Facility
Measurement and Verification Plan

LEED™ Energy and Atmosphere Credit 5

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Sample IPMVP-Compliant LEED Measurement and Verification Plan

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Preface

LEED-NC 2.2, EA Credit 5: Measurement & Verification calls for the applicant to “develop and implement a Measurement & Verification (M&V) Plan consistent with Option D: Calibrated Simulation (Savings Estimation Method 2), or Option B: Energy Conservation Measure Isolation, as specified in the International Performance Measurement & Verification Protocol (IPMVP) Volume III: Concepts and Options for Determining Energy Savings in New Construction, April, 2003.

The referenced IPMVP volume is one of several produced and maintained by the Efficiency Valuation Organization (EVO). EVO is the only non-profit organization in the world solely dedicated to creating measurement and verification (M&V) tools to allow efficiency to flourish. Our vision is a global market that properly values the efficiency resource, enabling and assisting the optimal investment in these opportunities.

The IPMVP Committee of EVO prepared this sample measurement & verification plan as an example to LEED applicants and LEED reviewers of an IPMVP-compliant plan. The primary authors of this plan are Mr. Tracy M. Phillips of Architectural Energy Corporation in Boulder, Colorado and Mr. Kevin Warren, P.E. of Warren Energy Engineering, LLC in Pennsylvania.

Users with comments or questions are encouraged to discuss them at http://www.evo-world.org by selecting “Resources” and then “Forums”.

0 Executive Summary

The measurement and verification plan presented here provides a systematic procedure for determining the energy performance of the facility's end-uses. The International Performance Measurement and Verification Protocol (IPMVP) provides the framework for this plan. IPMVP Option D, Calibrated Simulation, has been selected as the method of M&V for this project. This entails the use of an energy simulation model to estimate the annual building energy consumption of the facility.

The following building systems will be investigated and analyzed during the M&V process:

- HVAC components.
- HVAC system: interaction of cooling, heating, and comfort delivery systems.
- Building Automation System (BAS): control hardware and software, sequence of operations, integration of factory controls with BAS.
- Lighting system components.

All equipment will be monitored using the building automation system (BAS) with the exception of lighting. Lighting panels and circuits will be monitored using remote data logging equipment. Monitored points may include power, temperature, static pressure, airflow, water flow, status, and humidity. The points monitored will depend on the applicable energy saving measures or building end-uses to be measured and verified. The end-uses to be measured in addition to the energy saving measures include:

- Lighting systems and controls
- Constant and variable load motors
- Variable frequency drive operation
- Chiller efficiency at variable loads
- Cooling load
- Air and water economizer and heat recovery cycles
- Air distribution static pressures and ventilation air volumes
- Boiler efficiencies
- Building-related process energy systems and equipment

The following equipment will be monitored for a period of four weeks once the building has been completely commissioned and is operating under normal occupancy:

- Boilers
- Chillers
- Cooling Tower
- Selection of lighting circuits
- 3 Selected zone temperatures
- Hot Water Loop Pump
- Chilled Water Loop Pump
- Condenser Water Loop Pump
- Air Handling Unit supply fans (1, 4, 8)
- AHU economizer operation (1, 4, 8)

The facility is applying for LEED EA Credit 1 Optimize Energy Performance using Option 1 Whole Building Energy Simulation, which requires the development of a pair of energy models. One model represents the pre-construction design case, and the other model represents the pre-construction budget case, which is the design case model “crippled” to follow the Building Performance Rating Method defined in Appendix G of ASHRAE Standard 90.1 2004.

Once all performance data collected as part of this M&V effort have been analyzed, inputs to the pre-construction design case energy model will be revised to reflect the true operation of the building (based on the interval data collected). The energy performance of this model will also be calibrated using one year of utility billing information[1]. The same modifications (such as correcting the building operating hours and setpoints) will be made to the baseline model.

The energy savings for the building are calculated by comparing the actual utility consumption to the calibrated baseline model. The calibrated and the original design models are also compared to shed light on the true energy performance of the building’s various energy saving measures and building end-uses[2].

An M&V report will be presented to the building owner that describes the results of the monitored data analysis, and presents the energy performance results of the energy saving measures and building end-uses. Recommendations will also be presented to the building owner, that may potentially improve energy performance if the building is not performing as expected. The report will be reviewed via a conference call between the M&V Consultant and the building owner and facility personnel, to provide clarification of any of the items or observations in the report.

