RE-COMMISSIONING OF THE CAMET HVAC SYSTEM: A SUCCESSFUL CASE STUDY?

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ABSTRACT

Commissioning is a unique opportunity, for all partners concerned, to learn a lot about the real behavior of a HVAC system.

It has to start from comfort and health requirements in occupancy zones, and going back to the plant through the whole air conditioning system.

Focus is given here to the so-called “re-commissioning” and the proposed principles are illustrated by reference to a specific case study: the “CAMET” building.

The "CA-MET" is a new ministry office building, designed for an occupancy of about 1000 people and located in the city of Namur, in Belgium. The building is cooled, thanks to a VAV/CAV system. Heating is provided independently by a classical hydronic radiator system.

By lack of time, here as usually, the HVAC initial commissioning was done in a hurry…

And, as soon as starting his job, the manager received a fair amount of complaints from the building occupants.

The building was selected as a "good" case study to illustrate the work developed in the frame of the IEA-ECBCS "annex 40" project…

This paper is presenting the methodology used in the first re-commissioning phase, some examples of results and also some general recommendations.

INTRODUCTION: ABOUTCOMMISSIONING

<u>A Unique Opportunity</u>

Still today, and for too many practitioners, commissioning appears as a “boring-but-mandatory” task, from which very little is to be expected, except conflicts and waste of money…

But commissioning is also a unique opportunity, for all partners concerned, to learn a lot about the real behavior of a HVAC system. It should offer an interesting feed back to the designers and to the installers. And it should also help in performing corrective actions, before getting too many problems with the managers and with the occupants.

It's more and more obvious that a good initial commissioning may help to resolve, on time, a lot of problems.

<u>From the Sensors to the Plant(s)</u>

Starting from the comfort and health requirements in occupancy zones, and going back to the plant through the whole air conditioning system, we may list the items to be commissioned:

<u>The whole set of sensors and monitoring equipment</u> associated to the BEMS, allowing the manager to identify accurately enough both outside and inside building micro-climates, and main HVAC state variables: fluids temperatures, pressures, mass and enthalpy flow rates, thermal and electro-mechanical powers, etc;

<u>The building</u> (considered as a whole and as a set of zones), with its thermo-physical characteristics (tightness, thermal resistances, solar factor etc…), possibilities of human interactions (windows and doors opening…) and internal “sources” of water, heat and contaminant associated to the building occupancy (and to the activities developed in occupancy zones);

<u>The terminal units</u> (supply and exhaust air systems, emitters…), with their control and also with possibilities human interaction (actions on supply valves, on thermostats, hygrostats, etc.);

<u>The air distribution system;</u>

<u>The air handling units</u>**,** with control associated (actual control laws have to be identified);

<u>The water distribution systems;</u>

<u>The heating and cooling plants</u> (boilers, chillers, thermal storage systems, cooling towers…)

<u>What and How?</u>

The same questions has to be addressed for each item:

<u>What are we looking for?</u> (What might be the benefit of a more or less detailed commissioning?)

What accuracy do we need and what could we get with measuring equipment already installed and/or with some additional (portable) equipment?

Which ("passive" or "active") experiments do we need, within how much time and in which conditions?

Which simulation models should we use to prepare, interpret and evaluate the commissioning?

Could the procedure(s) be automated (i.e. performed by the BEMS, time-to-time or continuously), in such a way to help in daily management, fault detection, diagnosis and preventive maintenance?

When?

Different commissioning types can be distinguished, according to their time occurrences, all along the building life cycle:

The initial commissioning, which should be performed at the end of the construction phase and, if possible, before building occupancy;

The retro-commissioning, performed later, because the initial commissioning was not done or was considered as insufficient;

The re-commissioning, which may be decided at any time, because problems are encountered, or in view of some retrofit;

The continuous monitoring**,** which should be, as much as possible, automated and used to help for the daily management.

