CITE-AHU, An Automated Commissioning Tool for Air-Handling Units

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Synopsis

Automated commissioning tools are designed to facilitate part of the commissioning process, decreasing the amount of time and skill level required to carry out the process. They improve the quality and persistence of correct system operation, enabling more thorough testing of building HVAC systems. In 2003, CSTB and NIST collaborated to develop CITE-AHU, an automated commissioning tool for air-handling units, and perform a field-test of the prototype. This paper provides an overview of how CITE-AHU has facilitated the retro-commissioning process and illustrates how use the prototype tool.

About the Authors

Natascha Castro is the US team leader for Annex 40. As a Mechanical Engineer in the Mechanical Systems and Controls Group of the NIST Building and Fire Research Laboratory, she has worked on several projects in the areas of commissioning and fault detection and diagnostics. Natascha is currently working on her PhD at the George Washington University in the area of building control.

Hossein Vaezi Nejad is a Mechanical Engineer at CSTB, the main French research center for buildings. He is a part of the Building Automation and Energy Management Group and has been active in the development and testing of automated commissioning tools.
Background

The tool described in this paper was developed as part of an IEA Annex 40 research project that included the retro-commissioning of a real building in Paris as a field test of the prototype[1]. The collaboration between NIST and CSTB focused on creating a service tool called CITE-AHU, an automated commissioning tool for air-handling units (AHUs)[2]. The concept is to enable the testing and analysis of air-handling units by commanding the system into its normal modes of operation and then applying expert rules which are capable of detecting improper system operation[3]. Due to the gross nature of the faults that impact comfort and efficiency, it is usually sufficient to use qualitative models to identify faults.

Tools such as CITE-AHU are designed to decrease the amount of time needed to carry out manual commissioning and to reduce the skill level required to carry out the process. They enable more thorough testing of building HVAC systems to improve quality and persistence of correct system operation.

The basis for the analysis used in this study is APAR (AHU Performance Assessment Rules), a set of expert rules designed to assess the performance of AHUs using data from existing sensors in the building energy management system (BEMS). The extent of the assessment is generally limited by the availability of operational data (e.g., occupancy information, setpoint values, sensor measurements, and control signals) and design data (e.g., ventilation requirements and sequencing strategy). However, because the typical commercial grade sensors already installed for control purposes have sufficient accuracy, laboratory grade instruments are not required.

APAR uses control signals and occupancy information to identify the mode of operation for the AHU, where Mode 1 is heating, Mode 2 is cooling with outdoor air, Mode 3 is mechanical cooling with 100% outdoor air, Mode 4 is mechanical cooling with minimum outdoor air, and Mode 5 is used to designate unknown cases.

Once the mode of operation has been determined, the rules based on conservation of mass and energy are applied to the operational data in order to assess the system operation. House et al. [4] provide a detailed description of 28 APAR developed for Variable Air Volume (VAV) AHUs and the reasoning behind them. While many of the more general rules can apply to various systems, the rule set must be customized using expert knowledge of the design data and sensor availability of the system(s) to be tested. Furthermore, the research collaboration includes enhancements to enable a commissioning authority or a building operator to run test scripts for the purpose of exercising particular components and documenting test results.

CITE-AHU is a tool to assist operators in the process of commissioning air-handling units (AHUs) with the help of a Building Energy Management System (BEMS). The overall retro-commissioning process involves the seven steps summarized below.

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1 In 2000, the International Energy Agency’s (IEA) Energy Conservation in Building and Community Systems (ECBCS) program established Annex 40, a research working group on Commissioning of Building HVAC Systems for Improved Energy Performance.
### Table 1: Key Steps in the Retro-Commissioning Process with CITE-AHU