[1] The model will be calibrated to each month’s utility bill, within 10% of actual energy use. For the purposes of the calibration run, actual weather data for this time period will be used, rather than the TMY weather file, which is a 30-year average of weather conditions for the region.

[2] Thirty-year average (typical) weather data is used to compare the energy performance of the two calibrated post-construction energy models (budget and design cases).

These M&V services will be performed annually by the M&V Consultant, to ensure ongoing accountability of the building's energy performance.

1 General Introduction

1.1 Background

Client is the project architect for the new 200,000 ft^2 Facility in Anycity, Tennessee. The architect's client requires that the new facility be responsive to energy and environmental design considerations to reduce operating costs and to provide a visible expression of sustainable development and design. The client has established a sustainable design goal of Silver or better under the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED™) rating system.

The LEED Green Building Rating System is a voluntary, consensus-based, market-driven building rating system based on existing proven technology. It evaluates environmental performance from a whole-building perspective over a building's life-cycle, providing a definitive standard for what constitutes a "green building." The LEED v.2.2 Energy and Atmosphere Credit 5, Measurement and Verification, provides for the ongoing accountability and optimization of building energy and water consumption performance over time. This measurement and verification (M&V) plan provides a framework for accomplishing this accountability and optimization effort called for by the LEED credit.

1.2 Measurement & Verification

The M&V plan presented here provides a systematic procedure for determining the functional performance and energy consumption of the building's HVAC systems. The *International Performance Measurement and Verification Protocol (IPMVP) Volume III: Concepts and Options for Determining Energy Savings in New Construction, April, 2003*, provides the framework for this plan. IPMVP Option D, Calibrated Simulation, has been selected as the method of M&V for this project. This entails the use of an energy simulation model to determine end-use load shapes and annual building energy consumption. Method 2 of Option D is used as required by USGBC. This method compares the calibrated baseline model to actual consumption rather than comparing it to the calibrated design model.

Though not specifically required by Option D, Method 2, we will also compare the original design model to the calibrated design model. Rather than showing the savings for the building, this comparison provides insight into the operation of the building.

Selected points will be monitored through the building automation system (BAS). If any points cannot be monitored using the BAS, independent data logging equipment will be used to capture the necessary data. The monitored data will be analyzed to determine the performance and operating characteristics of various building HVAC system components, and the results incorporated into the calibrated energy simulation to determine their impact on energy consumption.

The following building systems will be investigated and analyzed during the M&V process:

- HVAC components.
- HVAC system: interaction of cooling, heating, and comfort delivery systems.

- Building Automation System (BAS): control hardware and software, sequence of operations, integration of factory controls with BAS.
- Lighting system components.

The implementation of option D as outlined in the IPMVP will entail the following items:

- Outline the method for determining energy savings.
- Determine and follow a site-specific plan.
- Specify the variables and assumptions to be used in the calculations.
- Establish quality assurance methods.
- Specify reports to be provided and time frame outlined.

2 Technical Approach

2.1 Building Energy Model Types

Regarding the technical approach used to measure and verify the energy performance of the building's end-uses, is useful to begin with a discussion of the various energy models and model runs that can be compared. To this end, consider six models.

The "pre" models are those that were created prior to the building having been built. These models represent the final result of a process of refining and optimizing the design of the facility through use of the model to asses design alternatives. The "post" models will be created after the building is occupied, commissioned and functioning under normal operating conditions. These models will be calibrated based on system-level and monitored data performance analysis results and using utility bills.

2.1.1 Pre-construction Design Case (Model DC_{pre})

The intent of Model DC_{pre} is to predict the energy performance of the design building pre-construction. The building is modeled with the systems and control strategies as they are designed, with assumptions regarding certain items such as equipment schedules, zone temperature set points, etc., (for example, model DC_{pre} may assume, based on the owner's best guess, that the mechanical systems would operate from 7:00 a.m. to 5:00 p.m.), and uses typical weather data (TMY2)[3]. This is one of the two models that is submitted as part of the initial LEED certification package to satisfy EA Credit 1 and EA Prerequisite 2.

