A Functional Test Procedure
for the improved commissioning of a VAV system

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ABSTRACT

In the context of the IEA40 research project, a specification of a "Functional Test Procedure" was progressively developed using the CA-MET building in Namur as real size test bench for the application and validation of the procedure. The target system is a typical VAV system devoted to the ventilation, cooling and air conditioning functions.

The procedure consists in a series of operations to be applied to the system, considered as a set of connected components and taking into account the following constraints:

-   time availability
-   intrinsic limitations of the system
-   reference performances

The proposed procedure is divided in two sets of actions:

-   a number of preliminary actions allowing to take the best benefit of the subsequent phases:
    o   identification of available measurement points
    o   identification of actuators characteristics
    o   identification of control strategies
    o   aeraulic network calculations
    o   selection of measurement techniques and experimental design
-   the verification tasks themselves:

The philosophy of the verification process is to bring the system into a number of states which allowed each specific check to be carried out. The organisation of the procedure tries to optimize the time spent for commissioning by logically sequencing the operations according to the following order:

-   test in manual (ie not controlled by the BEMS) operation
-   test in manual (ie not controlled by the BEMS) stop
-   test in normal operation
-   test at maximum flowrate
-   test at minimum flowrate
-   test in automatic stop

The paper will provide the specific operations to be carried out at each step and will illustrate the whole process with the prototyping work performed on the CA-MET building in Namur.

1. INTRODUCTION

IEA Annex 40 is targetting the development of specific procedures for supporting the verification of typical HVAC components in buildings. An important class of components is povided by VAV air-conditioning systems, which integrate a number of interconnected elements. Although the development of individual procedures for the different components corresponds to a real need, it is also useful to look at the system as a whole and to provide a procedure which aims at giving a global evaluation of the performance of the system. The purpose of this paper is to explain the philosophy and the content of such a procedure, which was developed for a typical office building in Belgium.

2. SUPPORT TO THE DEVELOPMENT OF THE PROCEDURE: AN OFFICE BUILDING IN BELGIUM

The test building is a recently completed office building constructed to host the headquarters of one Administration of the Walloon Region. This building was designed in the mid nineties (from 1993 to 1995), constructed between 1997 and 2000 and entered in operation at the end of the summer 2000.

This building was the object of a continous resarch work performed by the University of Liège and FUL all along the life of the building. It was used as a support to the launching of IEA Annex 30 ("Bringing Simulation to Application"), where the design of the building and of the HVAC system was assisted by the use of modern simulation tools. Afterwards, when the building was put into operation, it was used as a support to IEA Annex 34 ("Computer-aided evaluation of HVAC systems performance in buildings"). In this case, the goal was to identify faults appearing in the building and to propose automatic or manual methods in order to detect and eventually diagnose those faults. This part of the work showed that a lot of mistakes were committed during the construction and even during the design of the building and that a new "comissioning" or "re-commissioning" was really required. This was the reason to propose the building as a case study for the IEA Annex 40 project.

In that context, most of the efforts of the research team were applied to the aeraulic system where most of the problems were identified: a number of Air Handling Units were analysed, including their associated network, and this work was the basis of the development of a procedure (a so-called "Functional Test Procedure") to support the performance verification of the components. A typical application of this procedure is given in a companion paper [1]. This paper will concentrate on the procedure itself, which was developed following the general scheme given in the IEA 40 final report. This scheme identifies the following items:

- Presentation of the system
  - o Operating principles
  - o Manufacturers data
  - o Problems to be considered
- Preparation phase of the test

- o Evaluation of the available data and expected performance
- o Preparation of the additional instrumentation to install
- Test method
  - o Sequence of test
  - o Experimental method
  - o Test report content
- Additional possibilities

3. THE PROPOSED PROCEDURE

3.1. The system considered

This test of functional performances is applicable to the following air conditioning systems :
 - All air, Variable Air Volume (VAV), Single Duct"VAV" system, where the required sensible coolingpower is supplied to the zone by tuning the air flow rate at given supply temperature which is centrally controlled;
- with mechanical supply and exhaust ventilation system;
- for "type 4" building, i.e. large commercial building with centralized HVAC system.

