International Institute for Sustainable Laboratories®

I²SL Technical Bulletin: Retro-Commissioning Laboratories for Energy Efficiency

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Introduction

Retro-commissioning (RCx) has been extensively studied, and a large number of resources exist for understanding and implementing RCx projects and programs (including those listed at the end of this document). The purpose of this technical bulletin is to highlight unique process steps and energy-performance issues that relate to laboratories. When retro-commissioning laboratories to optimize their energy performance, three specialized areas need to be carefully evaluated:

1. Fume hoods or exhaust devices: the primary user-safety system.
2. Laboratory space or module: the secondary user-safety system.
3. HVAC systems that serve laboratory spaces.

Therefore, the primary issue for energy efficiency in laboratory modules is airflow, pressure, and temperature control in the lab space. RCx should eliminate waste and increase efficiency while maintaining or improving safety and reliability.

Basic Retro-Commissioning Process Steps

A brief review of a basic RCx process is presented for reference in Figure 1. Bold highlights and uppercased text indicate areas of focus in this Bulletin, and are described in more detail in the next section.

Lab-Specific Process Considerations

Retro-commissioning is typically a one-time effort. Monitoring-based commissioning (MBCx) is a related process that maintains, and continuously improves, building performance over time.

The RCx Process

Planning
Initial programming
KICKOFF MEETING
INFORMATION GATHERING
Developing a retro-commissioning plan

Pre-Investigation
Interview facility O&M
VERIFY MONITORING SYSTEMS
Drawing review
Site verification

Investigation
Benchmark utility and energy-use data
TREND REVIEW
DEVELOP FUNCTIONAL TESTS
Perform tests
Log findings
Compile summary report

Implementation
Prioritize and select improvements
Verify performance improvement

Handoff

Figure 1. Retro-commissioning process steps. Highlighted steps indicate areas of focus in this bulletin. Source: Labs21 original bulletin.

MBCx is defined as the implementation of an ongoing commissioning process with a focus on monitoring and analyzing system performance data on a continuous basis.

Consider available resources and goals to decide between an RCx or an MBCx approach. Both will yield operational improvements and energy savings. MBCx will ensure persistence of these benefits over time, but requires an ongoing effort, likely supported by data analytics from an energy management and information systems (EMIS) platform. (For resources and guides, see the Berkeley Lab's information at https://buildings.lbl.gov/emis/best-practice-guidelines-and-resources.)

This document focuses on RCx, but many of the recommendations also apply to MBCx. The recommendations below are specific to laboratory-related aspects of RCx.

1. Planning: Kickoff Meeting

Interviews with stakeholders are especially important when retro-commissioning laboratory spaces. The lab users must be consulted, followed by discussion with facilities personnel, EH&S department staff, and in-house design engineers. Safety and preservation of research data must not be compromised during the RCx effort. Therefore, a coordination "kickoff" meeting after individual meetings is essential.

A probable result of the coordination meeting is that a dedicated RCx "test day" will need to be arranged. Of particular importance at this stage of the process is to define the goals of the RCx effort, ensuring that any improvements will not adversely affect the research activities in the laboratory. Goals and expected outcomes may vary from project to project, and even between different stakeholders on the same project. The definition of project success should be established at the kickoff meeting to help guide subsequent efforts.

2. Planning: Information Gathering

The design of laboratory ventilation requirements is a key component impacting energy used by the lab. First, obtain the ventilation requirement for the lab as originally designed. Second, examine the derivation and reasoning that resulted in the specified requirement(s). This examination is warranted due to the ever-changing research mission of most laboratories and evolving design guidance or best practices. Third, confirm the current usage of the lab and reestablish ventilation design parameters.

The Smart Labs Laboratory Ventilation Risk Assessment (LVRA) process can be used to determine ventilation requirements based on evaluation of hazards (see https://smartlabs.i2sl.org/assess.html). Verify and catalog baseline readings and values for functional tests to be performed later.

