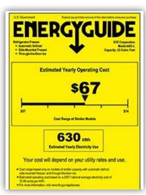
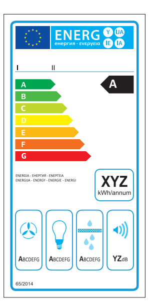
How to Design a Data Acquisition System to Ensure Energy Efficiency of Appliances and White Goods Products

The dual goals of minimizing energy costs and cutting carbon emissions drive white goods and appliance manufacturers to develop energy-efficient products. They need a quick way to communicate their products' efficiency to consumers. In the United States, they can do that by having their products carry the Energy Star label, which requires that the products meet the U.S. Environmental Protection Agency's strict guidelines for energy efficiency. Manufacturers of appliances that do not earn Energy Star certification must perform efficiency tests. The U.S. Federal Trade Commission mandates that these products carry an EnergyGuide label that advises consumers of estimated annual energy consumption and costs and an efficiency ranking compared with similar products.





Similar certification and requirements are in place worldwide. Energy Star international partners from Canada to Japan leverage their testing protocols, definitions, and datasets to meet their local needs. In Europe, the Energy Efficiency Directive, promulgated in 2012 and amended in 2018, sets rules and obligations for achieving the EU's energy-efficiency targets through 2030. The European Commission also recently revamped its energy label for appliances including freezers, dishwashers, and washing machines, imposing more stringent requirements to achieve the highest "A" rating on an A-G scale.

Temperature, Humidity, and More

To ensure products meet the requirements of the jurisdiction you choose to sell into and to earn an efficiency rating that will be attractive to consumers, you will need to collect and analyze extensive sets of data. That data can represent temperature, humidity, and other parameters such as a refrigerator door-open switch signal. You need to measure input current, voltage, and power precisely and vary the input voltage and frequency over the expected operating range of your product. In addition, you need to prove that your product is making efficient use of that input power—that your clothes dryer or refrigerator is operating at the right temperature, and that the temperature is sufficiently uniform within the appliance. And you will need to take the necessary measurements quickly and efficiently to minimize operating costs.

Several factors can contribute to a successful data acquisition strategy. First, you will need a system that meets your sample rate, channel count, accuracy, and resolution requirements. You will also want a flexible, scalable, and easy to set up system, enabling you to quickly change out a failed sensor or switch from one device under test (DUT) to another. In addition, you will want to keep your sensor leads short—both to minimize the cost of copper wire and to minimize the noise that long sensor leads can introduce into your measurement results. Keeping leads short can be particularly challenging if your DUTs are inside a thermal chamber, as is often the case. An effective strategy is to use a distributed approach that locates your data acquisition instruments close to the DUTs.

The instruments connect to remote computer resources using a low-cost Ethernet cable. In addition, Power over Ethernet (IEEE 802.3at PoE+) capability makes it unnecessary to run additional power-supply wires to the instrument.

To further minimize noise and match your sensor outputs to your data acquisition system's inputs, you will need flexible, high-performance signal-conditioning circuitry. Your data acquisition instrument should include an analog low-pass anti-aliasing filter with a cutoff frequency that accommodates your sample rate. You can also choose an instrument that offers digital filtering options. The digital filter should be implemented by an FPGA within the instrument so that it performs consistently without loading the host computer. You should be able to program the filter coefficients to achieve the optimum balance between aggressive filter performance and low data latency.

For temperature measurements using thermocouples, you will want a system accommodating various thermocouple types. You will need cold-junction compensation (CJC), which can require expensive, complex, and difficult-to-wire external CJC boxes that can be difficult to accommodate near the thermal chambers. As an alternative to a CJC box, you can choose a data acquisition instrument that implements the CJC function by measuring temperature at mini-TC thermocouple input jacks. You should choose a data acquisition device that can accommodate a wide range of thermocouple types (J, K, T, E, S, R, B, and N) to simply testing setup. You may also want the flexibility to use custom thermocouple types by being able to program each instrument channel with a user-defined custom 12th-order polynomial that describes the custom type. Thermocouple applications can also benefit from open transducer detection (OTD), which can alert you that a thermocouple has failed or become disconnected so you can terminate a test without wasting hours collecting inaccurate data. The mini-TC connectors also make it easy to replace faulty sensors or to reconfigure the system for different devices under test.