The working principles of this system are given here after

3.1.1. Working principles.

A typical VAV system (fig. 1) includes the following subsystem and components :
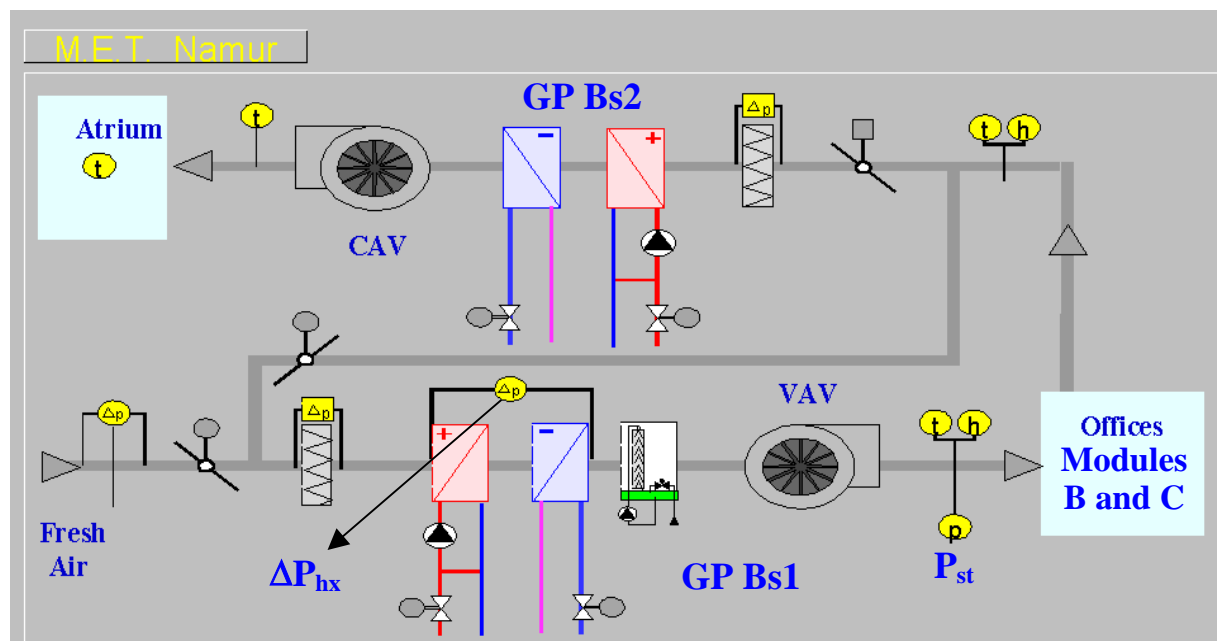

Fig. 1: Scheme of a typical VAV system , as concerned by the procedure

Terminal units (VAV boxes)
Air distribution network, including fresh air inlet, supply network, exhaust network, recirculation network

Air Handling Units with economizers, filters, coils, humidifiers (zones) supply fans
(zones) exhaust fans
Pumps
Control system with sensors, actuators and control units.

In order to provide good operating conditions to VAV boxes, the control system imposes a constant pressure at supply fan exhaust. This pressure must be high enough to compensate all pressures drops occurring in the air distribution network in most severe conditions (maximal airflow rate). This pressure set point has to be fixed after a correct balancing of the network.

The balancing is performed with the help of a set of dampers, located at different points of the network.
The economizer of each air handling unit is controlled in such a way to ensure a sufficient fresh air flowrate or to minimize the air treatment cost, while maintaining enough air renewal, the fresh air flow rate being adjusted in relationship with the occupancy of each conditioned zone.
The supply temperature can be controlled as a function of internal and/or external climate conditions, in such a way to optimize the VAV operational conditions and the corresponding comfort conditions.