Focus will be given hereafter to the third type: the re-commissioning, with reference to one specific case study…

A CASE STUDY: THE "CAMET" BUILDING

The "CA-MET" is a new ministry office building designed for an occupancy of about 1000 people and located in the city of Namur, in Belgium (Figure 1).

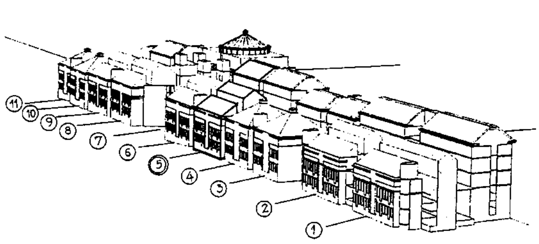

Figure 1: The CAMET building

The "temperate" climate of that region makes that air-conditioning is only required if the building is exposed to high internal loads, if it's not enough protected against solar heat gains, and/or if it's located in a noisy area.

All these conditions are met in the present case.

The building is therefore equipped with two classical systems working independently:

1) A VAV/CAV system for ventilation, moisture control and cooling (Figure 2);

2) A hot water heating system with radiators and thermostatic valves.

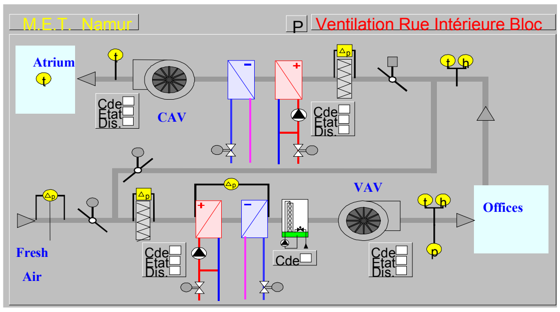

Figure 2: The VAV/CAV air handling units

Three separate plants are supplying the water distributions (Figure 3):

1. One heating plant with gas boilers;
2. Two cooling plants, each one equipped with a twin-screw chiller, with air-cooled condenser.

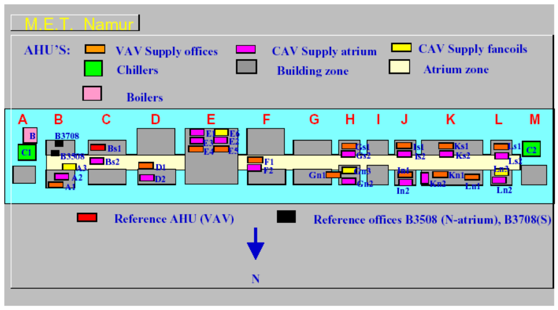

Figure 3: Locations of the air-handling units and of the plants in the building basement

It's a "typical" case:

- A rather classical building;
- With a classical HVAC system;
- Which has been submitted to a very poor initial commissioning (by lack of time, as usual).

Very soon after the building inauguration, a fair amount of complaints was collected about too noisy VAV boxes, about too hot conditions in some offices and also (at same time!) about too cold conditions in some other ones. The manager tried his best, but he couldn't get rid of all these (contradictory) complaints…

It became quickly obvious that the excessive noise was mainly due to some of the VAV boxes and also to the chillers (for offices located in the vicinity of the cooling plants).

An important re-commissioning work was launched in this building, with a governmental support, not only to help the manager, but also to identify better the actual electricity, heating and cooling demands, for possible use of co-generation in the future. The re-commissioning plan was also extended in order to assess some methodological aspect, in connection with the IEA-ECBCS "Annex 40" commissioning project [1].

COMMISSIONING METHODOLOGY

Focus is given here to the so-called "manual" commissioning. Automation opportunities are not yet analyzed, unless they look already as very promising [2].

Priority attention is paid to overheating risks, in order to illustrate the methodology developed here after.

The methodology is supported by:

- A strategy,
- A set of simulation models;
- A set of data;
- An experimental design;
- Some portable measuring equipment.