2.1.2 Pre-construction Baseline Case (Model BC_{pre})

This model is created by taking model DC_{pre} and adjusting building characteristics to comply with the methodology outlined in LEED EA Credit 1 Optimize Energy Performance Option 1 Whole Building Energy Simulation. Essentially, model DC_{pre} is "crippled" utilizing the methods described in the Building Performance Rating Method in Appendix G of ASHRAE Standard 90.1 2004. The model uses typical weather data and assumptions similar to those defined for model DC_{pre}. This model is also known as the "budget" model, as it represents the baseline energy budget for the facility. This is one of the two models that is submitted as part of the initial LEED certification package to satisfy EA Credit 1 and EA Prerequisite 2.

2.1.3 Calibrated Post -construction Design Case (Model $DC_{post,cal}$)

This model is created from model DC_{pre}. It uses actual weather data corresponding to the calibration period, and uses monitored system performance data and utility bills to calibrate the model. Operating schedules, equipment performance, and internal loads may all be altered to calibrate the model. For example, model DC_{pre} may have assumed that the mechanical systems would operate from 7:00 a.m. to 5:00 p.m. but the building occupants actually operate the systems until 7:00 p.m. This model will be constructed after at least a year of building operation.

[3] Which is a file representing a 30-year average of weather conditions for the region.

2.1.4 Calibrated Post-construction Baseline Case (Model $BC_{post,cal}$)

This model is created by taking model $DC_{post,cal}$, and adjusting building characteristics to comply with the methodology outlined in LEED EA Credit 1 Optimize Energy Performance Option 1 Whole Building Energy Simulation, similar to the methodology described for the creation of model BC_{pre} (using model DC_{pre}). Essentially, model $DC_{post,cal}$ is "crippled" utilizing the methods described in the Building Performance Rating Method in Appendix G of ASHRAE Standard 90.1 2004. Alternatively, this model can be created from model BC_{pre}, applying the same modifications to model BC_{pre} that were applied to create model $DC_{post,cal}$. This model will be constructed after at least a year of building operation.

2.1.5 Post -construction Design Case using TMY2 Weather (Model $DC_{post,typ}$)

This model is identical to model $DC_{post,cal}$ but uses 30 year average weather data for the energy simulation.

2.1.6 Post- construction Baseline Case using TMY2 Weather (Model $BC_{post,typ}$)

This model is identical to model $BC_{post,cal}$ other than that long term average weather is used in the simulation.

A summary of the model types are described in the following table.

Table 1 Building Energy Model Types

Model	Weather	Building Specs	Building Operation
DC_{pre}	30-year average (TMY2)	as-designed	predicted (pre-construction)
BC_{pre}	30-year average (TMY2)	code compliant	predicted (pre-construction)
$DC_{post,cal}$	actual (calibration period)	as-designed	actual (post-construction)
$BC_{post,cal}$	actual (calibration period)	code compliant	actual (post-construction)
$DC_{post,typ}$	30-year average (TMY2)	as-designed	actual (post-construction)
$BC_{post,typ}$	30-year average (TMY2)	code compliant	actual (post-construction)l

2.2 Building Energy Performance Evaluation

As part of the LEED certification process, a DOE-2.2 hourly building energy simulation (model) of the building was created following current known design specifications and operating conditions. This represented the building pre-construction "Design Case," or DC_{pre}. The model was then "crippled" back to the ASHRAE 90.1-2004 *Energy Standard for Buildings Except Low-*

Rise Residential Buildings defined minimally compliant standard parameters, as described in Appendix G of the standard. This "crippled" model effectively represented the pre-construction "Budget Case," or $BC_{pre.}$ The comparison of these two models (DC_{pre} and BC_{pre}) is the basis for EA Credit 1 in the initial LEED submission.

Model input values for DC_{pre} were derived from as-built building plans, sequences of operation, and discussions with the design team. The model was then revised to reflect a building minimally compliant with ASHRAE 90.1 standards. The energy consumption for both the Budget Case model (BC_{pre}) and the Design Case model (DC_{pre}) were calculated and compared, with the difference in energy use referred to as the predicted "energy savings" or "avoided energy use."

During the construction and Cx process, the M&V activities include working with the controls contractor to ensure that the EMS will trend the necessary data. We will also coordinate with the Cx agent and will make use of trend data collected by the Cx agent.

Once construction of the building and commissioning is completed, and the building is operating under normal operating conditions, interval data is collected. Utility data is also collected during this period. Performance data are collected, typically for a period of one month during the "swing season" (so a greater range of ambient conditions can be captured by the data).