3.1.2. Documentation

All designer, manufacturer and installer data are (or should be) included in the as-built records including :
- The Owner's Project Requirements established by the owner with the help of the commissioning authority including:
  o The owner program ;
  o The Design Requirements
- the design documents including:
  o The construction specification;
  o The guide for system control and operation:
  o The calculations (with corresponding hypotheses, methods and results);
- The testing, adjusting and balancing results for :
  o water flow in pipes adjusting;
  o air flow in ducts adjusting;
  o control parameters tuning.
- The previous commissioning results (if any)
- others technical documents:
  o The list of the components actually installed;
  o Installation plans;
  o The technical documentation of each component;

3.1.3. The most frequent problems

Problems may occur at any time, all along the building life cycle (BLC) but some of them can only be resolved at specific time. That's why the commissioning process have to be organized all along BLC.
The test of functional performance which is presented hereafter can be performed in initial, re-, retro- and on going commissioning. The so-called "initial" commissioning is supposed to

start very early in the BLC, because some problems can be related to design mistakes, undersized technical room, bad insulation, insufficient solar protections, bad equipment sizing (air ducts, fans, registers, coils, groups), oversized safety margins, wrong evaluation of working points, unadapted sensors, bad control strategy, bad data storage method, etc.
Some other problems are met at installation stage. The commissioning method should allow to detect and to correct these mistakes early enough, i.e. when all components concerned are still easy of access. This is particularly true for problems of :

(electrical, pneumatical and mechanical) connections;
balancing;
tightness;
set point tunings;
conversion laws;
control parameters;
component location (VAV boxes, sensors, …);
calibration of measuring devices ;
noise;
interferences;
control programming;
data storage.

Other aging problems are occurring in the system working phase. At this stage, the on going commissioning must be able to detect them.

Most typical aging problems for such systems are :

corrosion;
sensors drifts;
dirtiness of filters, coils, humidifiers and registers;
broken belt.

3.2. The Functional Performance Test (FPT)

The proposed testing procedure includes a preparation phase as well as a test method made of a number of steps.

3.2.1. Preparation phase of the test

Before applying the method described hereafter (3.2.2.) a certain number of preliminary actions have to be carried out in order to make easier and quicker the test sequence :

- As the test procedure may rely on the readings of some BEMS sensors and as its may use some commands of the BEMS, the following preliminary verifications should be made:
    o the evaluation of control characteristics (eg authority)
    o the evaluation of the monitoring points
    o the evaluation of the control strategies
- Therefrom, the additional resources to use in the commissioning can be identified:
    o the selection of the measurement techniques (eg for the fan flow rate)
    o some preliminary calculations (eg aeraulic network calculation)

  o the additional instrumentation to use in situ, specially concerning:
     ▪ the Air Handling Units to be checked (static pressure measurements)
     ▪ the ducting network
     ▪ some representative offices

3.2.2. Test Method

The method consists in testing the performance of a certain number of components and sub-systems of a ventilation system.

The originality of the method is that several functional performance tests elaborated individually per component and sub-systems are put together here, in a way to benefit from similar test conditions.

The operational conditions required for the individual performance test of each component and sub-systems are very often identical or at least similar. The fact of creating one time these required experimental conditions and organize afterwards the performance tests, allows to save time. The method includes six steps where the objective of each step is to bring the plant in a particular operational mode with specific associated testing objectives:

Test 1: test in manual operation

This test consists in operating the system manually (ie control laws implemented in the BEMS are no longer active) and to check the available commands: on/off and modulating commands.

