The building commissioning procedure in Finland (ToVa)

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Synopsis

A Building Commissioning-project (ToVa) was launched in Finland in the beginning of the year 2003, in which a comprehensive commissioning procedure, including the building process and operation stage was developed in the project. Similar to Cx-procedures used in the USA, this procedure will confirm the precise documentation of client's goals, definition of planning goals and design adequacy and the performance of the building - i.e. that the building which is completed performs according to plans and to set goals. The method has been tested in pilot buildings and the aim is to develop it further in practical construction projects. This project was a part of IEA (International Energy Agency) Annex-40 program and of the national CUBE Building Services – research program of National Agency of Advanced Technology (TEKES).

It is rather usual, that within 1-2 years after introduction the users complain about the defects or performance malfunctions of the building. Often the reasons are related to problems in building envelope, in building services, in HVAC-system, in automation system and, as combined effect, failures in indoor climate. In the worst cases there may be health hazards or risks. The energy consumption might have exceeded the estimated consumption. Part of the problems has been caused by improper use. In consequence of the problems the life-cycles of these buildings are shorter than in average. Need to repair is increasing as well as life-cycle costs.

The performance has been tried to confirm by various quality control methods during design-, -construction and -mobilization stages. The completed building, however, has not been as such as the client has ordered or wanted. There have been defects even in the pre-design phase, when the client or the representative of the client was not able to determine the goals precisely enough. If the various system solutions are not integrated properly during the design phase, problems may occur during the operational period in the joint operations of the systems. The installation defects at the building site will increase the risks of malfunction. All the malfunctions have not been detected during TAB-tests, partially because of defective working methods and tight timetables

The energy consumption level of a building is mainly determined when we set the goals during the pre-design phase and the design process. At that time it's the best possibility to affect widely on the factors of indoor climate because the project budget is not yet exactly fixed.

In this paper the concept of the Finnish Building Commissioning procedure (ToVa) will be introduced and also typical problems in performance of buildings which have been found.

About the Authors

The authors formed a research team of Building Commissioning-project. The project leader was Mr. Jorma Pietiläinen. All the authors have long experience in studies dealing with Building Diagnostics, Building Performance, Condition Survey, Energy Audits and HAVC-installations.

Systematic process for commissioning building energy performance and indoor conditions

Background
In Finland/1/, buildings are commissioned mostly in the end of the construction phase. However, the commissioning of building performance is a systematic process which should kick off already at the pre-design phase and it should be continued through design, construction and acceptation to occupancy, use, operation and maintenance. During the Cx process, it should be checked that owner's and users' needs and requirements are clearly defined and documented, and indoor and energy performance requirements are included to owner's program. In addition, it should be audited that the design solutions and installation outputs meet given requirements, and verified that the building satisfies given indoor and energy requirements in use. Commissioning should also be included as an essential part of a systematic facility management process over the building life cycle.

Later a systematic process is described for commissioning building energy performance and indoor conditions. The Cx process is developed to be applied in Finland. In addition, checklists for each commissioning phase for a commissioning manager were developed. Also preparation of a Cx plan and options for a Cx team and examples of task responsibilities are briefly discussed.

Introduction
Nowadays in Finland, building commissioning is not a standard procedure during the building life-cycle. Most often it is only used during building hand-over in new buildings, and sometimes as a separate measure in existing buildings.

Commissioning (Cx) process should be launched as early as in the programming phase to check that owner's and users' needs and requirements are clearly defined and documented, and that indoor and energy performance requirements are included to owner's program. In addition, it should be audited that design solutions and installation outputs meet given requirements, and verified that the building satisfy given indoor and energy requirements in use. Cx should also be included as a part of routine facility management process over the building life cycle.

Cx activities include the following goals:

- To provide safety, healthy and comfortable spaces for living and business
- To improve design quality by more effective feedback
- To assure that all building services systems are compatible with each other
- To improve energy efficiency of buildings and building systems
- To decrease operation costs
- To improve operation and maintenance personnel introductory briefing and training
- To improve documentation during the building life-cycle
- To meet customer needs and expectations and satisfy customer requirements

Cx process
In Figure 1, there is the outline chart of the Cx process /2/. The Cx processes presented in /3/ and /4/ were the starting points for the development of this Finnish Cx process. The attached checkpoints "diamonds" link the Cx activities to the building process phases in general. At the beginning of a construction project, goals are established and the owner's and users' needs are determined. Then, the system requirements are set with the help of design procedures. Thirdly, the goals are implemented and performance is verified in the elaboration and construction phases. Finally, indoor climate and energy consumption is managed with new building automation and online reporting systems.

