### Example of Functional Performance Test:
FPT for VAV Ventilation Systems

#### Document Identification

<table>
<thead>
<tr>
<th>Type of documents:</th>
<th>Glossary</th>
<th>Cx Process</th>
<th>Project</th>
<th>Tool</th>
<th>Model</th>
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</thead>
<tbody>
<tr>
<td>Type of building:</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Type of Cx.:</td>
<td>Initial Cx</td>
<td>Partial Initial Cx</td>
<td>Re-Cx</td>
<td>Retro-Cx</td>
<td>On-going Cx</td>
</tr>
<tr>
<td>MQC task</td>
<td>Pre-Design</td>
<td>Design</td>
<td>Elaboration</td>
<td>Construction</td>
<td>Operation</td>
</tr>
<tr>
<td>Final end users</td>
<td>Owner</td>
<td>Cx Authority</td>
<td>Design prof</td>
<td>Contractor</td>
<td></td>
</tr>
</tbody>
</table>

Others indications: A40-B2-M7-Be-Ulg-01 (glossary checked)

### Contributors

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Introduction

The present document describes a Functional Performance Test developed by the Belgian research team.

The FPT structure is in fair agreement with what was proposed at previous working meeting (Berkeley, October 2003). Just a few changes were introduced, as an attempt to make it easier to read.

This structure is explained hereafter.

1. THE SYSTEM CONSIDERED
   A technical description of the system has to be given here, before talking about how to test it.
   1.1. WORKING PRINCIPLES
   1.2. DOCUMENTATION
   1.3. THE MOST FREQUENT PROBLEMS

2. THE FUNCTIONAL PERFORMANCE TEST (FPT)
   2.1. TEST SPECIFICATION
      This is a summary of the specification content: scope and purpose of the test, sequence of test, required time and (equipment and operational) pre-requisites.
   2.2. PREPARATION PHASE
      This has to be done before performing any on site measurement...
      2.2.1. EXPECTED PERFORMANCE EVALUATION
         2.2.1.1. Pre-estimate of control authority
         2.2.1.2. Identification and evaluation of the monitoring and control points
         2.2.1.3. Selection of the zones to be checked
         2.2.1.4. ...
      2.2.2. INSTRUMENTATION TO BE PREPARED
         2.2.2.1. Instrumentation of the AHU's
         2.2.2.2. Instrumentation of the selected zones
         2.2.2.3. Instrumentation of the ducts

2.3. TESTING PHASE
   2.3.1.1. Method summary
   2.3.1.2. Scenario

3. ADDITIONAL POSSIBILITIES
Two very promising possibilities are indicated hereunder.

3.1. MODEL CALIBRATION

Such calibration on site allows some of the components to be used as measuring devices.

3.2. POSSIBILITY FOR AUTOMATION

Some FPT procedures can be repeated automatically by the BEMS…

4. APPENDIX

Here are listed other information sources…

4.1. ABOUT THEORY

4.1.1. BOOKS AND GUIDES

4.1.2. WEB SITES

4.1.3. REGULATION DOCUMENTS

4.2. ABOUT MODELING

5. OTHER POSSIBLE FPT PROCEDURES

The FTP presented hereafter is just an example submitted to annex 40 participants for evaluation. It might become a part of the Annex 40 FPT library.
Functional Performance Test: VAV Ventilation Systems (FPT_Be_AirSysVav)

Document Identification

- Type of documents: ☐ Glossary ☑ Cx Process ☐ Project ☑ Tool ☐ Model
- Type of building: ☐ 1 ☐ 2 ☐ 3 ☑ 4 ☐ 5
- Type of Cx.: ☑ Initial Cx ☐ Partial Initial Cx ☑ Re-Cx ☑ Retro-Cx ☐ On-going Cx
- MQC task: ☑ Pre-Design ☐ Design ☑ Elaboration ☑ Construction ☑ Operation
- Final end users: ☐ Owner ☑ Cx Authority ☐ Design prof ☐ Contractor

Tool Identification

- Functional Performance Test (FPT) for Conventional VAV Air Systems

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1. The system considered

This test of functional performances is applicable to the following air conditioning systems (Figure 1):

- “All Air”, i.e. with air as the only one heating or cooling source;
- “VAV” system, where the required sensible cooling power is supplied to the zone by tuning the air flow rate at constant supply temperature;
- with single supply air duct;
- 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.

More information about VAV and other air conditioning systems are given in:
- "HPCBS : Control System design Guide", chapter 4 : system configuration (guide)
1.1. Working principles

A typical VAV system includes the following subsystem and components:

- Terminal units (VAV boxes)
- Air distribution 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 registers, located at different points of the network.

The economizer of each air handling unit is controlled in such a way to minimize the air treatment cost, with maintaining enough air renovation. The fresh air flow rate has to be adjusted in relationship with the occupancy of each conditioned zone.