The Strategy consists of an "upstream" investigation (from the occupancy zones to the plants), in order to identify the most important "bottle necks" of the system.
The main investigation steps are described hereafter…
The Models are supposed to be available: at the time of the commissioning, we should have in hand the simulation models and the calculations tools already used by the designers.
Data should also be available: at least the manufacturer and installer data can be used for an initial tuning of the models.
The Experimental Design has to be based on what is already known about the building, about its HVAC control and about its monitoring equipments;
A Portable Measuring Equipment is always welcome, to check and complete the information given by the BEMS…

PRINCIPLES AND FACTS

Sensors and Monitoring Equipment

Outdoor climate.

The outdoor climate is (more or less) well defined, thanks to meteorological data. Local measurements should not be required, except if the building micro-climate is expected to differ very much from that of the nearest meteorological station.
But the BEMS is usually using its own outside air temperature definition and this one deserves a careful verification.

The difficulty of measuring a correct outdoor air temperature is well known and the "parasitic" effect of solar radiation is easy to simulate. But it's still neglected by too many practitioners…
In our case study, the BEMS makes use of two outside air temperature sensors, located on East and West façades respectively. The commissioning of these two sensors is made by comparison with a reference probe (called "METEO" in Figure 4). Both BEMS sensors are strongly affected by sunshine (and by infrared radiation from adjacent surfaces heaving been previously exposed to sunshine). The conversion law is also badly tuned. This makes that the BEMS is always overestimating a lot the outside air temperature, as shown in Figure 4.

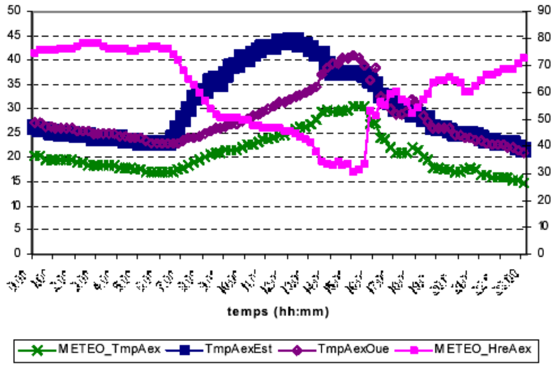

Figure 4: Example of wrong definition of outdoor air temperature

Such an error has unexpected consequences: in very hot and sunny conditions, the control unit may shut down the cooling in order to avoid the risk of getting a too strong difference between (wrong) outdoor and indoor air temperatures!

The inside climate is not easy to define.
The BEMS is usually only informed about air temperature, (time to time) about air humidity and (seldom) about air quality in a limited number of zones.
Most important uncertainties may come, not from the sensors themselves, but from their locations in the building.
In our case study, the BEMS is only informed about air temperatures at the return to air handling units (one average for each set of zones connected to a same AHU).
This tells little about what is occurring inside each zone. The temperatures detected by the VAV thermostats and by the thermostatic valves are, of course, not transmitted to the BEMS.
In the case considered, some spot measurements demonstrate the existence of a very important

vertical gradient of air temperature, whenever the heating system is running. This has a negative effect on the control performance: the VAV thermostat (located at ceiling level) and the radiator thermostatic valves are detecting two different temperatures.
In mid season, wherever the radiator is heating the zone, it generates a strong increase of the temperature at the ceiling level, which is detected by the VAV thermostat. This generates a useless cooling demand.
To avoid a simultaneous heating and cooling in a same zone, it's therefore necessary to increase the set point of each VAV thermostat at begin of each "heating" season!