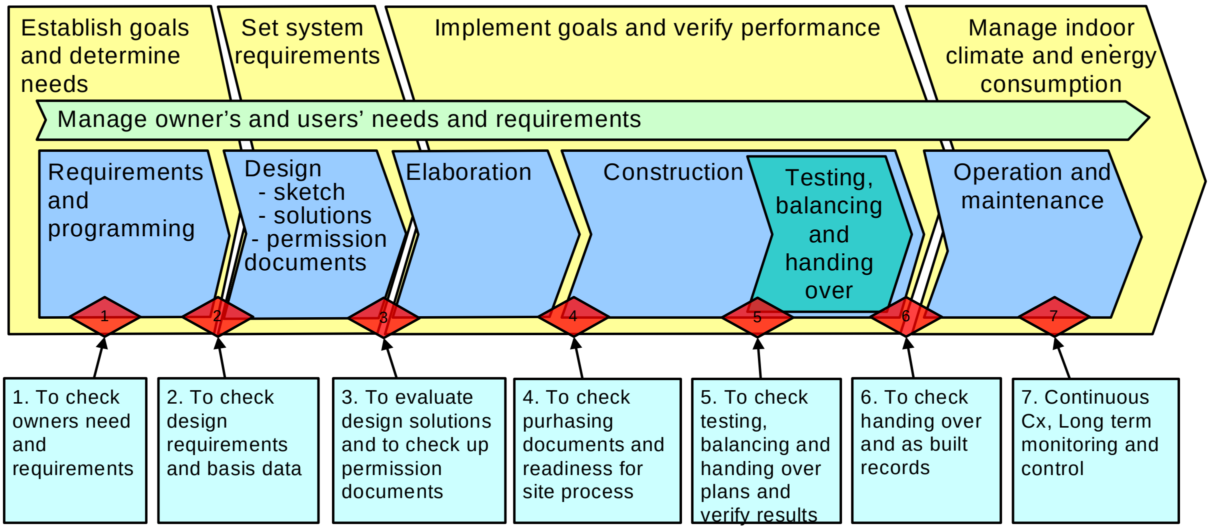

Figure 1. The Cx process.

Requirements and programming review
The objective of the phase (diamond 1) is to ensure that the owner's and users' needs and requirements are defined and documented. During the project planning different options to fulfill the owner's needs are clarified, plans for the project budget are made and the goals for the next phase (diamond 2) are defined.

Key activities are to:

- Check the owner's future strategies and action plans
- Check the owner's and users' needs and requirements
- Check the construction site and detailed town plan
- Check different goals and requirements and identify the possible risks

Design requirements review
The objective of this phase (diamond 2) is to ensure that the design requirements and basic data are relevant for setting up the system requirements. This information is also used to draw up contracts.

Key activities are to:

- Check design goals and requirements
- Check design contract documents
- Check that maintenance and monitoring requirements are sufficiently included

Design solutions and permission documents review
The objective of the phase (diamond 3) is to ensure that the design concepts and permission documents are correct. Indoor climate and energy consumption are based on the design concepts, proper results can be obtained only if the design concepts are relevant.

Key activities are to:

- Check design concepts
- Check building permits
- Take into account the system integration point of view

Purchase and contract documents and construction site reviews
The objective of the phase (diamond 4) is to ensure that the purchasing documents are relevant and the construction site is ready for implementation. In this connection, it is important to accept all system specific objectives with all the contracting parties. Especially, the integration perspective of different subsystems and procurements must be taken into account.

Key activities are to:

- Select and accept the systems to be implemented
- Calculate the design and construction cost levels for every system
- Agree the functional requirements for all systems
- Check that the tender documents meet bidding requirements

Functional testing and balancing review
The objective of the phase (diamond 5) is to ensure that the testing, balancing and hand-over plans are relevant. The main focus is on final tests and preparation for hand-over.