The supply air temperature can be controlled as a function of indoor and/or outdoor climate conditions, in such a way to optimize the VAV operational conditions without sacrificing health and comfort requirement.

More information about the VAV subsystems can be found in:

- "HPCBS : FTG for Air Handling Systems : from the fundamentals to the field“, chapter 3-18, Theory and application.

1.2. Documentation

All designer, manufacturer and installer data should be included in the as-built records, including:
The Owner's Project Requirements (OPR), established by the owner with the help of the commissioning authority, including:

- The owner program (OP);
- The Design Requirements (DR)

The design documents, including:

- The construction specification;
- The guide for system control and operation:
- The calculations (with corresponding hypotheses, methods and results);

The testing, adjusting and balancing results for:

- Water flow in pipes;
- Air flow in ducts;
- Control parameters.

The previous commissioning results (if any).

Others technical documents as:

- The list of the components actually installed;
- The technical documentation of each component;
- The installation plans.

1.3. The most frequent problems

Problems may occur at any time, all along the building live cycle (BLC), but some of them can only be resolved at specific time. That’s why the commissioning process has to be organized all along BLC.

The test of functional performance, which is presented hereafter, can be performed in initial, re-, retro- and ongoing commissioning.

The so-called “initial” commissioning is supposed to start very early in 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, maladapted sensors, bad control strategy, bad data storage method, etc.

Some other problems are met at installation stage. The commissioning method must permit 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, pneumatic and mechanical connections;
- Balancing;
- Tightness;
- Set point tuning;
- Conversion laws;
- Control parameters;
- Component location;
- Calibration;
- Noise;
- Interferences;
- Control programming;
- Data storage.

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

Most typical aging problems are:

- Corrosion;
- Sensors drifts;
- Dirtiness of filters, coils, humidifiers and registers;
- Mechanical degradations and failures (example: a broken belt).

**Is it possible to save energy in the air system?**

What to look at?

- Air network configuration
- Network tightness
- Network insulation
Focus is given hereafter to the verification of tightness, pressure drops, fans characteristics and control strategies.

For more informations :

- "Airways : source book for efficient air duct systems in Europe".
2. The Functional Performance Test (FPT)

2.1. Test specifications

**Objectives and Test steps**

The goal of this test is to verify if the installation complies with the specifications described in the 'design documents'.

This test allows also to verify if the specifications of the design documents are adapted to the real conditions of occupation of the building.

Sixth test steps are proposed, in order to perform different verifications.

**Required Material**

- The BEMS, to conduct the test and to store all information already available
- 1 portable pressure sensor
- 1 combined sensor of temperature/humidity
- 1 portable air speed sensor
- 1 portable CO2 sensor
- 1 wattmeter
- 1 tachometer
- 1 sound meter

**Required time**

[Information still to be given]

**Pre - requirements**

A successful achievement of this test requires that:

- The design documents are available;
- The measurements made by the BEMS are available;
- The whole air system is operational (the AHU, the distribution system and the VAV terminals are all connected among themselves);
- The air-conditioned zones are at a “neutral” temperature (of the order of 22°C, around the middle of the control range of VAV terminals);
- The heating and cooling plants are operational;

In addition, some steps could only be achieved if the system is still
“accessible”: for example, a tightness test should be done before insulating the ductwork…

2.2. Preparation phase of the test

Before applying the method described hereafter (1.2.3) some preliminary studies have to be performed with the help of the documentation available:

- Evaluate (on paper) the expected performances;
- Prepare the instrumentation in situ.

2.2.1. Expected performance evaluation

2.2.1.1. Evaluation of control components authority

<table>
<thead>
<tr>
<th>Initial Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>For each control device referred in the design documents:</td>
</tr>
<tr>
<td>- The total pressure drop of the control device</td>
</tr>
<tr>
<td>- The total pressure drop of the circuit in which is located this control device</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Evaluation Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ \Delta p_{\text{network}} ]</td>
</tr>
<tr>
<td>[ \Delta p_{\text{component}} ]</td>
</tr>
</tbody>
</table>

The registers (in air circuits) or the valves (in water circuits) are the control devices that allow to vary the flow rate. Very often, the flow varies in logarithmic way, in function of the component opening. The achievable range of flow variation depends on the control device “authority”:

\[ \text{authority} = \beta = \frac{\Delta p_{\text{min}}}{\Delta p_{\text{circuit}}} \]

With \( \Delta p_{\text{min}} \) = the minimal pressure drop imposed by the control device (when fully open).

These nominal pressure drops should be given in the design documents.

- Complete the form 4, column "Validation of the functioning (manual verification)"
In practice, the verification might be more delicate because of the network geometry. For example in the vicinity of the registers, the best measurements that one can make are generally static pressures.