Typically the first detailed M&V analysis occurs one year after the building is operating under these normal conditions. The performance data are analyzed, and once analysis is complete, inputs to the design case energy model DC_{pre} are revised to reflect the true operation of the building. The energy performance of this model is then calibrated using one year of utility billing information[4] to create $DC_{post,cal.}$

Once model $DC_{post,cal}$ is created and calibrated, the model is "crippled" utilizing the methods described in the Building Performance Rating Method in Appendix G of ASHRAE Standard 90.1 2004. The resulting model is the calibrated baseline model $BC_{post,cal.}$

An M&V report is then presented to the building owner that describes the results of the monitored data analysis, and presents the energy performance results of the energy saving measures and building end-uses. Recommendations will also be presented to the building owner that may potentially improve energy performance if the building is not performing as expected. The report will be reviewed via a conference call between the M&V consultant and the building owner and facility personnel, to provide clarification of any of the items or observations in the report.

In addition to presenting the true energy performance of specific energy saving measures, the report will present the energy performance of the different end-uses, using the output files from the energy models. Energy use for the end uses will be reported in both MBtus, as well as energy units appropriate for that end-use. The end uses will include:

- Lighting
- Miscellaneous plug loads
- Task lighting
- Space heating

[4] The model will be calibrated to each month's utility bill, within 10% of actual energy use. For the purposes of the calibration run, actual weather data for this time period will be used, rather than the TMY weather file, which is a 30-year average of weather conditions for the region.

- Space cooling
- Pumps
- Refrigeration
- Exterior equipment and lighting
- Heat rejection
- Ventilation fans
- Domestic hot water

Boiler efficiency and chiller efficiencies versus load will also be presented.

These M&V services will be performed annually by the M&V consultant, to ensure ongoing accountability of the building's energy performance.

2.3 Determination of Energy "Savings"

We have defined six simulation models. In addition to the output of these models, we have access to the actual energy use of the facility. Let us consider what can be gained from comparing the output of the various models and the actual data. Equally importantly, let us consider what certain comparisons do not show.

Actual Bills - $BC_{post,cal}$ = Energy Savings of the Building

This is the comparison that is defined in IPMVP Option D, method 2. Specifically, method 2 states that savings are obtained from subtracting "the metered post-construction energy use from the energy use of the calibrated Baseline model". This method is accepted by USGBC and is our proposed method of calculating savings.

Since this compares actual bills to a calibrated baseline building, it can be used as an estimate of the savings that occurred during the calibration period. Both values use the same weather, but the weather may not be representative of long-term average weather conditions.

The energy savings will be determined using the following equations presented in the IPMVP:

Verified Energy Savings = Budget Case Energy Use – Verified Design Case Energy Use +/- Adjustments

Where:

Budget Case Energy Use = Annual simulated energy use from Model $BC_{post,cal}$

Verified Design Case Energy Use = Annual energy use from the utility bills

Adjustments were already included in the calibration process for $BC_{post,cal}$ These are expected to involve changes to operating schedules, temperature setpoints, and other operating characteristics.

Actual Bills – Model $DC_{post,cal}$

This difference should be quite small, since the bills are used to calibrate this model. The difference can be thought of as the error or bias in the model.

Actual Bills - Model DC_{pre}

This comparison shows how well the model predicted the energy use of the building.

Model $DC_{post,cal}$ - Model DC_{pre}

These two models estimate the energy use of the building using the best information available at the time. The LEED-NC Version 2.2 Reference Guide states that one the purposes of Option D is:

> "Calibration of the as-built simulation model to actual energy use reveals ECM/design or operational underperformance."

We disagree slightly with this statement. Such a comparison reveals areas in which the actual operating characteristics of the facility differ from the assumptions modeled in the original as-built model. The intent of Model DC_{pre} is to predict the energy use of the building. However, any such model includes many assumptions about how the building will operate. Differences between the original and calibrated models may be due to:

1) Errors in the original model that are discovered during the calibration process,
2) Changes in the design between design and as-built,
3) Equipment operating at sub-design efficiency
4) Controls sequences of operations differing from those modeled, or
5) They may be largely due to how the building is operated (such as the actual hours of operation) that are outside the control of the modeler.

It is important to point out that changes in how the building is used by the owner, while they may have a large impact on the energy ***usage*** of the building, have a much smaller impact on the energy ***savings*** of the building.

$BC_{post,cal}$ - $DC_{post,cal}$

This is the comparison that is defined in IPMVP Option D, Method 1. Specifically, Method 1 states that savings are obtained from subtracting "the energy use of the calibrated as-built model from the energy use of the calibrated Baseline model". This method is not currently accepted by USGBC.