Fluids temperatures.
The difficulty of measuring a correct fluid temperature inside a conduit is also very well known…and ignored in the current practice!
The main mistake is often coming from conduction along the probe (and parasitic influence of the outside temperature).
This fact is well illustrated in Figure 5.
A careful inspection is required in order to select the sensors to be commissioned (it's useless if they are too badly located)…

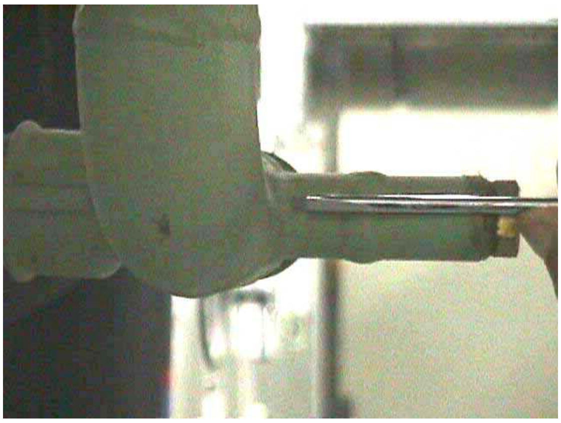

Figure 5. Example of bad sensor location (not deep enough inside the pipe)

Fluids pressures and corresponding flow rates.
Pressure sensors have to be handle with special care.
Faults may occur from sensor malfunction, wrong calibration and wrong conversion, as well as from bad location.
These faults might stay for long time undetected by lack of knowledge about the correct orders of magnitude.
An example of wrong conversion effect is given in Figure 6: the AHU air flow rate is here supposed to be defined with the help of a differential pressure sensor, measuring the head loss across the two (pre-heating and cooling) coils associated in series.

The three correlations presented in Figure 6 correspond to different measuring campaigns, made at different times. No physical reason, except a de-rating of the signal conversion, could explain the differences among them…

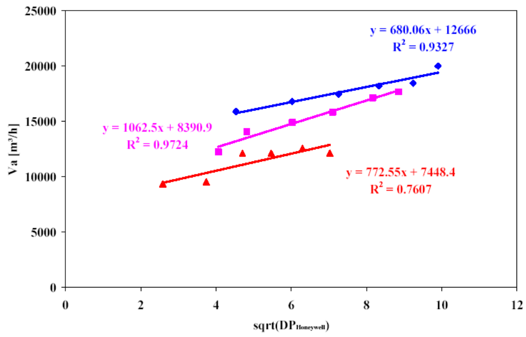

Figure 6: Uncertainty on airflow definition due to a wrong conversion of the pressure sensor signal

Building Occupancy Zones
When having resolved the previous uncertainties, it seems rational to check if the overheating of a zone can be explained by some excessive heat gains and/or by some lack of cooling capacity somewhere in the system.

This checking should be based on a zone thermal balance, with great caution to dynamic effects.
A "co-heating or co-cooling" method could be used in order to validate and to tune the thermal balance: A calibrated source is used as a reference heat gain generator, or as a substitute to the terminal unit (if this one can be easily closed).

Such method was successfully used a long time ago, in order to determine the efficiency of some heating equipment [3].
But co-heating and co-cooling methods are not applicable when having to deal with a large set of zones or even with the whole building.

A whole building thermal balance remains nevertheless always helpful, at least as a crosscheck of the overall electricity and gas consumptions.
This global checking may be affected by various uncertainties:
1. The average inside temperature is usually not well defined (just a few "zone" and "return" air temperatures);
2. Actual heat gains are difficult to track, when the building is already occupied;
3. Building thermal characteristics and control performances are affected by occupant's behaviors (windows and door opening, thermostats adjustment,);
4. Steady state conditions are never reached and strong dynamic effects may have to be taken into account (energy storage in the building structure).