<table>
<thead>
<tr>
<th>Step 1: Design Review</th>
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<tbody>
<tr>
<td>• check control logic, sensor placement</td>
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<tr>
<th>Step 2: Installation Review and Verification</th>
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<td>• conduct a field-inspection to determine installed characteristics of the equipment including condition and sensor availability and sensor accuracy</td>
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<tr>
<th>Step 3: Operator Interview</th>
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<td>• capture the Operator’s knowledge of the equipment, operation history, and general assessment of its operation</td>
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<th>Step 4: Measurement Verification Using the BEMS</th>
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<td>• define measurements to log with BEMS, evaluate the data for compliance and compare data.</td>
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<tr>
<th>Step 5: Configuration of CITE-AHU</th>
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<tr>
<td>• review the rule set and reconfigure, if needed, taking into account differences in equipment configuration and sequence of operations. The rules used to assess AHU performance are robust and applicable to various systems with some modifications.</td>
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<th>Step 6: Forced Response Testing and Analysis with BEMS</th>
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<tr>
<td>• <strong>Functional Testing</strong>—Active testing scenarios are applied to verify the performance of the AHU. Active tests can be automatically executed (direct manipulation of the system through manual override, setpoint change) during unoccupied period to minimize disturbances to normal building operation.</td>
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<tr>
<td>• <strong>On-going Commissioning</strong>—Under normal building operation, the data collected by the BEMS can be analyzed regularly (daily, weekly, or monthly) using CITE-AHU. CITE-AHU helps the user to detect and diagnose AHU faults and presents the results in a hierarchical way to provide the user with access to several levels of diagnostic detail</td>
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<tr>
<th>Step 7: Documentation of Test Results</th>
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<td>• includes a record of tests and evaluation of cost-benefit of commissioning as appropriate</td>
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</table>

### Design Review

During the design review phase the user will collect data on:

- AHU design: component specifications data, …
- Control design: sensors, actuators, control strategies, setpoints, scheduling, …
- BEMS: available data, data point names, logging data, …
The data will be used to configure the BEMS database to log the data that will be useful for the testing and assessment sequences, and to configure the CITE-AHU tool as illustrated below:

- Configure CITE-AHU with the AHU specifications- specify the type of unit to be tested and system capabilities, and enter on/off schedule for the system (see Figure 1).
- Create the CITE-AHU database links to the BEMS database (see Figure 2).

**Figure A.:** CITE-AHU configuration options for AHU type, system capability, and scheduling

**Figure B.:** Tool to create CITE-AHU database with available BEMS data listed.
Installation Review and Verification

During the manual verification step, the CITE-AHU tool advises the user on which points are essential to check, suggests a method to use and aids the user to save the results of the test activity in a formatted document.

For example, to test the “Return Air Temperature Sensor” the user must answer the following fundamental questions:

1. Is the sensor really available?
2. Is the sensor placement optimal for measuring the physical phenomena?
3. Is the sensor correctly connected to the control equipment (wiring)?
4. Is the sensor measurement consistent with reference values?

Figure C.: CITE-AHU interface for manual verification of the installation with documentation capabilities.
Operator Interview

This step involves collecting data about operator and occupant requirements and AHU actual performance. Although CITE-AHU does not provide assistance during this phase, it is envisioned that a guideline to assist the user during the operator interview and in collecting data could be included in a future version.

Measurement Verification Using the BEMS

This step includes the initial assessment of AHU performance and verification of sensor and actuator data. Again, CITE-AHU does not provide assistance during this step. However, a guideline to assist the user during the measurement verification using the BEMS could also be added in a future version.

Configuration of CITE-AHU

The rules used to assess AHU performance are robust and applicable to various systems. However, the rule set must be reviewed and reconfigured, as needed, prior to their implementation in a new system due to differences in equipment configuration and sequence of operations.

The following example presents a rule that is only applicable for AHUs on which the return air temperature is controlled. For other cases the rule must be disabled.

![Figure D.: CITE-AHU feature that enables the user to enable/disable specific rules based on equipment configuration and sequence of operations](image-url)

1 - Select an AHU
2 - Select an operating mode
3 - Enable or disable rules based on equipment configuration and sequence of operations

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Forced Response Testing and Analysis with BEMS

Functional Testing

During functional testing, active testing scenarios are applied to verify the performance of the AHU. Active tests can be automatically executed during unoccupied period so as not to disturb normal building operation. The different scenarios of active testing are saved in the CITE-AHU library and can be applied periodically (annually or seasonally).