3. Pre-Investigation: Verify Monitoring Systems

In addition to usual verification of direct digital control (DDC) or building automation systems (BAS) efficacy, consider supplementary monitoring instrumentation specific to lab operation. Adding such monitoring points can help address additional energy-use aspects of the lab space. These instruments and monitored points include:

- Supply air temperature sensors downstream of any reheat coil.
- Supply and exhaust airflow at the air-handling unit(s) and zones, e.g., from airflow stations or airflow control devices.
- Pressure differential monitor for lab space with reference to "cleaner" space.
- Stack exit velocity meter.
- Supply and exhaust duct static pressure.
- Variable speed drive (VSD) readings: input power, speed feedback.
- Laboratory equipment process load and lighting load (measured and/or nameplate).
- Measurements related to energy recovery systems, when present.

Always check accuracy of sensors before gathering or trending performance to ensure accuracy of the data. Laboratory controls tend to operate faster than other types of building HVAC controls; therefore, it is advisable to set the trending intervals for variables of interest in the BAS to 5 minutes (or even 1 minute, if the BAS and analysis tools can support it).

4. Investigation: Trend Review

Gather historical energy-use data and trends and compile data streams from supplementary monitoring instrumentation. Of particular interest are the performance of fume hoods and other exhaust devices and the behavior of pressure and airflow controls of individual lab spaces. These should be mapped and reviewed in relation to the rest of the HVAC system. Reviewing trends for all lab spaces is preferred if possible; otherwise, prioritize spaces based on airflow.

5. Investigation: Develop Functional Tests

Development of functional tests for various HVAC types is similar, but VAV systems have many additional components that will affect performance with respect to both safety and energy efficiency. Note that there are a variety of VAV terminal unit types. Specific and special tests, or challenges, for determining a lab's performance are presented below; others can be added depending on the lab's mission and the research performed. Accordingly, during actual testing, coordination between the RCx provider, laboratory users, facilities technicians, BAS manager, and EH&S personnel is essential.

Challenges listed below for each level of practice are over-and-above usual building-data measurements recorded during a basic RCx program. Recorded measurements are compared with nominal values, usually provided in a design basis document. The goal is to identify when a measured value exceeds a tolerance of the nominal reestablished design value, requiring a system adjustment.

Functional Tests—Standard Practice

- Measure and record face velocity for each fume hood with sash at design height.
- Measure and record laboratory-space differential pressure.
- Analyze supply and exhaust flow rates and calculate offset.

For VAV systems, measure and record these values while operating at minimum and maximum airflows, either by operating fume hood sash(es) full open to full close per ASHRAE 110-2016, Sash Movement Effect test, or by temporarily overriding the zone cooling temperature setpoint, cooling demand signal, or airflow setpoints, depending on the configuration of temperature and airflow controls.

Functional Tests—Good Practice

Advanced Fume Hood Containment Tests

In addition to Standard Practice tests, perform fume hood containment testing with tracer gas per ASHRAE 110-2016 to ANSI Z9.5-2012 thresholds. Although on the surface these tests seem to be solely intended for determining safety performance, energy use can be adjusted in ways that will support the safety aspects revealed during this level of testing practice. For example, if the fume hood's exhaust airflow exceeds the minimum flow required for space ventilation, then using the ASHRAE 110 test to determine the lowest face velocity that provides containment can provide significant savings.

Lab Environment Tests and System Operational Mode Tests

A "good practice" effort should include Lab

Figure 2. The Molecular Foundry building at Lawrence Berkeley National Laboratory (LBNL) has benefited from ongoing commissioning efforts starting in 2018, which resulted in improved comfort and a 30% reduction in natural gas consumption compared to 2016 and 2017. Source: Berkeley Lab - Roy Kaltschmidt.

Environment Tests and System Operational Mode Tests (SOMT) as described in the SmartLabs toolkit. This assessment procedure is a system-wide functional verification that examines how well all of the individual lab components and design features work together as a whole.

Functional Tests—Better Practice

Innovative fume hood containment tests

In addition to standard and good practices fume hood containment tests described above, perform innovative, non-standard tests, including:

- Human-as-mannequin tests.
- Walk-up and walk-by tests.
- Entry door operation during containment tests.
- Vary supply air temperature during containment tests.

System Sensitivity Testing

In addition to the “good practice” effort, VAV system sensitivity can be evaluated and optimized. More than coping with simultaneous actions in labs, this test determines how accurately changes of state are detected, reported, and processed by the BAS. Limiting factors for VAV responses include repeatability and sensitivity of sensor inputs; coarseness of control sequences; precision of VAV devices; and modularity of HVAC system components.