Even when dealing with long term recordings, the identification of a building thermal "signature" stays as a nice dream: the too poor indoor climate control makes, most of the time, that signature unreadable: any correlation between indoor and outdoor temperature may even generate a wrong identification of the global building heat transfer coefficient [4], [5].
Example of CAMET building "signatures" are presented in Figure 7; hourly values of both heating and cooling demands are plotted as function of outdoors air temperature. Only the working hours are here considered.
It's obvious that the cooling "signature" is still unreadable, due to a much too poor control of the indoor climate…

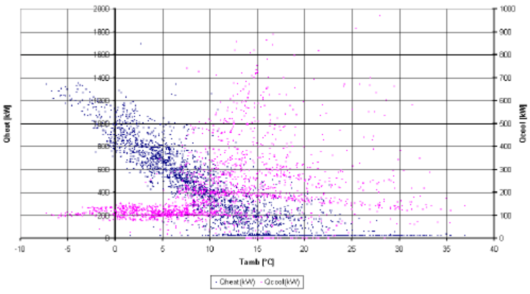

Figure 7. Heating and cooling "signatures" of the CAMET building

How far to go with the zone and building thermal balances is still an open question.

The same question remains also unanswered for water and contaminant mass balances:
Insufficient information is currently available about the indoor air quality and humidity control…

<u>Terminal Units</u>
Usually, simple terminal units, as heating radiators and heating/cooling fan coils, don't require any commissioning.
But VAV boxes may need, as it was found in the present case study:
It appears that some important mistakes can be committed when installing the boxes.
These mistakes concern, among others, connection of the thermostat and the limit position of the actuator.
The correct behavior of a VAV box, tested in laboratory, is illustrated in Figure 8.

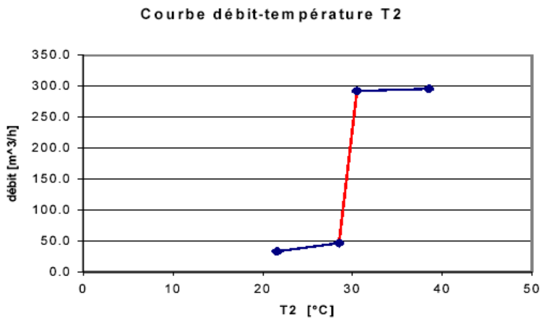

Figure 8: Correct behavior of a VAV box

Malfunctions are easy to detected, when visiting all the zones, one by one; but it costs a lot of time and money (in the case considered, more than one thousand VAV boxes would have to be inspected!).

An efficient procedure must be established in order to ensure a quick and correct diagnosis. One way to do it, consists in observing the system behavior in two extreme situations:
1. Highest set points of the VAV thermostats and low zone temperatures ("winter" conditions), in order to get the minimal opening of the VAV boxes;
2. Lowest set points and high temperatures ("summer" conditions), in order to get the maximal opening of VAV boxes.

In these tests and according to the circumstances, both "low" and "high" zone temperatures can be obtained by playing with:
AHU's heating and cooling coils;
Radiators thermostatic valves;
Lighting loads;
Windows and doors openings.

Global verifications can be done at the level of each AHU (observing the air flow rate variations).
But local verifications are still necessary:
If a VAV box is producing too much noise, too little or too much cooling, it might be because of:
1. A control default (at the level of the VAV box);
2. An air connection default (at the level of the VAV box);
3. An inappropriate air temperature at VAV box supply;
4. An inappropriate air pressure at VAV box supply.

The two first items are not always easy to check when the building is already occupied (some VAV boxes are no more accessible).

The two last hypotheses are easier to check than the two first ones, but this checking requires time.

In the case considered, it was discovered that the VAV boxes thermostats were not able to work properly, because the VAV box supply pressure

was too low. This was due to a wrong set point adjustment in the fan control.
It was also found that a wrong temperature at VAV box supply was sometime achieved, because of the wrong outside temperature measured by the BEMS…

Air Distribution

Unacceptable pressure drops, leakage and heat transfer across the ducts envelope may affect the air distribution.

Pressure drop is the most important item to be verified.
Having a fair idea of what is occurring in the distribution systems, we can pay more attention to the commissioning of the air-handling units.

Air Handling Units

Control laws and physical characteristics of the HVAC components (fans, coils, humidifiers, filters, economizers) may have to be checked.