Key activities are to:

- Make sure that the systems and subsystems are functioning as agreed
- Make sure that the agreed level of indoor climate can be achieved
- Make sure that the assignment and maintenance manuals are relevant

Hand over review
The objective of the phase (diamond 6) is to ensure the hand over; also the as built records play an important role. At this phase the interoperation of all systems is crucial.

Key activities are to:

- Review all possible defects in the hand-over process and assess the repair work to be done
- Make sure that the building is faultless
- Make sure that all subsystems are tuned and operating as planned

Long term review of operation and maintenance
The objective of the phase (diamond 7) is to ensure that the indoor climate and energy consumption are managed and monitored for the optimal performance of the building during its whole life cycle. At this phase the continuous commissioning tools play an important role.

Crucial activities are to:

- Monitor the indoor climate, energy consumption and water consumption
- Measurements, audits and functional tests can be used when needed

Cx management
Before any Cx activities can be realized, a project specific Cx plan must be prepared and a qualified Cx team gathered. In the following, these issues are shortly discussed.

Cx plan

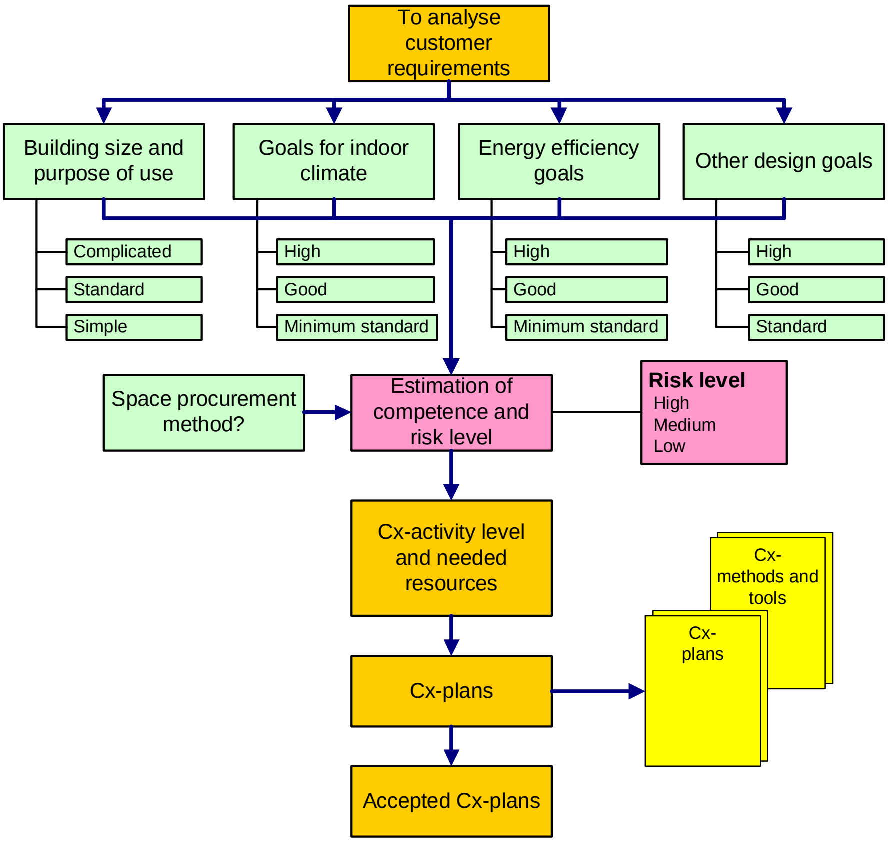

Figure 2. Preparing a Cx plan, applied from [2].

It is necessary to prepare a Cx plan according to the project phases. If on hand, general commissioning planning procedures support the Cx manager's work. However, different building projects have different features like size, complexity, and procurement method or risk profile. Altogether, the Cx manager should prepare a project specific overall plan and detailed phase plans in cooperation with the owner and the design professionals. In Figure , there is shown a procedure for preparing a Cx plan. There several important aspects should be taken into account. In the implementation of the Cx activities a number of checklists and verification documents are also needed.