Your data acquisition system should provide flexibility in data storage. For quick data-logging applications, you may want an instrument to store data locally via a USB port. USB storage can also provide data redundancy to protect against data loss even when streaming data over Ethernet. And finally, an instrument that supports the IEEE-1588 v2 Precision Time Protocol standard for synchronization and time-stamping at the hardware level makes it easy to track when data was recorded.

Data Acquisition Software

Software adheres all the disparate components of a test setup into a single, coordinated system. Some data acquisition instruments come with off-the-shelf software GUIs that acquire and store data. However, these packaged software GUIs typically fall short of providing a fully automated test system. To provide full automation, the software must integrate all test system components into one software application. This requires communication to data acquisition instrumentation, thermal chambers, programmable power supplies, onboard appliance control units, external control systems that manipulate actuators, and centralized servers used for cloud infrastructure and database storage, all of which are often from different vendors utilizing different software drivers. Because of this, custom-designed software applications typically work best for these test systems.

These custom applications provide ultimate flexibility to ensure the software meets the specific requirements of each appliance manufacturer, integrating with the specific test equipment that each manufacturer uses. While these custom applications can be written in nearly any programming language, the most common languages used are C/C++/C#, Python, and LabVIEW.

Developing and maintaining software requires hiring and supporting a software engineering team, but it gives a company ultimate control over the software's initial development and long-term support. Depending on the resources available, a manufacturer can build and maintain software internally or use external software integration firms. Using an external software integrator requires more up-front capital and provides less control over the end product. However, these external integrators are valuable for manufacturers that don't have their own internal engineer resources to write custom software or when aggressive timelines demand rapid development.

No matter which software development option a manufacturer chooses, it is critical to create a long-term software support, maintenance, and documentation strategy. Changes in personnel and technology are inevitable. A software application can quickly change from a valuable tool to a seemingly insurmountable obstacle to future product development without a clear long-term support strategy. The source code for the software application should be well-annotated such that a new software engineer familiar with the programming language can clearly understand the architecture of the code. There should be ample documentation describing every function and setting in the application for advanced users. User-manuals or video tutorials should be provided to the technicians and engineers using the system regularly. These user manuals ease the burden of onboarding new personnel, and they ensure the software is used in a consistent way between all users. There must be a system to identify bugs and new features, then assign these to software engineers to ensure they are addressed. Version control should be implemented to track changes.

The Data Acquisition Instrumentation

One product suited to white goods' energy-efficiency measurements is AMETEK Programmable Power's VTI Instruments EX1401 16-channel isolated thermocouple and voltage instrument. It offers a maximum 20-kS/s/channel sample rate independent of the number of channels used, with each channel having a 24-bit ADC. As shown in Figure 1, the EX1401 employs uncompensated (Cu-Cu) mini-TC female jacks as input connectors, which permit different thermocouple types to be mixed across one instrument. The EX1401 also features PoE+ and USB ports.

In thermocouple mode, each EX1401 input can be individually configured to support standard and custom thermocouple types. To implement OTD, each thermocouple channel carries a low nanoampere-level current, and the EX1401 senses when this current is interrupted. The function operates continuously, not just after installation, and it requires no user function calls.

The EX1401 offers several benefits for such an application. It can acquire temperature and humidity data as well as auxiliary signals. Multiple instruments can be used in parallel. The EX1401 supports easy integration and synchronization of multiple devices through the IEEE-1588 v2 Precision Time Protocol standard; the architecture can scale from tens to thousands of channels. Figure 2 shows multiple EX1401 instruments used in the data acquisition system for making measurements on refrigerators.