Figure 3. Sample data analytics and visualization tool used by the LBNL ongoing commissioning team. This tool shows the zone reheat valve commands for all zones served by a selected air-handling unit (y axis: zones) over a week (x axis: time) and allows the user to identify patterns and outliers. Here, one zone has its reheat valve 100% open all the time, shown as a solid horizontal red bar. Source: Berkeley Lab.

Energy Performance Issues

Significant opportunities exist for saving energy in laboratories, and these are well-covered in the literature. The most common issues below are typical to laboratory spaces and can be addressed as part of an RCx effort, without the need for a major retrofit. Levels of effort are estimated based on typically required project timelines: High (several weeks), Medium (several days), Low (several hours).

Issue 1: Zone-level **temperature setpoints** are too demanding and/or **temperature deadbands** are too tight.

Mitigation:

- Implement temperature setpoint management. Specify allowable ranges and minimum deadbands (e.g., default zone setpoints should be 68°F heating and 74°F cooling, adjustable ±2°F while maintaining 6°F deadband).
- Calibrate or replace temperature sensors.

Level of effort: Low

Issue 2: Zone-level unoccupied **temperature setbacks** are dysfunctional or missing.

Mitigation:

- Program occupancy schedules.
- Program unoccupied zone-level temperature setpoints based on warm-up and cool-down capabilities of the systems. Ensure that setbacks will not adversely affect experiments.
- Calibrate or replace occupancy sensors, if present.

Level of effort: Low.

Issue 3: Zone-level **airflows** are not appropriate.

Mitigation:

- Implement airflow management, lab risk assessment.
- Clean, calibrate/rebalance, or replace supply and exhaust airflow/velocity sensors.
- Repair or replace dampers, actuators.

Level of effort: High.

Issue 4: Zone-level unoccupied **airflow setbacks** are dysfunctional or missing.

Mitigation:

- Implement airflow management, lab risk assessment.
- Program occupancy schedules and related occupied and unoccupied airflow setpoints.
- Calibrate or replace occupancy sensors and other overrides (see https://smartlabs.i2sl.org/cs-emory-occupancy-sensors.html).
- Clean, calibrate, or replace supply and exhaust airflow/velocity sensors.

Level of effort: High.

Issue 5: Zone-level **airflow controls** are hunting.

Mitigation:

- Clean, calibrate, or replace supply and exhaust airflow/velocity sensors.
- Tune lab airflow tracking and/or pressure controls.
- Confirm pressure integrity and air tightness of the control zone. Seal gaps in room construction that counteract maintaining zone pressure.

Level of effort: Medium.

Issue 6: Air handler **supply air temperature** is constant and/or missing a deadband.

Mitigation:

- Program separate supply air heating and cooling temperature setpoints so supply air temperature (SAT) floats with outside air temperature (OAT) in mild weather conditions (e.g., heating setpoint could be fixed at 55°F and cooling setpoint could modulate between 56°F and 65°F).
- Program cooling supply air temperature setpoint reset.
- Couple any cooling temperature reset with an override to limit maximum supply air dew point to ensure humidity control is maintained in the space.

Level of effort: Medium.

Issue 7: Air handler **supply air temperature** is hunting (can cause airflow hunting at the zone).

Mitigation:

- Tune heating and cooling control loops.
- Program deadband between heating and cooling setpoints.
- Calibrate or replace temperature sensors.
- Repair or replace valves, actuators.
- Clean heating and cooling coils to ensure effective heat transfer.

Level of effort: Low.

Issue 8: Air handler **supply duct static pressure** is constant.

Mitigation:

- Program supply duct static pressure setpoint reset (see https://www.i2sl.org/documents/toolkit/bulletin_pressure_508.pdf).
- Calibrate or replace static pressure sensors.
- Ensure fan speed controls are not overridden or VFDs in “hand” mode.

Level of effort: Medium.

Issue 9: **Energy recovery systems** are dysfunctional.

Mitigation:

- Ensure the DDC/BAS system includes clear and simple conditions under which the energy recovery system is enabled to operate.
- Ensure that the BAS is operating the energy recovery system and it is not disabled.

Level of effort: Medium.