Cx team
Different procurement and delivery methods establish different starting points and terms to organize Cx activities. In the traditional design-bid-build projects the owner must hire also a Cx manager. In the design Build contracts the owner has only one contracting party and it is possible to transfer at least some of the Cx responsibilities to the general contractor. It's the question of the owner's strategy and decision, how detailed commissioning process he wants to implement. Table 1 gives examples for selecting the Cx manager in different projects.

According to Finnish Land use and Building code every building project must have the principal designer. Tasks and responsibilities of the principal designer are partly similar with Cx responsibilities. It is necessary to adjust the role of a Cx person with principal designer tasks. In many cases the principal designer and the Cx manager could be the same person. It's also related to the project size and complexity as well as the professional background of the principal designer.

Table 1. Options to select a Cx team manager.

Cx manager ¿ Strong role l Participation ¢	Small DBB project	DBB project	DBB project	Design & Build project	Design & Build project	DBOM project
Principal designer	l	¿	l	l	l	l
Independent Cx consult (ToVa)				¿	¢	¢
Owner's agent	l	¢	¿	¢	¢	¢
General contractor's agent	¢	¢	¢	¢	¿	l
HVAC designer	¿	l	l	l	l	l
Electrical designer	¢	¢	¢	¢	¢	¢
Construction designer	¢	¢	¢	¢	¢	¢
Automation designer	l	l	l	l	l	l
FM service engineer		l	l			¿
Supervisor	¢	¢	¢	¢	¢	¢
HEPAC contractor	¢	¢	¢	¢	¢	¢

The most building projects are rather small or medium sized. The Cx team manager may be an external consultant. On the other hand, the Cx manager can be seen as a role and he or she could also be a design professional, a FM service engineer or an owner's supervisor. In design build projects and DBOM projects the Cx manager may be a service provider's agent. In very large and complex projects, it's a better possibility to engage the whole external commissioning team.

An example: Thermal performance of building envelope - design of the details

The thermal performance of the building and the energy efficiency and indoor conditions has been basically set already in the design phase – figure 3 shows in which stage there are the most feasibilities to have an effect on the performance – the users will find the deficiencies and failures when it is very expensive or at least more difficult to improve or repair them.

In cold climate conditions, especially, the proper functioning of the building envelope is very essential in terms of thermal conditions. Indoor environment contains many factors (see figure 4) and thermal conditions depend on

- the performance of exterior walls
- the functioning of ventilation (and cooling) system
- heating system
- building automation system and controls
- internal loads and external loads (weather)
- activity of the users

