of HVAC engineering to include into OPR, which used to be left free on designer's liking or easy manner if not given any constraints. Examples follow.

5.2 Load Calculation

Recently load calculation looks rather ignored in spite of highly developed calculation theory and codes. If client wish to accept as reasonable a system as possible with energy-efficient and cost-effective, OPR should specify followings.

1) HVAC zoning and control strategy should reflect annual load variation to warrant comfortable environment through the year (or to be specified). For that purpose, indoor heat generation shall be properly estimated to decide cooling and heating zoning, and energy plant and air-conditioning unit capacities.

2) For large scaled and well insulated building, the TAC of weather data to determine peak demand has little sense but using excessive percentage of heating and cooling load during the specified term is more reasonable.

3) Dynamic calculation method shall be used for annual energy estimation as well as for determining peak demand, however, it shall be noted that preheating hours especially on Monday morning vastly affects the capacity.

An example calculation of heating load of west facing office room by dynamic simulation is shown in Figure 9, showing 8.3kW peak value at 7-8 o'clock a.m. in the condition that pre -heating time is two hours. The load also varies according to the time elapse and counts about 3kW of cooling load at 3 o'clock pm. Static calculation result is 3.7 kW heating in the early morning that is almost the same as the value for

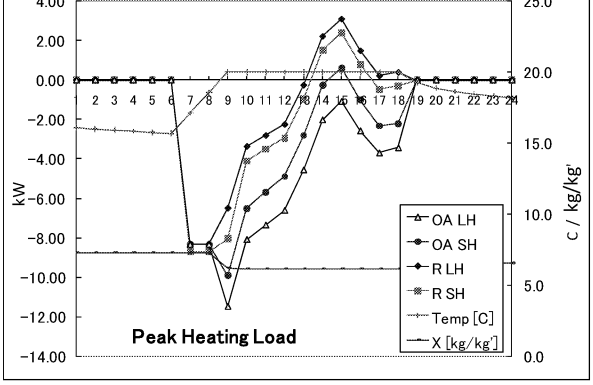

Figure 9 Hourly Heating Load of Peak Day

10 o'clock a.m. with dynamic calculation. The figure must give designer important hint how to select air-conditioning zone and control method to meet this kind of cool-heat load variation.

Then, OPR will need an description that load calculation shall be done with dynamic mode for year round using annual meteorological data and incorporating proper factor of internal heat gain and proper preheating to provide sufficient heating, to be controlled between 20~27 ET* for comfort through the year, with minimum annual energy consumption whose goal is, e.g., 2000MJ/m^2/a of primary energy.

Though all glass façade is becoming popular everywhere in the world in spite of the present crisis on energy and global warming, this kind of strict OPR description viewing at lifelong performance will minimize the fruitless efforts by HVAC engineers' "*façade engineering*" to exclude excessive perimeter load.

5.3 Individual Control System and Ventilation

The history of HVAC engineering can be said the battle between centralized and individual, or decentralized, together combined with the battle between fuel and electricity, between separated self-contained units and central systems, among air, water and refrigerant systems as the heat media to supply to objective air-conditioned space, between constant and variable flow rate of the heat media, and between simple cooling/ heating changeover system and simultaneous heating and cooling system.

Occupant's desire is to freely control either heating or cooling by his own demand, which accelerated application of VAV (variable air volume) system in case all air system, combined air and fan-coil unit system as air-water system, and then VRV (variable refrigerant) multi-unit system especially in Japan with the naming of "building multi system", which is now being exported world wide.

Generally, individual system is thought to have energy saving character, however, energy saving effect is limited, and yet comfort, healthy and hygienic requirements for HVAC cannot be satisfied without following consideration.

1) The VAV for heating is not preferable because of poorer air quality, especially when applied to interior zone with cooling demand.
2) Heat pump packaged units and others that allows simultaneous heating and cooling between adjacent units produce necessarily energy mixing loss.
3) Unit application, whichever kind of HVAC unit it may be, ventilation air distribution and air filtration ability shall not be ignored.
4) Individual packaged units shall have sufficient level of COP, variable volume system shall have proper fan and pump drive control system that needs most careful consideration for system design and control tuning.

Clients and designers should know these fact and OPR shall say that "Whatever system may be selected for energy conservation to fulfill the energy goal as defined in this OPR, ventilation demand per occupants and air-filtration ability for hygiene shall not be neglected. Energy efficiency shall be verified through adoption of high COP packaged units, if ever used, and/or with proper control design and optimal tuning for variable drive. Be careful not to generate much mixing energy loss"

6. Conclusion

Reflecting the path he walked with the ECBCS /Annex friends for energy conservation and IAQ through the studies from BEMS to Cx and introducing his Cx experience, the author has overviewed how to achieve the true object of HVAC and building environment control and how important it is to define OPR properly to realize energy-efficient and healthy buildings.

The author acknowledges the kind offer by AIVC2008 organizing committee and Dr. Takao Sawachi, Building Research Institute of Japan, for my keynote presentation, also acknowledge Annex friends who he worked with since 1987,

REFERENCES

ASHRAE Guideluine0-2005. The Commissioning Process

Hyvarinen, editor, et al. (1996), Building Optimization and Fault Diagnosis Sourse Book and Technical Papers of IEA Annex 25, IEA.

Ito, K., Sumitomo, T. and Nakahara, N. (2004). First Experience of the Commissioning Process in Japan - Initial commissioning and continuous improvement-. National Conference on Building Commissioning: May 17-19, Atlanta

Nakahara,N.(2003). Study and Practice on HVAC System Commissioning, The 4th International Symposium on Heating,Ventilating and Air Conditioning, Beijing

Visier, J.C., et al. (2005). Commissioning tools for improved energy performance, Results of IEA ECBCS ANNEX 40