This is an estimate of the energy savings of the building as compared to a code compliant building, operating with the specific weather for the calibration period, and with the actual operating characteristics of the occupied building. It can be used as an estimate of the savings. However, the comparison has at least one major bias. Both values use the same weather, but the weather may not be representative of long-term average weather conditions.

$BC_{post,typ}$ - $DC_{post,typ}$

This the energy savings of the building as compared to a code compliant building, operating with typical weather, and with the actual operating characteristics of the occupied building. If you could only do one M&V report ever, then this option would be the most accurate and unbiased estimate of the long term savings of the actual building, as operating, compared to a code baseline building.

2.4 Weather Data

Two forms of weather data are required for this analysis: typical and actual. Data that is typical of long term average weather conditions was used in the original energy models used to predict the energy savings of the building. Specifically, the appropriate typical meteorological year (TMY) weather data set for Anycity, Tennessee was used. TMY data is not appropriate for calibration of the model after construction. Instead, the calibrated models will be simulated using the actual weather data for the calibration period. This weather data is collected from NOAA's National Climactic Data Center. The data must be manipulated to conform to the format required by DOE2.2.

Information on obtaining actual weather data (as opposed to typical data) can be found here:

http://www.eere.energy.gov/buildings/energyplus/cfm/weatherdata/weather_request.cfm

Information on appropriate typical meteorological year weather data can be found here:

http://rredc.nrel.gov/solar/pubs/tmy2/

2.5 Short-term Monitoring and Analysis

Short-term monitoring will be performed on a variety of system components using the BAS or independent data logging equipment for points that cannot be monitored by the BAS. These monitored points will help to assess the actual operation of the building's general components and specific system components. The data are then used as part of the calibration process of the simulation model, leading to $DC_{post,cal}$.

For cases in which the BAS cannot be used for system monitoring, data logging will be performed using portable data logging equipment. The data collected using any remote data logging equipment will be compiled with the data collected via the BAS, and all data analyzed using a suite of analysis tools. The Onset EnergyPro™ logger will be used for all remote data logging. The data logger equipment specifications have been included in the appendix.

Power will be measured for most major pieces of equipment, as previously described. For some equipment status will be monitored and combined with spot measurements of equipment power to calculate associated load shapes. For lighting fixtures, current for whole lighting panels or individual lighting circuits will be monitored and combined with spot measurements of equipment power to calculate associated lighting load shapes.

The points monitored will depend on the applicable energy saving measures or building end-uses to be measured and verified. The end-uses to be measured in addition to the energy saving measures may include:

- Lighting systems and controls
- Constant and variable load motors
- Variable frequency drive operation
- Chiller efficiency at variable loads
- Cooling load

- Air and water economizer and heat recovery cycles
- Air distribution static pressures and ventilation air volumes
- Boiler efficiencies
- Building-related process energy systems and equipment
- Indoor water risers and outdoor irrigation systems

2.6 Visual Inspections

Visual inspections of lighting fixtures and controls, as well as HVAC equipment characteristics and controls will be performed. These observations will be incorporated into the DOE-2 model as necessary, to verify predicted energy performance.

2.7 Training and Ongoing Accountability

Although the M&V Consultant will only perform detailed M&V services once a year, facility personnel will be trained, and materials developed, that will allow facility personnel to periodically check on the building's energy and water performance throughout the year, albeit with less rigor than the full annual M&V efforts. These materials will be based on observations made during the initial M&V effort, and will involve detailed instructions for the facility personnel to check trend data, or perform targeted functional performance tests, to identify any changes in the energy or water performance of the building, that may warrant immediate attention.

3 Building System Description

3.1 General Building Overview

The project involves construction of a new classroom building. The building has four above ground floors plus a basement. The basement houses mechanical equipment. The first through fourth floors house primarily offices, lounges and classrooms. Floors 2 through 4 are rectangular. The first floor has the same rectangular footprint with additional wings on both sides for two large lecture halls.

3.2 Chilled Water System

Chilled water will be provided by a 225-ton water cooled screw chiller (CH-1), located in the basement. The cooling tower will be located on a pad on the ground above. The design calls for chilled water temperature reset based on CHW valve position. Chilled water coils at the air handlers will be equipped with 2-way valves, making the loop variable flow. The loop will be a variable speed primary loop driven by a pair of 10 HP pumps equipped with VFDs.