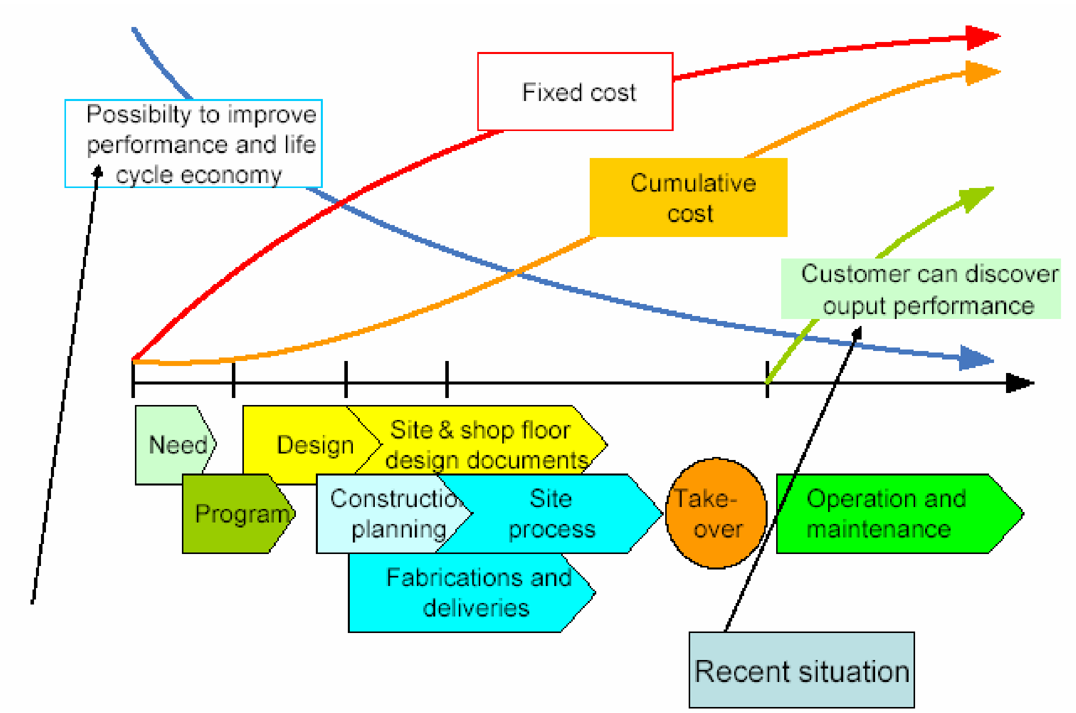

Figure 3. Potential to effect on the performance of a building

This commissioning procedure is planned to cover both new building and renovation – in practice there will exist differences and variations in the procedure, depending on that, which is in question. This procedure is still in the testing stage, and the next step is to apply it into the practice with contractors and other group of interests.

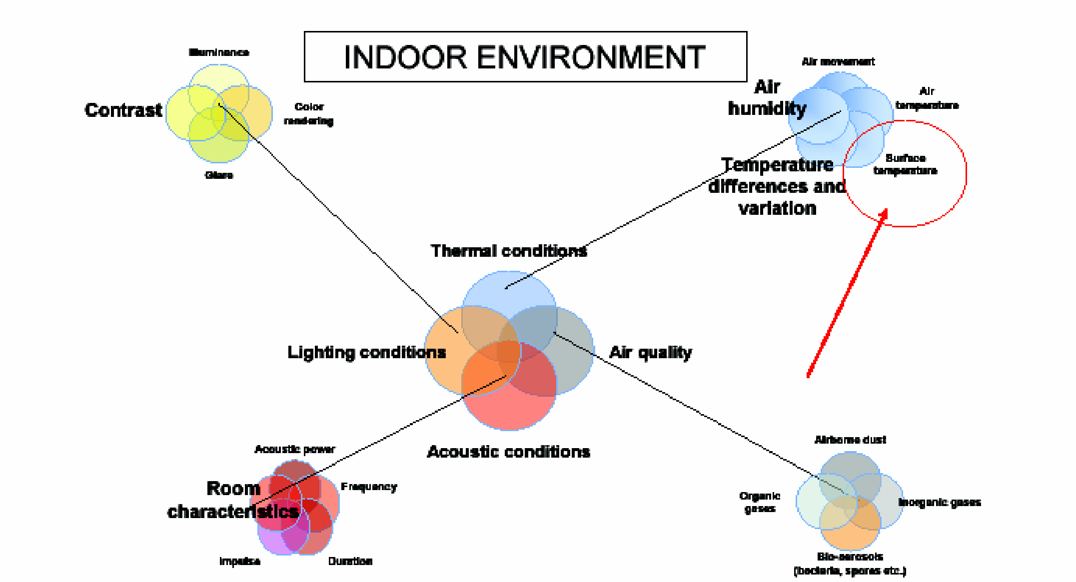

Figure 4. The factors of indoor environment

Most of renovation projects are based on IAQ-problems, on building defects – such as moisture and even mold problems - or change of use. Usually renovations are not based on energy related topics

In the design phase the designer must pay attention to the details, which may cause problems in the installation stage or during the use. The details of exterior walls and, the heating and ventilation system solutions close to the possible risky areas must be revised.