Concrete actions include:

  - opening of dampers at different values (from 0 to 100% opening) and check of the real state of the damper and real opening degree
  - operation of the VAV fan at different regimes (between 0 and 100% maximum speed) and check of the real speed of the fan
  - operation of the pumps and check of the real state of those pumps

Test 2: test in manual "stop"

This test consists in manually shutting down the system and to check the status of the controls and readings of some sensors in these conditions:

  - all fans and pumps should be off
  - dampers should be in the position corresponding to the "off" status (usually closed)
  - all pressure sensors should read the atmospheric pressure (or a 0 relative pressure)
  - all temperature sensors locted in the AHU should give similar results
  - temperature and humidity sensors can be checked against "reference" sensors located as near as possible to the sensors to check
  - the operation of the data archieving procedures can also be checked at this moment: effective recording of the selected variables, sufficient precision of the measurement recordings, adequate time step,…

Test 3: test in normal operation

This test consists in running the system in the "normal" operation mode and verifying the performances of selected components in those "natural" conditions. A typical example of such

a verification is concerning the peformances of the fan (essential component in a VAV system). This performance verification can be carried out with different techniques. The choice of the technique should have been made prior to the test, during the preliminary operation. As direct measurement of the flow rate is difficult to carry out, verification should use other measurements, depending upon the fan type: forward or backward inclined blades.

For forward inclined blades: electrical power and rotation speed
For backward inclined blades: total pressure and rotatio speed
For both types: total pressure and electrical power

Test 4: test in maximum flow rate conditions

This test consists in artificially "forcing" the system in summer operation, creating that way the conditions for maximum flow rate. This is done by changing the setpoint of the VAV terminals to the lowest possible value, which forces the boxes to open with the maximum flow rate. A number of practical checks can be operated once the flow rate is stabilized around its maximum value:

- verification of the supply and exhaust pressure sensors (at maximum value) by comparison with a reference sensor (including verification of the measurement range and the conversion law of the air pressure sensors
- verification of the aeraulic actuators (dampers) position and authority in summer operation
- verification of the pressure drops and aeraulic network aeraulic balancing
- verification of the supply pressure setpoint
- verification of the air flow in the AHU (supply flowrate that should correspond to the maximum design value, fresh air and exhaust air flowrates) and in selected rooms(by CO_2 or an other tracer gas measurements)
- verification of the tightness of the aeraulic network

Test 5: test in minimum flow rate conditions

This test consists in artificially "forcing" the system in winter operation, creating that way the conditions for minimum flow rate. This is done by changing the setpoint of the VAV terminals to the highest possible value, which forces the boxes to close with the minimum flow rate. A number of practical checks can be operated once the flow rate is stabilized around its minimum value:

- verification of the performance of the fresh air flowrate control in minimum regime (fresh air flow rate in the AHU inlet should correspond to the design value) and in selected offices (by CO_2 measurements)

Test 6: test in automatic stop

This test consists in returning to the automatic mode of the system and checking that, when the system is supposed to enter its "shut-off" conditions (eg outside of occupation hours), all features of this mode are verified, eg:

- fans are of
- pumps are off
- fresh air dampers are closed

4. APPLICATION

This procedure was applied to several Air Handling Units of the CA-MET building in Namur, described here above. This allowed the procedure to be progressively improved although each implementation of the test sequence brought additional problems to solve. Detailed results of the implementation of the procedure are given in [1].

5. CONCLUSIONS

This paper proposed a systematic procedure for testing typical VAV Air Conditioning systems as encountered in west european offices buildings. The procedure is made of a number of preliminary steps and "real testing" steps. The general philosophy of the procedure is to bring the HVAC system in an organized sequence of predefined conditions with as much as possible continuity between the different phases. This is organized in order to save time in the testing process and take the best benefit of the commissioning action.

6. REFERENCES

[1] Philippe André, Cleide Aparecida-Silva, Nestor Fonseca, Jules Hannay, Jean Lebrun and Patrick Lacôte RE-COMMISSIONING OF A VAV AIR-DISTRIBUTION SYSTEM , submitted to ICEBO 2004, 2004.