3.3 Hot Water System

The proposed facility will be heated by a pair of gas-fired condensing hot water boilers. The hot water coils at the AHUs and at the VAV reheat boxes are equipped with 2-way control valves. Heating hot water will be circulated in the building in a primary/secondary arrangement. The primary loop will be constant speed. The proposed primary hot water pumps are 3 HP. The secondary loops are variable speed equipped with VFDs and are 15HP.

3.4 Air Distribution System

The plans show a total of 3 major air handlers. All of these units will be equipped with chilled water coils and with glycol preheat coils a well as outside air economizers. The chilled water coils are to be equipped with 2-way control valves.

Unit	Serves	SF HP	SF CFM	RF HP
AHU - 1	Levels 1, 2, 3, 4	2 x 50	70,500	25
AHU - 2	Lecture 1	10	8,800	N/A
AHU –3	Lecture 2	5	5,500	N/A

AHU-1 will serve most of the building. It will be a variable air volume system that distributes air to VAV boxes with hot water reheat coils. Supply air will be pressurized by a pair of 50 HP plenum fans. In addition to the chilled water and glycol coils, it will be equipped with a direct evaporative cooling section with a saturation efficiency of 89%. Use of this section should reduce hours when the chiller is required. Return air will be ducted and drawn back by a 25 HP VFD-controlled return fan. CO_2 monitoring will be used to control the minimum outside air volume.

AHU-2 and AHU-3 will each serve large lecture halls. These will be single zone units and have CO_2 monitoring to control the minimum outside air volume. These units will be equipped with VFDs but serve constant volume networks; there will be no VAV boxes or automatic dampers that will reduce the airflow to the spaces.

3.5 Building Management System

A Johnson Controls Metasys energy management system will control all mechanical equipment and also lighting circuits.

3.6 Lighting

Lighting will primarily be provided by hardwired compact fluorescent lamps, T5 lamps, and by “premium” T8 lamps with low ballast factor electronic ballasts. The fixture schedule specifically state that the electronic ballasts for the T8 lamps have BF of 0.8, thus complying with the program definition.

4 Verification and Monitoring Plan

4.1 Performance Verification

In addition to the measures that exceed the ASHRAE 90.1 Standard, general system characteristics and performance will be verified as part of the M&V process. This section describes the specific building system components and control strategies that will be assessed and analyzed to characterize their performance and operation. The components selected are those that may affect overall building energy consumption, and include the measures that exceed the ASHRAE 90.1 Standard. These components to be verified as part of the M&V process are listed in Table 2.

Components that will not affect energy consumption differences in the Budget and Design Cases directly are classified as "energy neutral." These include:

- Building occupancy density;
- Outdoor shading;
- Electrical power density (plug loads);
- Infiltration;
- Occupancy and plug load schedules;
- Zone temperature setpoint schedules.

Although these factors are essentially "energy neutral", that is to say, they are the same in both the Budget and Design Cases, they can affect buildings loads, which may in turn affect the predicted savings associated with the measures that exceed the ASHRAE 90.1 Standard. Therefore, any large changes to these types of building characteristics will be documented and implemented into both the Budget and Design Case models to recalculate savings as necessary.

4.2 Monitoring Plan

The following table outlines the monitoring points to be used to accomplish the verification tasks outlined in Section 4. Each major piece of equipment has been designated whether or not it has points to be monitored. The BAS will be used to monitor most of the selected points. Points that cannot be trended using the BAS will be monitored using independent data loggers. All data (trended and logged) will be collected at the same sampling rate, and during the same sampling period, to allow for easy comparison of data streams and subsequent analysis of equipment performance and operation. Specifications for the data logging equipment, and the BAS control points, are included in the appendix.

Note that for constant-speed motors, spot measurements of power will be combined with monitored motor status, to calculate electric consumption. Similarly, for motors equipped with VFDs, spot measurements of power will be taken at a number of various motor speeds. VFD speed will be monitored and combined with the spot measurements to calculate electric consumption.