In new building, during the last years the following structural details which have caused problems have been relatively usual/5/:

- large windows with narrow metal frames, often close to outer surface
- two windows in the corner, with 90 º angle, joints of windows in the corner
- large window areas combined with low-temperature floor heating (direct or storage heating, based on electrical heating or hot water circulation)
- complex structures of exterior walls (lot of corners and junctions)
- lead-ins, doors
- thermal bridges, especially the connections of intermediate floors and exterior walls

The parts of the wall must be tight enough. Air leaks through the structures causes local cooling and draft.
The designer should verify the possible impacts of various detail solutions on thermal comfort and thermal performance. Thermal comfort calculations are often time-consuming and need special skills.
If the plans are properly done, and installations are carried out as they should, and the performance has been confirmed also by calculations, the problems which may occur are caused by faults in installation or, in some case, by misuse. The thermal conditions are a result of integration of the systems. The performance of structures and systems will be confirmed in the implementation stage and with performance tests, when the building will be taken into use.

To confirm the proper functioning of the building envelope, certain tools must be used. One very important tool is thermography and supporting methods, such as blower-door tests. In installation stage and also when the building is taken into the use, the systematic use of thermography and other techniques is relevant and useful.

In the case of renovation, the existing conditions and thermal performance of the building envelope must be known. Based on the commissioning results and possible determined requirements for the thermal conditions, one can make conclusions about the level of renovation and what kind of repairs is needed.

Figure1. showed the various stages of building commissioning procedure. After each step of the building project, the performance vs. owner's requirements must be verified. The crucial plank is that in pre-design phase all the owner's requirements has been properly set – and also the needs and requirements in terms of thermal conditions have been determined. In many building projects the owner's requirements leave open, which means that one has no specific requirements to verify. Need and requirements will be verified by checklists – every diamond or salmiac represents the checking points, and the checking will be carried out according to checklists.

In surveying the condition and energy efficiency of buildings, various auxiliary means are needed. We can compare the consumption data of the target building with other, same type of buildings by benchmarking. Energy audit helps to localize and determine the energy saving potential. Reasons for possible increased consumption must be clarified.

The most general and also most effective auxiliary tool in monitoring the thermal performance of building envelopes is the use of thermography, but in many cases also other measurements come into the question supporting the surface temperature measurements. This type of measurements includes/6/:

- air tightness measurements (blower door-tests)
  - blower-door test can be done also by using the own ventilation system of the building
- draft measurements
- heat-flux measurements
- globe temperature measurements
- continuous surface temperature measurements by datalogger
- pressure conditions measurements

The building envelope measurements are just one part of manual measurements needed. Ventilation measurements, heating systems measurements etc integrates another group of measures. The essential thing is that thermal scanning in this connection is a part of larger schedule.

The ventilation systems must be properly balanced. In cold climate conditions and in normal office- or apartment buildings there must be a slight negative pressure difference between indoor and outdoor space, 0 – 5 Pa typically. It means that cold air will flow against the warmer space. In the contrary, the warm air moving out through possible leak patterns may condensate, causing moisture risks.

When scanning exterior walls, it is very important that you always measure the pressure conditions. If there is a positive pressure drop in the building, compared with outdoor air, it is difficult to see the defects in such areas, which have leak patterns. Oversize negative pressure difference represents unusual conditions, and before the final evaluation the ventilation must be rebalanced.

Results and experiences from Cx- (commissioning) pilot targets

In the Cx (commissioning)-pilot project there were two educational buildings as target buildings: a new secondary school and a building of technical college, including offices, library, laboratories and classrooms. Here some results of the new school/5/:

In the first stage, the detailed risk points in building envelopes were mapped during visual inspection and based on drawings. The details in which needed to pay attention were

- Window and door structures
- Junctions of the structures
- Lead-ins

There was no possibility to make any calculations-based evaluation of thermal conditions in advance at this time (in the design phase).

Thermal scanning was carried out in winter weather conditions, in December. (The school started in late autumn of the year 2005). In case the use would be started earlier, in August, the tests should be carried out afterwards and preliminary measurements in the spring, when the building was not fully completed.
This date was ideal for the tests, also because of no effect of sun radiation (the darkest conditions during the year).

- Findings and comments during the preliminary audit (figure 5):

    - The window structure of some classrooms may cause a thermal bridge

    - The design solution excepted an uniform wall-line

    - The final functioning was confirmed by thermal scanning

Figure 5. Window structure of the pilot building (during construction).