Issue 10: Zone-level **reheat valves** are leaky, stuck, clogged, or hunting.

Mitigation:

- Tune heating control loops.
- Calibrate or replace temperature sensors.
- Repair or replace valves, actuators.
- Clean strainers.

Level of effort: Medium.

Issue 11: **Fume hood sashes** are left open.

Mitigation:

- Implement awareness programs to educate occupants (see https://smartlabs.i2sl.org/cs-csm.html).
- Provide sash height sensors or calculated sash heights.
- Repair or replace sash closers and occupancy sensors, if present.

Level of effort: Medium.

Issue 12: **Fume hood face velocity and/or occupancy** controls are dysfunctional.

Mitigation:

- Calibrate or replace face velocity sensors.
- Calibrate or replace occupancy sensors, if present.
- Program appropriate face velocity setpoints, including unoccupied setpoint if available.

Level of effort: Low.

Issue 13: **Fume hood** or other exhaust devices are underutilized.

Mitigation:

- Implement fume hood management program.
- Decommission unused fume hoods and perform airflow balancing.

Level of effort: Low.

Issue 14: Zone-level **pressure controls** are dysfunctional or hunting.

Mitigation:

- Calibrate or replace pressure and airflow/velocity sensors.
- Repair or replace dampers, actuators.
- Tune lab-specific control parameters, or other control loops.
- Confirm pressure integrity and air tightness of the control zone; seal gaps in room construction that counteract maintaining zone pressures.

Level of effort: Medium.

Issue 15: **Exhaust** fans and bypasses are dysfunctional.

Mitigation:

- Repair or replace bypass dampers, actuators.
- Program exhaust fan staging controls.
- Verify stack discharge velocity.

Level of effort: Medium.

Issue 16: Chiller plant is **false-loaded**.

Mitigation:

- Verify minimum turndown capability of each chiller.
- Program staging of chillers based on load and flow and review related chiller settings; consider favoring infrequent cycling (e.g., one cycle per hour) rather than false loading.
- Increase system volume with buffer tanks to minimize short cycling.
- Adjust the chilled water (CHW) setpoint deadband to allow more float in the CHW temperature.

Level of effort: Medium.

Issue 17: Automated **lighting** controls are dysfunctional.

Mitigation:

- Move or add occupancy sensors if:
  - Obstructions create a dead occupancy sensing zone.
  - Lab equipment triggers occupancy sensors (movement or vibrations).
  - HVAC equipment triggers occupancy sensors (warm air or vibrations).
- Calibrate or replace occupancy sensors.

Level of effort: Medium.

In addition to the above, there are many other typical RCx issues that are also relevant to laboratories, such as daylighting controls, chiller optimization, etc. We did not include these since they are not unique to laboratories and are covered in other guides and resources.

Conclusion

Retro-commissioning of laboratory spaces presents numerous design, personnel, and safety challenges and opportunities. Prudently evaluate ventilation, airflow, pressure, and temperature requirements to accommodate current lab operations. Scrutinize simultaneous heating and cooling throughout lab spaces and try to minimize or eliminate this. RCx payback periods are usually less than three years, with additional advantages realized in reduced maintenance costs, increased system reliability, improved safety, and satisfied lab users.

Selected Resources on Retro-Commissioning

Building Commissioning Association. Existing Building Commissioning Best Practices. Retrieved May 6, 2021, from https://www.bcxa.org/resources/existing-building-commissioning-best-practices.html

Building Commissioning Association. Ongoing Building Commissioning Best Practices. Retrieved May 6, 2021, from https://www.bcxa.org/resources/ongoing-building-commissioning-best-practices.html

U.S. Environmental Protection Agency. (2007). ENERGY STAR Building Upgrade Manual, Retrocommissioning. https://www.energystar.gov/sites/default/files/buildings/tools/EPA_BUM_CH5_RetroComm.pdf

National Renewable Energy Laboratory / I^{2}SL. Conducting a Laboratory Environment Test (LET) During Commissioning. Retrieved May 6, 2021, from https://smartlabs.i2sl.org/pdfs/let-procedure.pdf

U.S. Department of Veterans Affairs. (2014). Retro-Commissioning Process Manual. https://www.wbdg.org/ffc/va/commissioning/retro-cxmanual

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