When both fresh and return air registers are part of the AHU (as shown here above, the authority of these registers can be evaluated as follows:

\[ \beta = \frac{\Delta P_{\text{component}}}{\Delta P_{\text{total}}} = \frac{P_{t3} - P_{t2}}{P_{t3} - P_{t1}} \quad (1) \]

Considering, in first approximation that:

- \( P_{t3} = P_{s3} \) (because of the strong increase of transversal area)
- \( P_{t1} = 0 \) (taking the atmospheric pressure as reference)

or,

\[ \beta = \frac{P_{s3} - P_{s2}}{P_{s3}} = \frac{(P_{s3} - P_{s2}) - P_{d2}}{P_{s3}} \quad (2) \]

with \( P_{d2} = \rho \frac{v_2^2}{2} \)

This means that a register authority can be verified on site, thanks to static pressure measurements (\( P_{s2} \) et \( P_{s3} \) for the fresh air register, in the example considered), providing that the corresponding dynamic pressure are negligible (as \( P_{d3} \)), or fairly well estimated (as \( P_{d2} \)) by velocity measurement (with an anemometer) or by calculation (from flow rate measurement). I
some cases, the static pressure measurements are difficult to measure due to the local fluctuations (turbulence, and local flow instability).

In such cases, it’s better to measure only the total pressure drop in the circuit ($P_{t3}=P_{s3}$) and, to “trust” the As Built Files for the component pressure drop. This is a way to limit the accumulation of measuring uncertainties:

$$\beta = \frac{\Delta P_{\text{component}}}{\Delta P_{\text{total}}} = \frac{\Delta P_{\text{component\_th}}}{P_{s3}}$$  \hspace{1cm} (3)

### Conclusions

Theoretical verification of the authority of a control device :

- $\beta = \frac{\Delta P_{\text{component}}}{\Delta P_{\text{total}}}$

Verification on site of this same authority :

- $\beta = \frac{(P_{s3} - P_{s2}) - P_{d2}}{P_{s3}}$ with $P_{d2} = \rho \frac{v_2^2}{2}$
- $\beta = \frac{\Delta P_{\text{component\_th}}}{P_{s3}}$

2.2.1.2. Evaluation of monitoring and control points

...

2.2.1.3. Evaluation of the number of offices to be checked

...

2.2.1.4. Evaluation of fan performances

...

2.2.1.5. Evaluation of automatic stop control

...

2.2.1.6. Evaluation of pressure losses and of air balancing

...
2.2.1.7. Evaluation of air flow measuring techniques

...

2.2.2. Instrumentation to be prepared

2.2.2.1. Instrumentation of AHU's

Sensor “sockets” have to be prepared, in order to make possible some static pressure measurements along the air distribution network:

- At some room supplies
- At the level of zones branches
- At the level of floors branches
- At the level of the reference office branches

A static pressure “socket” consists in a hole in the duct, equipped with flexible tube a connector.

*A “level” is understood here as any appropriate location for pressure measurement. It can be before, or after, a branch, preferably where the duct is as straight as possible.

2.2.2.2. Instrumentation of test offices

...

2.2.2.3. Instrumentation of the ducts

...

2.3. Test Method

2.3.1.1. Method summary

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

The originality of the method is that several components and sub-systems FPT are co-ordinated into a global procedure, in such a way to take profit from the same experimental conditions.

Almost the same experimental conditions would have indeed top be prepared an individual test applied to each component and subsystem.

A lot of time can be saved by applying the global method proposed hereafter.
### 2.3.1.2. Scenario

#### 1st step: test of manual start up

**Objectives**
- Verification of the control devices in ON/OFF and modulation commands

**Actions**

In order to run the ventilation in “manual” mode, the following actions have to be performed through the BEMS:

- Manual opening of registers and valves (modulation to 100%)
- Manual setting of fans in maximum regime (modulation to 100%)
- Manual starting of pumps and fans ("ON" command)

- Verification of the commands and modulations of the control devices
  - compare the real state of these components with the commands and modulations taken from the BEMS
  - from BEMS, put the fan in minimum regime (modulation to 0%)
  - on site, verify the real state of the fan

  Complete the form 4, column “verification of functioning (manual verification)”.

#### 2nd step: test in manual stop

**Objectives**
- Verification of the commands and modulation of the control devices
- Verification of temperature and humidity sensors functioning
- Verification of pressure sensors offsets
- Verification of data storage (BEMS) functioning

**Actions**

In order to put the installation in “manual” stop, the following actions have to be performed through the BEMS:

- “manual” closing the registers and valves (modulation to 0%)
### Functional Performance Test:
VAV Ventilation Systems (FPT_Be_AirSysVav)

- **“Manual” turning off of pumps and fans (“OFF” command)**

  - **Verification of the commands and modulations of the control devices**
    - compare the real state of these components with the commands and modulations given by the BEMS
    
      Complete the form 4, column "verification of functioning (manual verification)".