Even the contractor paid special attention to the air tightness and the details discussed above, during the measurements some defects were found. The ambient outdoor temperature was -8 ºC, indoor temperatures changed between 21 ºC – 23 ºC. The measurements were done in three stages:

1. In the normal conditions and 2.Under 50 Pa negative pressure difference, this was produced by the building ventilation system. 3. Outdoor scanning.

- Based on the results of thermography and visual inspection:
    - The functioning of hatches and doors of operating rooms was not correct. Some faults and defects like air leaks and poor sealing. Ventilation devices are in the operation room, and cold air is cooling the pipelines
    - Also the front doors had thermal bridges and seal leaks - the main entrance doors had no seals in the sill rails.
    - The representative of the contractor was present during all the measurements and registered directly defects and proposals. Repairs were done, according to the preliminary report, just after the measurements.
    - Windows: Se<al defects locally, condensation. There were various types of windows. Thermally, the wood framed windows performed better than metal framed windows. Metal framed windows had thermal bridges.
    - Exterior walls and roof junctions: Local cold patterns
    - Supported structures (above the ground), library- and dining areas: Thermal bridges in windows, supported structures were visible both in outdoor- and indoor scanning (thermal bridges)

- The performance of the building envelope was good, in general. Only the functioning of the doors was not acceptable (seal defects).
- Also the differences of thermal performance were clearly seen between various window types. Some minor defects in installations.

- Balancing of the heating system was not completed (temperature differences between classrooms). Some teachers opened windows because of overheat, even the outdoor temperature was below 0 ºC
- The basic tuning of heating system was done but the final tuning was not completed
- Recommendations for some checking also for ventilation system
- Pressure conditions were proper and within usual limits.

The rest of the suggested actions were made during the winter. The air tightness test made using the ventilation system succeeded well in this particular case, and the contractor got good experiences for the future. The determination of air leak number caused some extra problems, because the individual exhaust fans must be tightened before air-tightness tests (extra work needed).

One goal in ongoing IEA Annex-46 project "ENERGO" /7/, /8/, is to combine, test and introduce various measuring tools for energy audit – thermography is one practical tool the potential and use are not still exploited as much as it could be. One of the results is a protocol for audit, including also description and procedure for thermography /8/.

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Evaluation of the effects of the quality of building on energy consumption

This case study deals with evaluation of the effects of the quality of building on energy consumption /9/. The quality of structures and HVAC is evaluated from point of view of effects on energy consumption. Case simulations and sensitivity analysis can be added to a certain risk evaluation procedure, which is one part of commissioning. The energy performance of the building is depending strongly on the efficiency of the ventilation systems. The example shows (the school described earlier) the influencing factors and ways to reduce heating energy consumption. Three factors are considered: 1) air flow rates and running times of ventilation, 2) heat recovery of ventilation and 3) air tightness of the building envelope. This case is evaluating the risks when taking the responsibility of energy consumption of the building service system.

Figure 6 shows an energy balance of a building in cold climate conditions. In this example the biggest losses are caused by ventilation. If building owner or facility manager has set targets for energy consumption, they must have possibility to monitor the distribution of energy. By generating energy balance chart (e.g. Sankey-diagram) it is possible to observe, which the main factors are influencing on heat and electricity usage.

Even in well-performing buildings the energy consumption may vary within relatively wide range. The estimated consumption of district heating (DH) of a new school in Southern Finland was 26, 3 kWh/m^3/year (real building, calculations based on Finnish Building Code, part D5). The biggest component of heat losses was ventilation. Changing the operation time from daily 12 hours to 10 hours decreases the heating energy consumption to 23,1 kWh/m^3. Increasing the efficiency of heat recovery device from 50 % to 60 % decreases the heating energy consumption to 20, 1 kWh/m^3, and finally improving the air tightness of the building from 0, 1 change/hour to 0, 05 change/hour decreases the heating energy consumption to estimation 18, 1 kWh/m^3. This decrease of 32 % in heating energy consumption (DH) is realized by optimizing operation hours, selecting more energy efficient heat recovery device and realizing the air-tight building. This case simulation is showing the influence and risks of these factors on heating energy consumption ('severity' is presented as energy consumption). The most important influencing factors should be analyzed in a systematic way showing the influence of the factor on consumption. This analysis could be presented in form of table or Sankey-diagram including basic value and sensitivity to influencing factors (e.g. heat recovery device has influence 0, 3 kWh/m^3/1 % change in efficiency).