Two main types of active tests are open-loop and closed-loop:

- With open-loop tests, the performance of different components of the AHU is evaluated while exercising the component over its full range of operation. Here, the system is operated in manual override and the performance of the component is evaluated over the operating range (i.e., the cooling coil valve is opened to 0%, 30%, 60% and 100%). A diagram depicting this process using CITE-AHU is shown in the following figure.

- With closed-loop tests, the performance of the overall equipment is evaluated while operating in different functional modes (heating, free-cooling, mechanical cooling, etc.). To perform the tests, the setpoints are changed to operate the system in the chosen mode (example: the setpoint of the supply air temperature is changed from 20 °C to 16 °C to test the cooling mode and from 20 °C to 25 °C to test the heating mode).

Execute Scenario 2.1, shown in Figure 5, is used to automate the tests. When the scenario is being executed, the actions are highlighted in green as a signal to the user that they are completed.
To configure the communication interface between the “scenario execution” module of CITE-AHU and the BEMS we need to know the list of the BEMS point names. The “scenario execution” module of CITE-AHU runs at the management level of the BEMS and it communicate via the BEMS supervision with an OPC communication interface, shown in Figure 6.

Figure F.: Illustration of a BEMS interfaced to CITE-AHU using the OPC data access specification

Figure 7 shows the overall process in executing automated tests. Using the BEMS, CITE-AHU helps the user to analyze the results and automatically saves the results in a formatted document.
**On-going Commissioning**

Under normal building operation, the data collected by the BEMS can be analyzed regularly (daily, weekly, or monthly) using CITE-AHU. This tool helps the user to detect and diagnose AHU faults and presents the results in a hierarchical way to provide the user with access to several levels of diagnostic detail.

In Figure 8, a series of images illustrate the steps to use CITE-AHU in the commissioning process. The first step is to import the data. When this is selected from the main menu, a separate screen appears that shows all of the existing files available for import. Next, the AHU must be selected from the pull-down menu. And the user can select the week and year to view the automatic fault detection summary for one or more specified AHU(s). The user then tells the program to ‘go’ and analyze the data. The results are then produced in this table where the darker color red indicates the importance of the fault detected for an AHU, based on fault duration and threshold levels. The repetition of the faulty days in the table is also an indication...
that the system is in need of maintenance. If too many faults appear, the sensitivity can be lowered to show the user the largest faults. Once those are addressed, the sensitivity could be increased. By clicking on a specific cell on the table, the user can access more detailed diagnosis results stating which fault was detected and under which operating mode. The user can also validate the diagnosis by using graphs (temperature plots and control signals plots) accessible at this level.

**Step 1:** Select ‘Import Data’ to call up the Import Data Module

**Step 2:** Select a particular AHU to work on or select ‘All AHUs’

**Step 1:** Importing data module- choose the BEMS logging data to analyze with CITE-AHU

**Step 2:** Define the testing period: week and year

![Collection of CITE-AHU images illustrating the step-by-step process to evaluate AHU data](image)

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Step 3: Analyze the AHUs performance by clicking on “Go”. Step 3: Adjust the sensitivity filter for the fault detection program to manage the number of faults displayed. The “low sensitivity” setting means CITE-AHU will display only the faults having the greatest impact).

Step 4: Access more detailed diagnosis results for a particular day by selecting the corresponding cell on the table. A summary of the fault causes will appear, listing which faults were detected under which operating mode.

Step 4: Further details from the fault summary can be obtained by selecting ‘Details’. Additional graphing features can be used to validate the diagnosis. ‘Graphic T’ provides a link to temperature plots and ‘Graphic CMD’ provides a link to control signals plots.

Figure H. (continued) : Collection of CITE-AHU images illustrating the step-by-step process to evaluate AHU data

CITE-AHU is self-documented. It can be used with different AHUs (constant and variable air volume) and can be reconfigured for specific cases.
Documenting Results

The documentation of the tests (manual, automatic…) are saved automatically in an HTML format file. You can access to this file by using the “Print” function of the “Files” menu.

![Illustration of an automatically generated test report](image)

**Figure I.: Illustration of an automatically generated test report**

### References