Table 2 Verification Components and Monitoring Points List

#	System	Measure / Verification Component	Verify Measure / Condition	Monitoring Points
1	Boilers	Hot water reset based on outside air temperatures. System enabled based on outside air temperatures.	- boiler efficiency (920%) through combustion efficiency test - heating plant enabled when outside air temperature drops below 60ºF, and enable when temperature rises above 65ºF - second boiler enabled when heating water supply temperature is 5ºF (adjustable) below set point; second boiler disabled when heating water load is less than 90% of the output capacity of one boiler - hot water temperature set point reset from 140ºF to 120ºF based on outside air temperatures from 40ºF to 60ºF.	- boiler enable
2	Hot Water Loop	Variable-flow loop; hot water pumps equipped with VFDs.	- variable-flow operation, to maintain pressure differential set point between supply and return heating water piping mains - interlocked with boiler operation; two minute delay on boiler disable	- VFD speed[5] - pump status[4] - differential pressure between supply and return - water flow rate - heating water supply and return temperatures
3	Chillers	Equipped with VFDs. Reset chilled water supply temperature to maintain air handler discharge air temperature.	- chiller efficiency (NPLV = 0.50)[6] - chiller VFD operation - chilled water supply temperature reset from 48ºF to maintain air handler discharge air temperature	- chiller power - chiller efficiency (calculated point)
4	Chilled Water Loop	Variable-flow loop; chilled water pumps equipped with VFDs.	- variable-flow operation to maintain discharge air temperature at main air handling unit (increased pump speed as discharge air temperature drops) - pumps interlocked with chiller operation - if both pumps operating, operate at same speed	- VFD speed[4] - pump status[4] - water flow rate - chilled water supply and return temperatures
5	Cooling Tower	Equipped with VFDs. Serves tenant condenser water system as well as chiller plant. Reset condenser water supply temperature based on outside air wet-bulb temperature and chiller operation.	- cooling tower fan VFD operation, modulate to maintain condenser water supply temperature - cooling towers interlocked with chiller operation and tenant condenser water system - condenser water set point control: 1) If one or both chillers are running, then setpoint shall be 7ºF (adjustable) above outside air wet bulb temperature (i.e. 7ºF approach). The setpoint shall not be set lower than the minimum condenser entering water temperature recommended by the chiller manufacturer. 2) If neither chiller is running, then setpoint shall be 85ºF (adjustable) to satisfy the heat pumps on the	- VFD speed[4]

[5] To be combined with spot measurements of power.

[6] NPLV = Non-standard part load value

#	System	Measure / Verification Component	Verify Measure / Condition	Monitoring Points
			tenant condenser water system.	
6	Condenser Water Loop	Constant speed.	- pumps interlocked with cooling tower operation	- VFD speed[4] - pump status[4] - condenser water supply and return temperatures
7	Tenant Condenser Water Loop	Constant-flow primary, variable-flow secondary loops. Secondary loop pumps equipped with VFDs. Utilizes two plate-and-frame heat exchangers.	- secondary loop variable-flow operation, to maintain pressure differential set point between supply and return piping mains - pumps interlocked with cooling tower operation and water-cooled tenant AC units - heat exchange temperatures - loop temperatures maintained between 60ºF and 90ºF	- secondary loop pump VFD speed[4] - primary and secondary loop pump status[4] - secondary loop water flow rate - secondary loop differential pressure between supply and return - condenser water supply and return temperatures - heat exchanger entering and exiting water temperatures - condenser water system load (calculated point)
8	Air Handling Unit	VAV; discharge air temperature reset to satisfy worst-case cooling zone. Airside economizers. Supply and return fans equipped with VFDs. Office areas served by under-floor air distribution, with static pressure set point reset.	- supply fan VAV operation, to maintain duct static pressure set point of 0.5" wc - return fan VFD operation, modulate to maintain airflow at 90% supply airflow, less a constant value to maintain space at slight positive pressure relative to ambient. Initially set constant equal to the sum of the flow rates for exhaust. Both fans operate at same speed - discharge air temperature reset as high as possible to satisfy worst-case cooling zone - minimum outside air fraction maintained; demand controlled ventilation performed in assembly area - economizer operates when outside air temperature lower than return air temperature - optimized start; morning warm up operation (outside air dampers closed, return dampers open, heating coil on, as long as return air temperature below 70ºF) - raised floor plenum static pressure set point of 0.05" wc; reset based on zone temperatures	- discharge air temperature - mixed air temperature - return air temperature - mixed air damper position - return air damper position - exhaust air damper position - minimum and main outside air damper positions - supply and return fan VFD speed[4,7] - duct static pressure - total supply airflow - total return airflow - entering outside airflow - chilled water valve position - hot water valve position - cooling coil entering and leaving temperatures - heating coil entering and leaving temperatures - raised floor plenum static pressure
9	Zones	Zones have occupied and unoccupied set points. CO_2 levels monitored and maintained.	- occupied temperature set points of 76ºF for cooling and 70ºF for heating; and unoccupied heating set point will also be used (user defined) - CO_2 levels not above 800 ppm	- zone temperatures - zone temperature set points - zone terminal heating coil valve position - zone CO_2 levels

[7] To be combined with spot measurements of power.