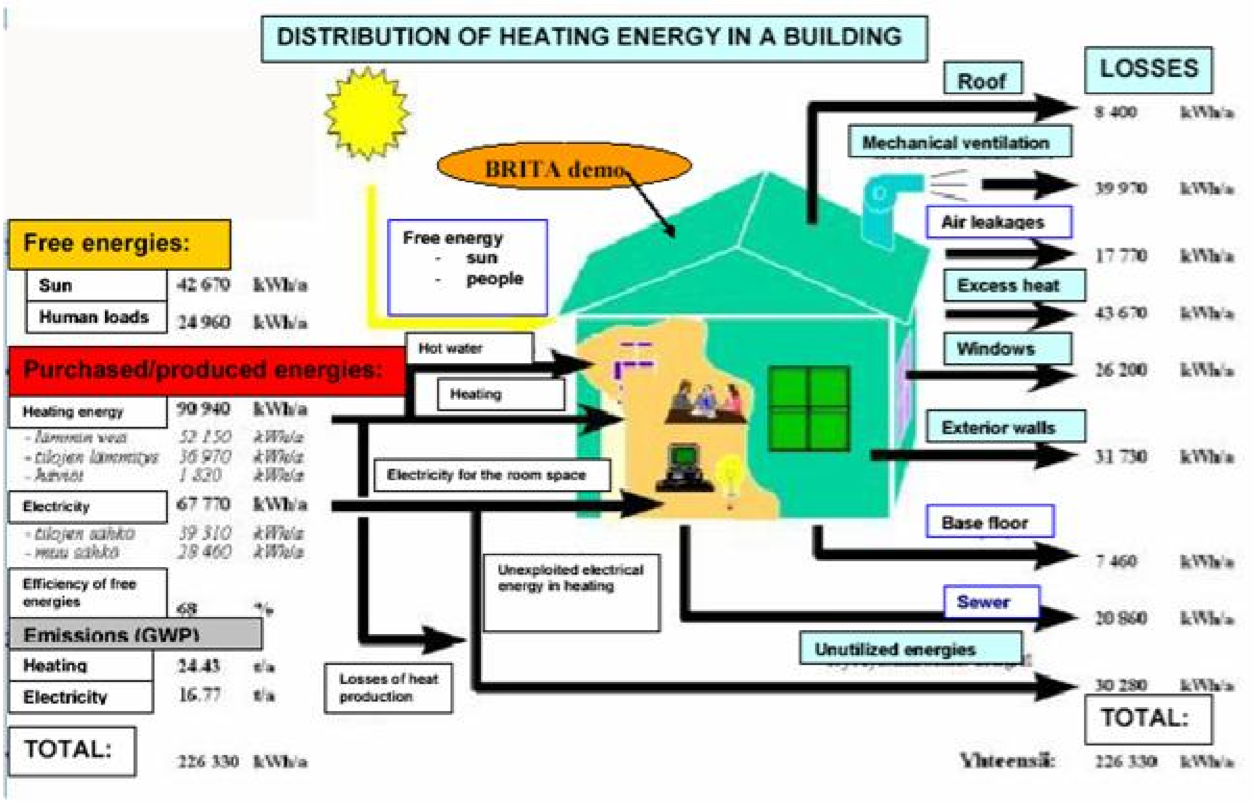

Figure 6. An example of the energy balance of the building.

Discussion

In the construction market some big trends point to the need of a systematic Cx process. Especially upward energy prices and increasing requirement for a good and healthy indoor air are the drivers.

The commissioning concepts and processes are not yet widely accepted and in use. The Cx concepts and procedures need to match with the actual project and quality management practices. In addition, the Cx team should match with the normal project organization. So, the key question is the role of the traditional supervisor and the building services supervisor. We cannot only add an extra Cx organization to the traditional construction project practices. The whole project management needs to be reformulated somehow. The Cx concept has challenging goals: to achieve good indoor conditions, energy efficiency and the other owner's goals at the same time. It's necessary to implement a growing amount of pilot projects in order to prove benefit potential in practice,

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