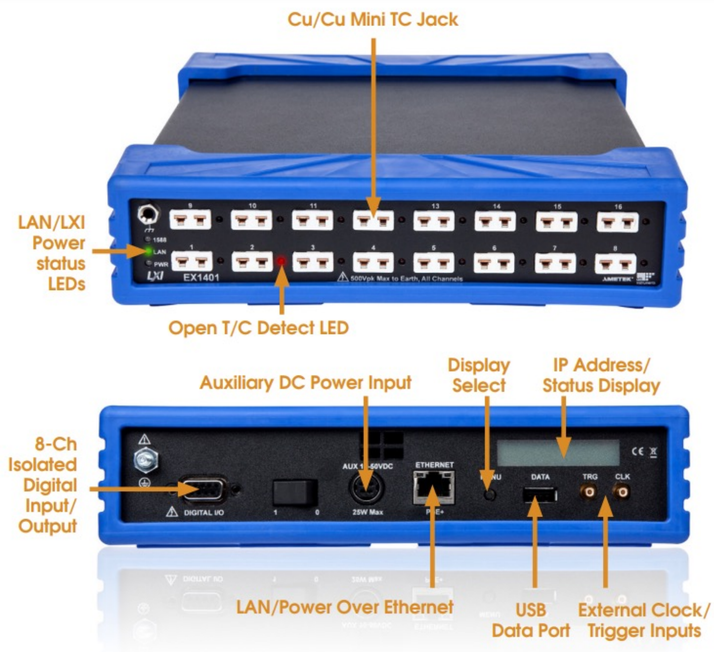


Figure 1. The EX1401 includes mini TC connectors and a PoE port.

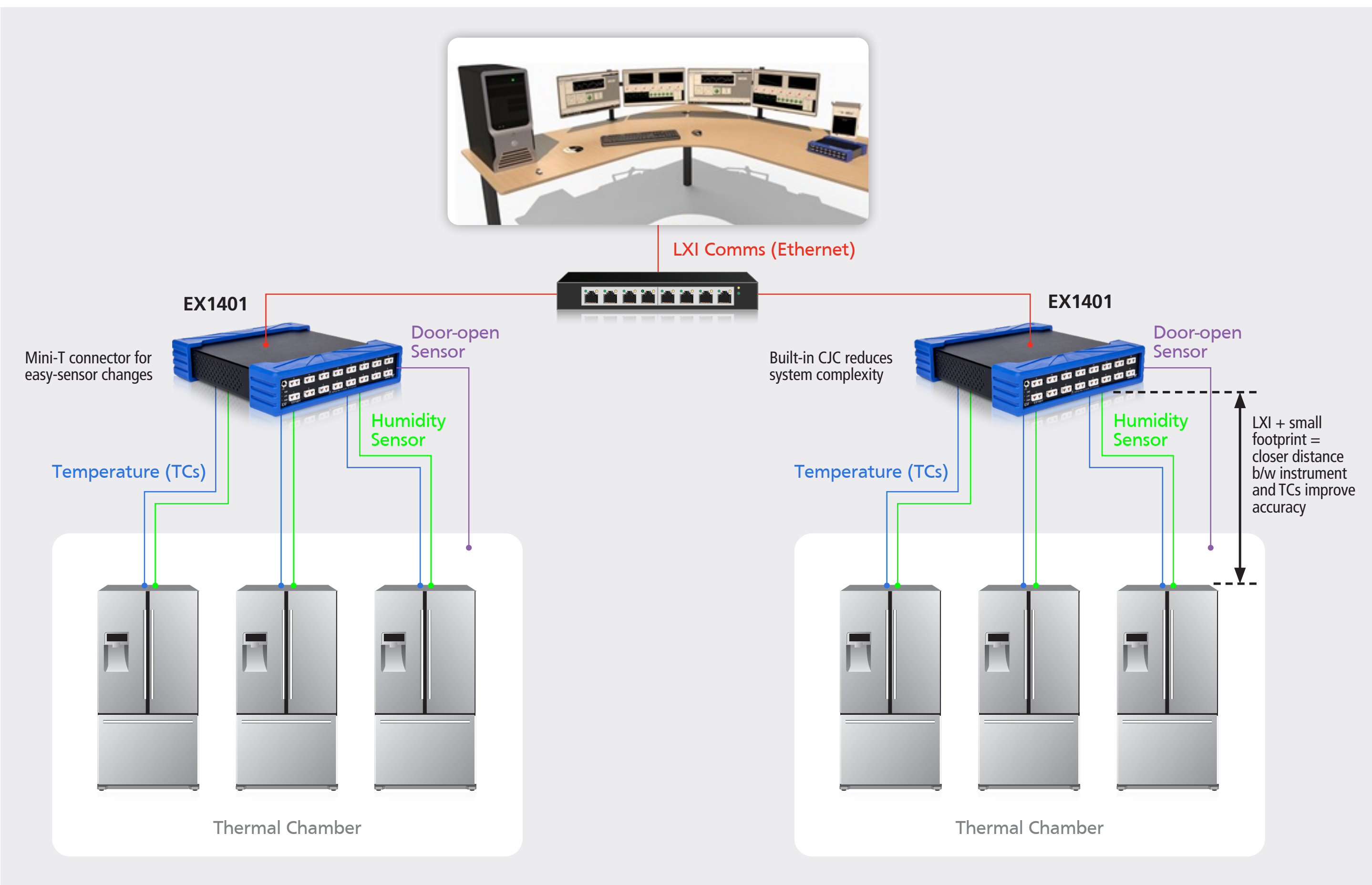


Figure 2. EX1401 instruments acquire data from multiple refrigerators under test in multiple thermal chambers.