#	System	Measure / Verification Component	Verify Measure / Condition	Monitoring Points
10	HVAC	Operates according to occupancy schedule. Utilizes optimum start / stop.	- equipment only operates during occupancy schedule - optimum start / stop operation	
12	Miscellaneous Exhaust Fans	Exhaust fans serving toilet, electrical, and mechanical spaces.	- toilet exhaust only operates when central air handling unit operates - electrical room exhaust operates continuously - main electrical and all mechanical room exhaust operate to maintain zone temperature set points	
13	Lighting	Lighting in restrooms controlled via occupancy sensors	- lighting fixture and ballast type installed - lighting in restrooms controlled by occupancy sensors	
14	Ambient / Building	Lighting in restrooms controlled via occupancy sensors		- outside dry-bulb and wet-bulb temperatures

5 Quality Assurance

Quality assurance activities will include… BAS sensors will be calibrated as part of the Cx effort. Model $DC_{post,cal}$ will be calibrated within 10% of each month's actual utility bill.

6 Schedule

Trends will be programmed during the commissioning phase. Short term loggers will be installed after Cx is largely complete and during a "swing" period. Data will be collected for a period of four weeks. Visual inspection of all proposed equipment and controls upgrades will also be performed during this period, as well as combustion analysis tests performed for the boiler.

Results developed by analyzing the collected monitored data and calculating the verified energy savings will be presented in a summary report. The report will detail the information described in the Technical Approach section (section 2). Once the report is reviewed by the building owner and facility personnel, a conference call will be scheduled to discuss the findings and potentially discuss recommendations to improve the building's energy performance.

The M&V Consultant will direct and coordinate all M&V tasks outlined within this plan on an annual basis, including:

- Assist the building facility personnel and commissioning agents to set up the required trends outlined in Table 2 including sampling interval, trending time period, and trend duration.
- Coordinate inspections of the completed installation of components outlined Table 2, with the commissioning agents and take spot measurements of power, temperature, or flow on selected equipment as necessary. A subcontractor will be hired to perform the necessary combustion efficiency testing of the new boiler.
- Analyze the collected trend data to assess and verify the performance of the components outlined in Table 2.
- Determine calibration adjustments based on the results of the monitored data analysis and implement these adjustments into the Budget and Design Case models (used to create $BC_{post,cal}$ - $DC_{post,cal}$) as appropriate. Any adjustments will be approved by the building owner.
- Revise and calibrate the Design Case model ($DC_{post,cal}$) as necessary based on utility billing information as well as the results of the system inspections and trended data analysis to reflect actual building operation.
- Calculate the various energy savings and model comparisons using the six different model types and the utility billing information, as described in Sections 2 and 3 of this plan..
- Develop a report that presents the results of the investigation, data analysis, and verified energy performance of the buildings (presenting a subset of the calculated energy saving comparisons developed as part of the previous task). The report will also provide insight into methods to improve energy performance of the building systems.

Develop materials and train facility personnel to perform periodic inspection (most likely quarterly) of the building's energy performance.

7 Reporting

The M&V report will include the following: graphs of selected metered end uses, historical utility data, results of the simulation models, charts showing the calibration of the models.

At the heart of the report is a comparison of the energy use of each of the end uses. An example of such a table is shown below:

End-use	Original Model	Calibrated Model	Reason for Change
Chiller Energy Use (kWh/yr)	125,000	130,000	Longer hours of operation
Peak Cooling Load (tons)	225 tons	215 tons	
Peak CHW Pump Demand (kW)	12	24	2 pumps are required at peak, original model assumed 1 pump
Occupied schedule	7:00 – 17:00 M-F	7:00 – 18:00 M-F plus 8:00 – 12:00 Sat	Owner's prerogative

In addition, we will report the total savings which, as shown earlier, is equal to:

$$\text{Savings} = \text{Actual Bills} - BC_{post,cal}$$

Appendix: Monitoring Equipment Specifications and BAS Control Points