In the case considered, three relationships are crucial:
- AHU fan speed as function of exhaust air pressure;
- Heating and cooling coils valves openings, as function of exhaust air temperature.
-AHU exhaust air temperature set point as function of the corresponding return temperature (Figure 9).

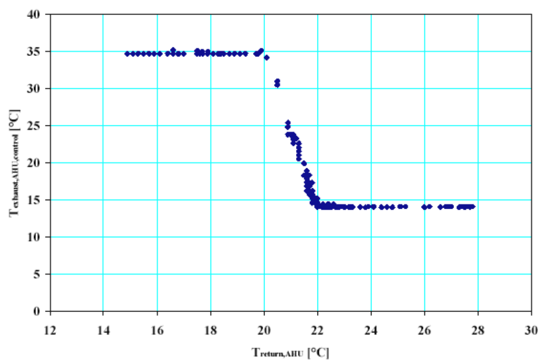

Figure 9: Example of relationship between air set point and return temperature

Water Distribution

The same defaults (except leakage) may be encountered as in air distribution.

A correct balancing of all water distribution circuits is not easy to achieve.
Balancing valves can usually be used as flow rate measuring devices, providing they are correctly installed…
In the case considered, many of these valves were found as badly positioned and badly connected.
When having more than on chiller mounted on a same water loop (two in the present case), the part load control strategy has also to be carefully verified.
Usually, the strategy consists in maintaining almost constant values of the water temperature and of the pressure at water distribution supply (but reset strategies are also sometime used in order to reduce the chillers and pumps consumptions).
Such strategies disserve verification.
Last but not least, the check valves have also to be commissioned…

Commissioning of the Plants

This is the last step in this commissioning strategy: if the temperature and/or the pressure are not correctly maintained at the supply of the water network, it's because there is something wrong in the plant…
Modeling is of great help at this level, in order to understand the performances of each machine in the conditions considered (and in order to transpose the results to other conditions).
An example of chiller model output is presented in Figure 10: it shows how the COP and the electricity consumption of a chiller of our case study should vary with the outside temperature in full load, according to manufacturer's data.
Less beautiful results were got in the commissioning: it appeared that the chillers were consuming about 20 % more electricity than expected for a given cooling power. This fact is not yet fully explained. Only a part of the performance degradation seems to be due to a microclimate effect: air re-circulation from the exhaust to the supply of the condenser. This effect is shown in the results presented in Figure 10.
And this is not the end of the CAMET re-commissioning story…

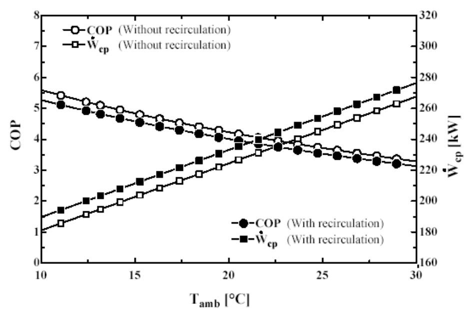

Figure 10: (Simulated) chiller performances in full load

PROVISORY CONCLUSIONS AND PROSPECTIVE

The case study presented here has nothing exceptional: it's unfortunately true that the best ideas and the best component performances are often "wasted" in the building.

Responsibilities and competencies are dispersed among too many people and quality control is not achieved at a satisfactory level.

In such circumstances any serious statistical analysis would demonstrate a high probability of mistake in many parts of the HVAC system.

If not corrected on time, these mistakes may generate a lot of complaints and (energy and money) wastes.

In the case study considered, a serious initial commissioning would have allowed us to resolve at lowest costs almost all the problems encountered.

Most of these problems were indeed due to mistakes committed in control connections or in initial tuning. None of them was due to the malfunction of a HVAC component.

Better late than never, let's hope that the re-commissioning of this HVAC system might contribute in restoring people's confidence in air conditioning…

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