  - **Verification of the sensors used to measure:**
    - **Air temperature and humidity:**
      - Remove the sensor from its support;
      - Introduce it for a few minutes into a thermostatic enclosure, equipped with reference sensors and verify the time (from BEMS)
      - Compare the measurements taken by the BEMS with the reference measurements
      - Replace each sensor on it support
    - **Surface temperature:**
      - Place the reference sensor as near as possible to the sensor to verify
      - Compare its measurement with the value given by the BEMS
      - Heat the sensor with an external heat source (hair dryer,...) during a period superior to the acquisition step of the BEMS and mark down the time (from the BEMS)
      
      Complete the form 3, column "verification of functioning (manual verification)"

  - **Verification of the offsets of pressure sensors**
    - Put the orifice of each sensor to the atmospheric pressure, during a period superior to the acquisition step of the BEMS and mark down the time (from the BEMS)
    - Verify on the graphic interface of the BEMS that the pressure has fallen down to zero
    - Replace the sensor in its original location
      
      Complete the form 3, column "verification of functioning (manual verification)"

  - **Verification of the data storage (BEMS)**
    - Stop the acquisition, recuperate the data and restart the storage
    - Verify that the storage is well done for each sensor previously before verified
    - Verify that archived variable corresponds to the component considered.

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3rd step: Test in “Normal” running conditions

Objectives

- Verification of fan performances

Actions

In order to get the fan in “normal” running conditions, the following actions have to be performed:

From the BEMS:
- Put the registers and valves in automatic mode
- Put the fan considered in automatic mode
- Put the pumps and other fans also in automatic mode

4th step: Test in maximum flow (summer condition)

Objectives

- Verification of the measuring ranges and conversion laws of supply and exhaust pressure sensors
- Verification of the system configuration
- Verification of the network balancing
- Localization of the most and less “privileged” offices (according to the air supply pressure)
- Verification of supply pressure setting up
- Verification of air flow rates at the level of the AHU (supply, fresh and return air) and at the level of reference offices
- Verification of pressure drops along the air distribution network
- Verification of the authority of the control devices (registers)
- Verification of network tightness

Actions

In order to get the ventilation in maximum flow,

- Verify that the offices are at a “neutral” temperature (ideally the
Functional Performance Test:
VAV Ventilation Systems (FPT_Be_AirSysVav)

<table>
<thead>
<tr>
<th>point in the middle of the control range of the VAV boxes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set the thermostats of the VAV boxes in their lowest temperature</td>
</tr>
<tr>
<td>Wait for the stabilization of the maximum flow</td>
</tr>
<tr>
<td>Verification of measuring range and conversion laws of supply and exhaust air pressure sensors</td>
</tr>
<tr>
<td>…</td>
</tr>
</tbody>
</table>

5th step: test in minimum flow (winter condition)

<table>
<thead>
<tr>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verification of the performance of the fresh air flow control in minimum regime</td>
</tr>
<tr>
<td>Verification of the minimum air flow rates blown in the reference offices</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>In order to get the ventilation in minimum flow,</td>
</tr>
<tr>
<td>Set the VAV thermostats in their highest position</td>
</tr>
<tr>
<td>Wait for the stabilization of the maximum flow rate</td>
</tr>
<tr>
<td>Verification of the performance of the fresh air flow control in minimum regime</td>
</tr>
<tr>
<td>…</td>
</tr>
</tbody>
</table>

6th step: test in automatic stop

<table>
<thead>
<tr>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verification of the system state in automatic stop</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Put the ventilation in automatic stop</td>
</tr>
<tr>
<td>(through the BEMS clocks management program)</td>
</tr>
<tr>
<td>Verification of the system state in automatic stop</td>
</tr>
<tr>
<td>…</td>
</tr>
</tbody>
</table>
3. Additional possibilities

3.1. Model calibration

3.1.1. Fan

3.1.2. Air duct system

3.2. Possibility for automation

4. Appendix

4.1. More about theory

4.1.1. Books and guides

- "High Performance Commercial Building Systems : Control System design Guide"
- ...

4.1.2. Web sites

- Annexe 40 : program of the International Energy Agency (IEA-ECBCS)...
  http://www.commissioning-hvac.org/
- ...

4.1.3. Regulation documents

- "Norme NBN EN 12599 : Ventilation des bâtiments – Procédure d'essai et méthodes de mesure pour le réception des installations de ventilation et de climatisation installées".

4.2. More about modeling

5. More about FPT

More information about functioning performance tests can be found in the following reference:
- "HPCBS : FTG for Air Handling Systems : from the fundamentals to the field", Appendix A, Appendix A - Overview of the Commissioning Test Protocol Library (CTPL)