EX1401 measurements are configurable per channel so that you can mix voltage and thermocouple measurements on one device. The EX1401 integrates the CJC function by providing a precision analog temperature sensor for each channel to measure the reference/cold-junction temperature of the mini-TC connector. Each CJC channel includes a separate dedicated ADC, and CJC measurements are time-correlated to the thermocouple channel. The accuracy of the reference-junction temperature sensor is typically within ±0.05°C at a 20°C to 30°C operating temperature. For users who prefer to employ an external cold junction, the EX1401 also allows you to program up to sixteen unique external cold-junction temperatures, one for each input channel. The use of internal and external CJC inputs can be mixed throughout the unit on a per-channel basis. The internal CJC sensors reside within an isothermal environment and are not disturbed by the instrument cooling fan or by thermal disturbances from adjacent channels.

The instrument's Ethernet/LXI capability is ideal for distributed operation. Each unit can operate near the devices under test, including within the thermal chambers as long as the chamber environment remains within the EX1401's -5°C to +55°C operating temperature range. With the EX1401, you do not need to select and connect separate terminal blocks, signal-conditioning cards, a digitizer, power supply, and chassis. The EX1401 includes an isolated digital I/O port, trigger inputs, and an IP address/status display.

For signal conditioning, each EX1401 input channel has a fixed, 2-pole, 30-kHz low-pass filter to provide anti-alias filtering. ADCs oversample the filtered analog signals at 320 kHz to 640 kHz to provide 60 dB of rejection in the aliasing band. The EX1401 also allows you to configure different digital filters per channel. An FPGA implements the digital-filter functions.

EX1401 Software Support

The EX1401 supports a variety of software environments. Suppose you want to use it as a standalone data logger. In that case, you can use VTI Instruments' EXLab full-featured turn-key data acquisition software, which offers spreadsheet-style channel configuration, allowing for independent sampling rates and real-time displays, graphical post-acquisition analysis, and data playback.

Typically, however, you will want custom software that meets your specific needs for controlling the AC power supply, the data acquisition system, the thermal-vacuum chambers, and the appliance control system. You can perform the software development in-house, or VTI can recommend one of its software-integrator partners to help. VTI Instruments supports all programming languages, including C, C++, C#, Python, and NI LabVIEW.

The EX1401 comes with two types of drivers, including an IVI driver for Windows-based on industry-standard IVI driver architecture specifications. The IVI driver exposes both IVI-COM and IVI-C interface APIs. The IVI-COM interface can be used from any programming language that supports Microsoft COM (Component Object Model). For Linux, a driver that provides a C++ API is available. The drivers are compatible with both 32-bit and 64-bit operating systems.

In addition, you can operate the EX1401 in a driverless mode thanks to VTI Instruments' adoption of the Representational State Transfer (REST) over HTTP standard, which is seeing widespread use as cloud-based industrial internet of things (IIoT) applications proliferate. VTI Instruments' RESTful APIs use JSON (Javascript Object Notation) as the data-interchange format because JSON is more compact than XML and can be parsed faster. Figure 3 shows the VTI RESTful HTTP interface having been imported into Python. Typing "rest." brings up a list of options specific to the instrument you are calling.

Figure 3. Typing "rest." in Python brings up a list of options specific to your calling instrument.

Conclusion

Energy efficiency measurements are critical for manufacturers of white goods and appliances as the manufacturers strive to meet government certification and labeling requirements. These measurements require a capable data acquisition system that can reliably record the necessary data from thermocouples and other sensors. An effective architecture will keep accuracy high and costs low by locating data acquisition instruments close the DUTs, thereby simplifying wiring and minimizing operating costs.

VTI Instruments and AMETEK Programmable Power stand ready to apply their years of experience to provide white goods manufacturers with reliable, high-performance AC sources and data acquisition instruments. Used in conjunction with AMETEK Programmable Power's AC sources, the VTI Instruments EX1401 thermocouple and voltage instrument is ideally suited to testing white goods. In addition, the products can serve over the entire product lifecycle, from quick prototype measurements to long-term reliability tests.